# Space Perception by Acoustic Cues Influences Auditory-induced Body Balance Control

Shinichi Yamagiwa[1] and Naka Gotoda[2] and Yuji Yamamoto[3]
[1]*Faculty of Engineering, Information and System, University of Tsukuba/ JST PRESTO, Tsukuba , Japan*
[2]*Department of Sports Science, Japan Institute of Sports Sciences, Tokyo, Japan*
[3]*Research Center of Health, Physical Fitness and Sports, Department of Psychology and Human Developmental Sciences, Nagoya University, Nagoya, Japan*

Keywords: Acoustic, Visibility, Blind, Vection, Body balance.

Abstract: The auditory-induced illusion called *vection* has been investigated for decades. However, it is not confirmed how the illusion affects to body balance. Especially, during a dynamic activity such as walking, it has not confirmed whether any clear effect to the body balance control appears or not. This paper focuses on investigating the effect of vection during walking. Especially this paper will discuss the space perception induced by acoustic stimuli that indicate the directions. The authors of this paper measured the response time from the acoustic cue to body balance control and the rotation amount using a small sensor system with accelerometer, magnetic and gyro sensors. According to the experiments with sight/blind participants from young to old ages, requesting them to walk to the directions of the acoustic cues with/without sight, the authors confirmed a close relation between the vision and the auditory of human during a dynamic activity.

## 1 INTRODUCTION

We are surrounded by sounds in our life such as the winds in a green field, whisper in a silent room, noise in a hard traffic between high buildings, chat of peoples in a restaurant and so on. A sudden large sound lets your head turn up and see its direction. In a fog, you would try to know the circumstance around you hearing sounds and then you try to know if any danger is coming to your side or not. These human natural behaviors are coming from potential ability of *space perception* (Blake and Sekuler, 2005) with auditory and visual information acquired from the environment. However, the certainness of the space perception from the auditory information includes many unknown cognitive responses, especially the influence of the auditory related to the body balance control during active movements like walking.

Several advanced research results have been reported to show that how cognitive behavior would happen when the body balance is influenced by auditory cues given to human. There exists a cognitive illusion called *vection* (Valjamae, 2009) that causes a misunderstanding of changing posture by the auditory cues which is experienced in an environment with multiple speakers surrounded in a human (Lackner, 1978). However, it is not known how auditory cues influence the space perception during dynamic body balance control. For example, how correct does a human follow auditory cues with walking? How fast is the response from the cues to the body balance controls? And how the vision influences to the body balance when the different types of auditory cues are given?

This paper focuses on these unknown human nature responses regarding the dynamic body balance control using auditory cues that changes the sound pan directions among left, center and right. To investigate the influences by the auditory cues given to human, we categorized two types of cognitive behaviors. The first one is the interference to the body balance control potentially affected by the cues. Another is the interference to the human body balance control guided by the cues when he/she chases the cues. We focus on the latter one by performing experiences at walking situation giving acoustic cues that the sound pan is changing suddenly or smoothly among right, center and left randomly. In the experiments, we applied the auditory cue patterns to congenital and acquired blindness and healthy sighted (with/without eye mask) participants to compare the cognitive behaviors from the acoustic cues to the body balance


Yamagiwa S., Gotoda N. and Yamamoto Y..
Space Perception by Acoustic Cues Influences Auditory-induced Body Balance Control.
DOI: 10.5220/0004601200300040
In *Proceedings of the International Congress on Sports Science Research and Technology Support* (icSPORTS-2013), pages 30-40
ISBN: 978-989-8565-79-2

control during walking situation.

According to the experiments, three main findings are resulted in this paper: 1) space perception between blindness and sighted people differs. Especially, congenital blindness people have a keen space perception from the auditory cues used as the guide for the walking direction. 2) Patterns of sound pan as the acoustic cues induce different body balance control behaviors in the aspects of response speed and rotation amount of body. The sudden change of the sound pan induced fast and large balance control. Finally 3) vision of sighted or acquired blindness people is combined to control their body balance. They had performed faster to response against the acoustic cues without eye mask than invalidating the vision with eye mask.

In the next section, we introduce the advanced research results related to our experiments. Section 3 will explain the methods of our experiments and propose hypotheses expected from the experiments. Section 4 will explain the results of the experiments and will show proofs for our hypothesizes. Finally we will discuss the experimental results, the findings and will conclude this paper.

## 2 RELATED WORKS

The relationship between acoustic cