# TRANSFER EFFECTS OF PLAYING A VIRTUAL THREE-DIMENSIONAL AUDITORY GAME: INFLUENCES ON THE PERFORMANCE IN A COMMUNICATION TASK AND A COLLISION AVOIDANCE TASK

*Akio Honda*[*], *Hiroshi Shibata*[*], *Jiro Gyoba*[*], *Yukio Iwaya*[**], *Yôiti Suzuki*[**]

*Department of Psychology, Graduate School of Arts and Letters, Tohoku University
27-1 Kawauchi, Aoba-ku, Miyagi, 980-8576, JAPAN
** Research Institute of Electrical Communication, Tohoku University
2-1-1, Katahira, Aoba-ku, Miyagi, 980-8577, JAPAN

`*{aki0611, hshibata, gyoba}@sal.tohoku.ac.jp,`
`** iwaya@fir.riec.tohoku.ac.jp, yoh@ais.riec.tohoku.ac.jp`

## ABSTRACT

We investigated the transfer effects of playing an auditory game with a virtual auditory display (VAD) on various auditory skills in daily life situations. To measure those effects, all blindfolded participants performed a communication task and a collision avoidance task on the first day. They were asked to perform the same tasks two weeks later. Participants of the training condition were asked to play the VAD game for seven days (30 min/day) for two weeks, whereas the control group did not play the game within that period. Results of playing the VAD game revealed that the number of face-contacts in the communication task increased significantly. In contrast, no difference was detectable in the subjectively rated levels of tension during the communication task between the two conditions. Furthermore, results showed that playing the VAD game altered the participants' avoidance behaviors. Therefore, we can conclude that the effects of playing the VAD game transfer to communication behaviors in social interaction and to avoidance behaviors from approaching objects in a real environment.

## 1. INTRODUCTION

This study investigated transfer effects of playing a VAD game on various auditory skills in daily life situations. Transfer effects are commonly observed in various kinds of motor or verbal learning. Recently, several researchers have examined transfer effects of playing video action games [1, 2, 3]. However, few previous studies have investigated transfer effects of playing auditory games [4]. Auditory games with VAD offer advantages over visual action-video-games because the auditory games can be enjoyed by normally sighted persons as well as by visually impaired people. They can be effective auditory support tools for visually impaired people if auditory games are shown to provide transfer effects to relating auditory information processing in daily life situations.

Vision-impaired and sightless people are known to have better auditory perception capabilities than sighted people, especially for sound localization [5]. However, previous studies revealed that sensory compensation varies according to the etiology and extent of vision impairment [5], and the age of blindness onset [6]. Therefore, early support to improve various auditory skills has important meaning for improving the quality of life for vision-impaired people. Ohuchi, Iwaya, Suzuki and Munekata [4] proposed techniques using a VAD for auditory skill education for supporting visually impaired people. However, the availability of VAD games has not been examined thoroughly using behavioral and psychological testing.

Recently, Honda, Shibata, Gyoba, Saitou, Iwaya, and Suzuki [7] investigated transfer effects of playing an auditory game with VAD on sound localization performance for actual sound sources. Normal visual participants were asked to play the game for seven days (30 min/day) within a two-week period. Results of playing the VAD game revealed that: (1) the hit rate of the sound localization task for real sound sources increased approximately 20%; (2) vertical and horizontal localization error decreased considerably; (3) a follow-up test showed that the transfer effects persisted one month later. This study revealed that the effects of playing the VAD game transfer to the sound localization performance based on perceptual-motor learning. Furthermore, the study suggested that VAD techniques can provide effective auditory training tools for visually impaired people.

This study shows that the VAD game can be an effective training tool for improving sound localization skills and various auditory skills in daily life situations. First, we attend to the transfer effects of communication skills in a face-to-face situation. Sighted people devote attention to non-verbal information in interpersonal communication. For example, eye contact in face-to-face situations has a conversationally regulatory function [8]. The use of eye contact in social interaction with sighted people is a critical component of rewarding social exchanges [9]. In contrast, visually impaired people use more non-visual cues in social interaction [10]. The difference of communication cues affects impressions for visually impaired people [11, 12]. Several researchers have sought effective training methods for communication skills education that supports visually impaired people [12, 13, 14]. For example, Sanders and Goldberg [13] suggested visually impaired people can be taught more effective communication skills by training sound localization skills through perceptual-motor learning.

The second objective is to investigate the transfer effects on avoidance behaviors from an approaching object in a real environment. The ability to avoid unwanted collisions is a critical aspect of adaptive behavior [15, 16, 17]. People with normal vision are able to use auditory information in addition to visual information when they judge an object's approaching course or time to arrival. Previous studies have revealed that visual information tends to be used more efficiently than auditory information in terms of the accuracy of judging the time to arrival [16]. Visually impaired people are hard or unable to use visual cues. Consequently, for them it is very important to take appropriate avoidance behaviors using acoustical information. However, few previous studies have investigated avoidance behaviors using acoustical information. Furthermore, few studies have examined avoidance behaviors based on auditory information processing to a natural stimulus in daily life situation.

In our previous study [7], we also investigated blindfolded individuals' communication and collision avoidance behavior, but we have not reported those results yet. Higher real sound localization skills are important to conduct better communication and more appropriate avoidance behaviors based on auditory information. Therefore, in this study, we precisely described the transfer effects of playing the VAD game on blindfolded individuals' performances in the communication task and the collision avoidance task.

## 2. METHOD

### 2.1. Participants

This study examined the performance of 40 participants, 20 women and 20 men, who are university graduate and undergraduate students with age between 19–25 years. All participants reported that they had normal hearing, normal vision, and no prior experience of conducting psychoacoustic tasks. They were separated into two groups, maintaining the same proportions of men/women in each group. The training group of 20 participants participated in the auditory game using their own Head-Related Transfer Functions (own HRTFs) with the blocked ear canal technique [18], or using fitted HRTFs from 16 pairs of those of other listeners with the tournament-style listening test [19, 20, 21, 22]. The control group of 20 participants could not play the VAD game. One participant of the training group was excluded from the experiment because of a health problem.

That study [7] revealed that the VAD game performance and the sound localization performances for real sound sources using fitted HRTFs were similar to performance using own HRTFs. Then, we considered that the own HRTFs and fitted HRTFs groups showed equal levels of transfer effect on sound localization skills for real sound sources.

### 2.2. VAD game used in this study

For this study, we used a newly developed VAD game called *BBBeat*. The VAD game is an action game that has been developed with the intention of training sound localization skills and relating auditory information processing of game players. This game resembles the popular 'whack-a-mole game'.

In the game, honeybees appear instead of annoying moles. One honeybee appears within reach of the player's hand. The bees' positions of appearance are determined automatically and randomly. The game player has a plastic hammer that is used to hit the honeybee. A three-dimensional position sensor (MDP-A3U9S) and a vibration unit are installed in the hammer. Another three-dimensional position sensor is attached to the headband of the headphones to sense the direction of the listener so that the honeybee's buzzing can be localized reliably through realization of relative HRTFs to the position of the honeybee according to listener's movement. This real-time signal processing to reflect the influence of the listener's dynamic motion is remarkably effective to realize correct sound localization [23] (see Figure 1).

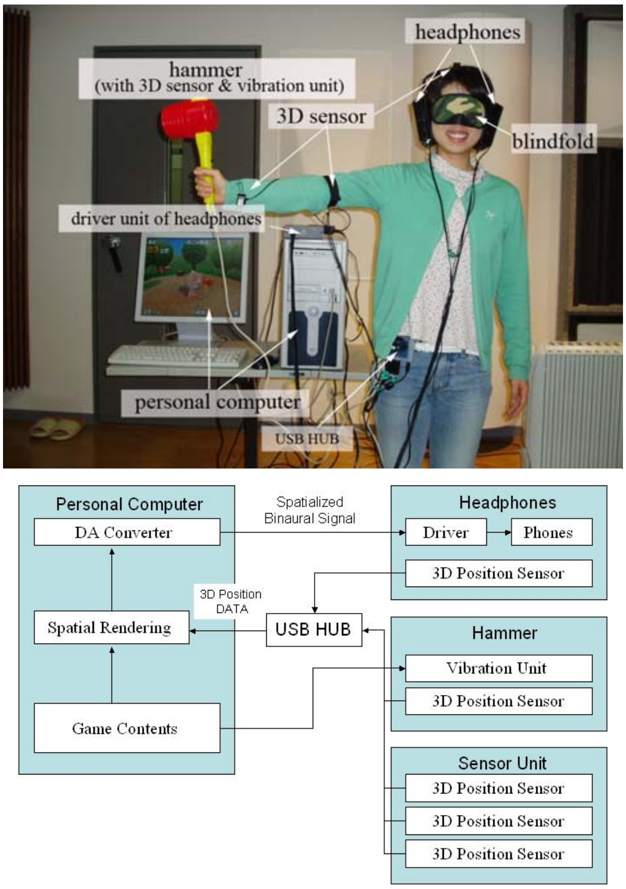

Figure 1. *Architecture of the VAD game used in present study*

The player's task can be summarized as follows. First, the player listens attentively to the background music to discern the sound of the bee's appearance. Second, the player must detect the target sound as rapidly as possible. At that time, the player frequently uses head movements to detect the target sound. Finally, the player localizes the target sound position using the hammer. The player receives an immediate vibration feedback signal from the hammer; another honeybee is given to the player when the sound localization is correct.

We expected that the players would develop more effective sound localization skills by playing the VAD game because of perceptual-motor learning. In addition, we anticipated the effect transfer to the face-contact behaviors because the player would learn a series of movements to turn quickly to the location of the presented target when playing the VAD game.

### 2.3. Auditory training with the VAD game

In the VAD game, the training group was asked to localize the honeybee position and strike it with the hammer as quickly and correctly as possible. The sound pressure level (SPL) of the game was adjusted individually to each participant's most comfortable level. The VAD was responsive to head movement. Therefore, participants were allowed and encouraged to use free head movement in the VAD game. The player was asked to perform the game blindfolded because we anticipated that their visual information processing would interfere with the transfer effects of playing the VAD game. After playing the VAD game, the experimenter informed the player of the number of hits and misses (see Figure 2).

Figure 2. *Auditory training with the VAD game*

In the experiment, all participants did the sound localization task of which results were reported in [7], the communication task, and the collision avoidance task on the first day (pre-test). They were asked to perform the same tasks two weeks later (post-test). The training group was asked to play the game for seven days (30 min/day) within a two-week period, but the control group did not play the game within that period. All participants conducted all these tasks while blindfolded.

### 2.4. Communication task (and procedure)

All blindfolded participants conducted a communication task in a soundproof room. The participants sat on a chair that allows free head and body movement. They were asked to talk about some topics with two interviewers (pre-test). Two trained female experimenters played the role of the interviewers to ensure uniformity of the task. These interviewers had never met the participants. In the communication task, the interviewers sat on a chair that was positioned at 30° left or right from the participants. The distance between the participant and the interviewers was 2.5 m. Two video cameras recorded the scene from these positions.

The interviewers provided questions for the participants according to a script. For example, this script included weather topics, health problems and opinions concerning this experiment. In all, 36 questions were used. The face-contact behaviors were defined as the participant's face turning to a location of the interviewer when they listened to each question from the interviewer or tried to answer each question. Each interviewer was asked to check whether the participants showed face-contact behaviors on each topic with four phases (start-phase of listening, end-phase of listening, start-phase of speaking, and end-phase of speaking). Another interviewer confirmed whether the participants showed face-contact behavior to the querying interviewer when the one interviewer provided the question and the participant answered it. Reliability obtained using the corresponding rate between the interviewers was 83%. They were resolved through verification using recorded videotapes and discussion of two interviewers if mismatches of checked face-contact behaviors existed (see Figure 3).

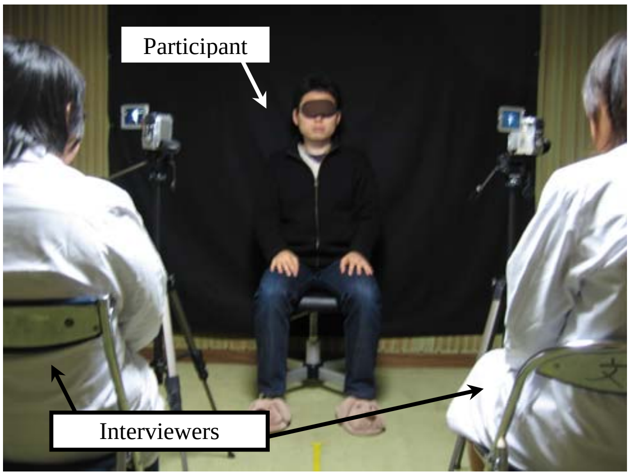

Figure 3. *Communication task in the present study*

After the task, the participants were asked to rate the subjective levels of tension during the communication task ("Did you feel tense during the communication task?"). Tension was rated on a 7-point Likert scale (1 = *Not at all* to 7 = *Very much*).

All participants were asked to perform the same task two weeks later (post-test). In the post-test, several topics were altered and the position of the interviewers was exchanged.

### 2.5. Collision avoidance task (and procedure)

All blindfolded participants performed a collision avoidance task in an experiment room. They were asked to avoid approaching objects when they felt it was moving toward a collision course (relevant path). Furthermore, they were asked to perform avoidance behaviors with minimum moving distance from their position. In contrast, they were instructed not to avoid an approaching object when they felt it was moving from irrelevant paths. The distances between the relevant path and two irrelevant paths were 80 cm. A colliding object was a toy car (width = 30 cm, weight = 2.5 kg). The front of the toy car was covered with soft material. The participant confirmed the safety of the approaching object before initiating the task. Furthermore, one experimenter stood behind the participant to prevent a fall on the floor just in case.

The approaching stimulus was presented repeatedly at random to participants from either relevant or irrelevant paths. The SPL of the approaching sound was 75 dB and the background noise level of the experiment room was 35 dBA. The toy car was placed at 50 cm height on lanes (initial velocity = 0 m/s) and slid along the lane slopes (2 m/s). Three lanes were used. The center lane was for the relevant (collision) path and the lanes of both sides were for irrelevant paths. The distance between the participants and the lanes was 4.0 m. The participants needed to perceive a correct sound localization of the approaching object based on auditory information and to decide their behaviors within 2 s. The trials numbered 36 in all. The approaching object was delivered through a randomly selected lane 12 times for each course. The body direction of the participant was changed for each trial; consequently, the toy car approached from the front, back, left, or right direction (each direction = total 9 trials). The experimenter checked whether the participant had done the avoidance behaviors for each trial. In addition, they measured the distance from participants' start position to the end point of their actions. Two video cameras recorded the scene (see Figure 4).

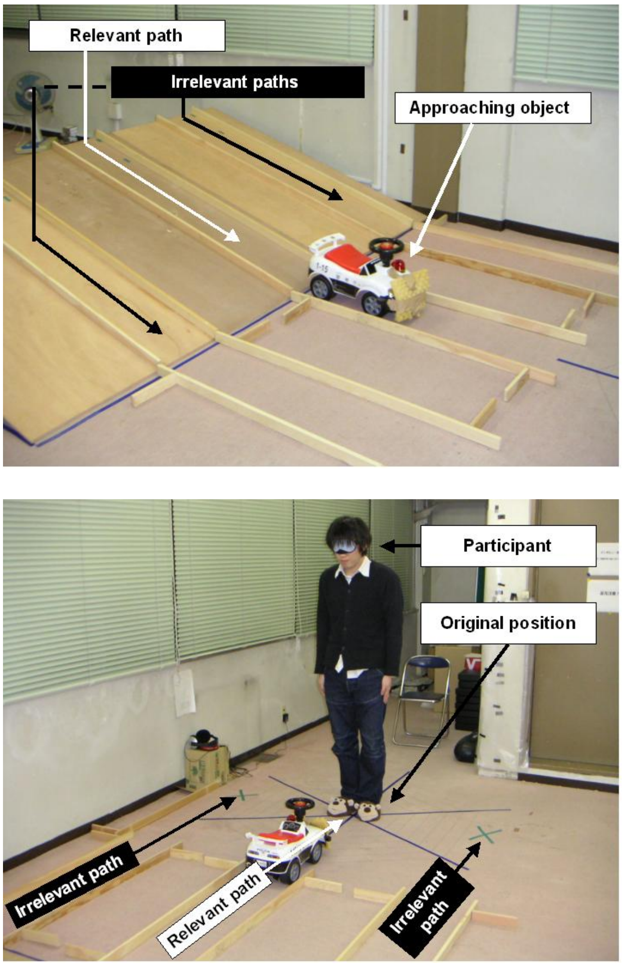

Figure 4. *Collision avoidance task in the present study*

After the task, the participants were asked to rate the subjective levels of difficulty of the collision avoidance task ("Did you feel that the collision avoidance task was difficult?"). The difficulty was rated on a 7-point Likert scale (1 = *Not at all* to 7 = *Very difficult*).

Additionally, we asked the participants to judge the subjective levels of threat about the collision ("Did you feel a threat that you might bump against the moving object?"). The threat levels were rated on a 7-point Likert scale for each direction (1 = *Not at all* to 7 = *Very fearful*).

All participants were asked to perform the same task two weeks later (post-test). In pre-tests and post-tests, they were given a short practice to adapt themselves to this task. Then they performed the task.

## 3. RESULTS

### 3.1. Transfer effects on the communication task

#### 3.1.1. Face-Contact Performances in the Start-Phase of Listening

Figure 5 shows the face-contact performance of the start-phase of listening in the communication task.

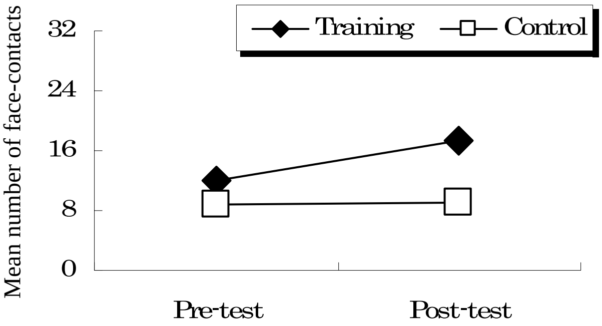

Figure 5. *Mean face-contact performances in the start-phase of listening for training and control groups*

A two-way analysis of variance (ANOVA) was performed on the number of face-contacts, considering the group (training, control) and the test phase (pre-test, post-test) as factors.

The number of face-contacts was significantly higher in the post-test than in the pre-test [$F(1, 37)=10.1$, $p < 0.01$]. The main effect for the group was not significant. Interaction between the group and the test phase was significant [$F(1, 37)=9.7$, $p < 0.01$]. Post hoc analyses (Ryan's) revealed that the face-contacts of the training condition increased significantly after playing the VAD game ($p < 0.001$) and the training group in the post-test showed more face-contacts than the control group in the post-test ($p < 0.05$).

#### 3.1.2. Face-Contact Performances in the End-Phase of Listening

Figure 6 shows the face-contact performance of the end-phase of listening in the communication task.

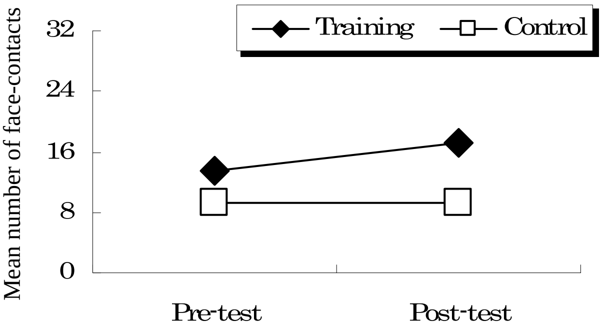

Figure 6. *Mean face-contact performances in the end-phase of listening for training and control groups*

A two-way ANOVA was performed on the number of face-contacts in the end-phase of listening with the group and the test phase as factors.

A significant main effect of the test phase was observed [$F(1, 35)=4.6$, $p < 0.05$]. Participants displayed significantly more behaviors in the post-test than in the pre-test. Significant interaction between the group and the test phase was found [$F(1, 37)=4.1$, $p < 0.05$]. Post hoc analyses (Ryan's) revealed that the face-contact performance of the training group was increased significantly by playing the VAD game ($p < 0.01$). The training group in the post-test showed more face-contacts than the control group in the post-test ($p < 0.05$).

#### 3.1.3. Face-Contact Performances in the Start-Phase of Speaking

A two-way ANOVA was conducted on the number of face contacts in the start phase of speaking with the group and the test phase as factors.

Although a slight advantage was apparent for the training group over the control group ($M$=17.1 vs. $M$=11.8), no significant effect was found for the group. The main effect for the test ($M$=13.7 in the pre-test and $M$=15.1 in the post-test) and interaction between the group and the test were not significant.

#### 3.1.4. Face-Contact Performances in the End-Phase of Speaking

A two-way ANOVA was conducted on the number of face contacts in the end-phase of speaking with the group and the test phase as factors. These data are presented in Fig. 7.

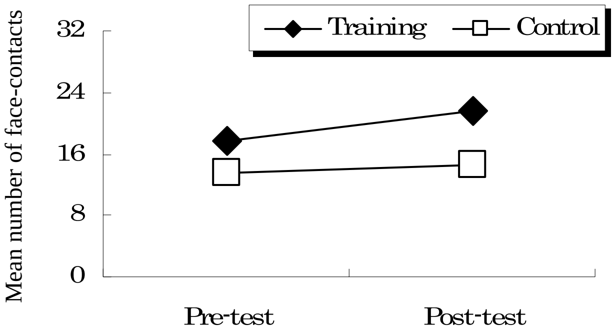

Figure 7. *Mean face-contact performances in the end-phase of speaking for training and control groups*

The number of face contacts was significantly higher in the post-test than in the pre-test [$F(1, 37)=9.5$, $p < 0.01$]. However, the main effect for the test and the interaction between the group and the test were not significant.

#### 3.1.5. Subjective tension during the communication task

A two-way ANOVA was conducted on the subjective rated levels of tension during the communication task with the group and the test phase as factors.

Levels of tension of the training group were slightly higher than those of the control group ($M$=4.1 vs. $M$=3.5), but no significant effect was found for the group. The main effect for the test ($M$=4.0 in the pre-test and $M$=3.7 in the post-test) and the interaction between the group and the test were not significant.

### 3.2. Transfer effects of the collision avoidance task

In the task, individual differences of avoidance behaviors were large. For example, some participants showed exaggerated avoidance behaviors in all trials, whereas some participants seldom moved from their original positions.

For the following analyses, six participants for each group were removed based on total avoidance distances in the task (the upper three participants and the lower three participants for each group).

#### 3.2.1. Number of collisions in the avoidance task

A three-way analysis of variance (ANOVA) was performed on the number of collisions with approaching objects from the relevant path (see Table 1), considering the group (training, control), the test phase (pre-test, post-test), and the direction to approaching object (front, back, left, right) as factors.

No significant differences were found among the number of hits, except for a main effect of the group [$F(1, 25)=4.8$, $p < 0.05$]. The collisions of the training group were fewer than those of the control group.

Table 1. *Mean of the number of collisions with the object approaching from the relevant path for the training and the control groups*

| | **Training** | | **Control** | |
|---|---|---|---|---|
| | **Pre-test** | **Post-test** | **Pre-test** | **Post-test** |
| **Front** | 0.9 | 0.7 | 1.5 | 0.6 |
| **Back** | 1.2 | 1.5 | 1.4 | 1.1 |
| **Left** | 1.0 | 1.1 | 1.4 | 1.6 |
| **Right** | 0.9 | 1.2 | 1.7 | 1.7 |

A same three-way ANOVA (group × test × direction) was performed on the number of collisions with objects approaching from irrelevant paths (see Table 2).

No significant main effects or interactions were observed.

Table 2. *Means of the number of collisions with objects approaching from the irrelevant path for training and control groups*

| | **Training** | | **Control** | |
|---|---|---|---|---|
| | **Pre-test** | **Post-test** | **Pre-test** | **Post-test** |
| **Front** | 0.08 | 0.08 | 0.11 | 0.04 |
| **Back** | 0.15 | 0.19 | 0.07 | 0.04 |
| **Left** | 0.04 | 0.12 | 0.11 | 0.14 |
| **Right** | 0.12 | 0.00 | 0.14 | 0.00 |

#### 3.2.2. Avoidance distances from the original position

A same three-way ANOVA (group × test × direction) was performed of total avoidance distances from the original position in the case of relevant paths (see Table 3).

No significant differences were shown among the avoidance distances, except for a main effect of the direction [$F(3, 75)=7.0$, $p < 0.001$]. Avoidance distances were significantly greater when the object approached from the participants' front-direction than when it approached from the back, left, or right directions.

Table 3. *Mean total avoidance distances (cm) from the original position for objects approaching from the relevant path for training and control groups*

| | **Training** | | **Control** | |
|---|---|---|---|---|
| | **Pre-test** | **Post-test** | **Pre-test** | **Post-test** |
| **Front** | 45.5 | 48.0 | 44.0 | 56.1 |
| **Back** | 34.5 | 23.2 | 35.5 | 40.3 |
| **Left** | 37.8 | 34.5 | 30.0 | 34.6 |
| **Right** | 33.7 | 37.7 | 25.0 | 26.4 |

The same three-way ANOVA was performed on the total avoidance distances from the original position for the object approaching from irrelevant paths, with the group, the test phase, and the direction as factors (see Table 4).

Table 4. *Mean total avoidance distances (cm) from the original position for objects approaching from irrelevant paths for training and control groups*

| | **Training** | | **Control** | |
|---|---|---|---|---|
| | **Pre-test** | **Post-test** | **Pre-test** | **Post-test** |
| **Front** | 21.8 | 15.6 | 15.9 | 17.9 |
| **Back** | 22.8 | 12.9 | 26.5 | 18.0 |
| **Left** | 31.3 | 13.4 | 19.7 | 28.2 |
| **Right** | 22.1 | 14.8 | 19.0 | 21.3 |

Avoidance distances in the post-test were significantly shorter than those in the pre-test ($M$=22.4 vs. $M$=17.8) [$F(1, 25)=4.5$, $p < 0.05$]. Results showed that a two-way (group × test) interaction was significant [$F(1, 25)=6.9$, $p < 0.05$]. Post hoc analyses (Ryan's) revealed that avoidance distances of the training group were decreased significantly by playing the VAD game ($p < 0.001$). A significant three-way interaction was also apparent [$F(3, 75)=3.4$, $p < 0.05$]. Two-way interaction between the group and the test was significant when the object approached from the left [$F(1, 100)=15.9$, $p < 0.001$]. A two-way (test × direction) of the interaction of the control group was significant [$F(3, 75)=3.0$, $p < 0.05$]

### 3.2.3. Subjective difficulty of the collision avoidance task

A two-way ANOVA was performed on the subjective rated levels of difficulty of the collision avoidance task with the group and the test phase as factors.

The levels of difficulty in the pre-test were slightly higher than those in the post-test ($M$=5.6 vs. $M$=5.1), but no significant effect of the test was found. The main effect of the group ($M$=5.3 of the training group and $M$=5.4 of the control) and the interaction were not observed.

### 3.2.4. Subjective threat of collision

A three-way ANOVA was performed on the subjective rated threat levels of collision, considering the group, the test phase, and the direction to the approaching object as factors.

A significant main effect of the direction was observed [$F(3, 75)=3.3$, $p < 0.05$]. The threat levels of were significantly higher when the object approached from the back than when they presented from the front ($M$=4.4 vs. $M$=4.0). The main effect of the group ($M$=4.4 of the training group and $M$=3.9 of the control group) was not significant. In addition, main effects of the test ($M$=4.2 in the pre-test and $M$=4.2 in the post-test) and the interactions were not significant.

## 4. DISCUSSION AND CONCLUSIONS

This study investigated transfer effects of face-contact performances in a communication task from playing the VAD game. Results revealed that, by playing the VAD game: (1) the face-contacts in social interaction increased significantly; and (2) subjective rated levels of tension during the situation did not change. In particular, these transfer effects were observed through listening to the speaker's voice.

In addition, the avoidance task results showed that the avoidance distance by playing the VAD game decreased when the object was approached from the irrelevant path. In contrast, their subjective estimation of difficulty or threat about the task did not change by playing the VAD game. These findings suggest that auditory training using the VAD modified the executed avoidance behaviors. In initial trials of this task, several participants reported that they felt their own body stiffen by feelings of anxiety or fear. For that reason, our future studies will aim to design VAD games that will train participants more in safe navigation or somehow reduce way-finding anxiety in real environments. Findings of these studies would contribute to improvement of the quality of life for visual impaired people.

Our experiment demonstrated that playing the VAD game transferred communication behaviors in face-to-face situations and avoidance behaviors in real environments. It is likely that the transfer effects revealed in this study are based on automatic perceptual-motor learning by playing VAD game because training did not alter their subjective awareness. In conclusion, this VAD game can be an effective training tool for skills related to auditory information processing in daily life situations. Future studies must also investigate optimum training methods that produce the strongest transfer effects in playing the VAD game.

## 5. ACKNOWLEDGEMENTS

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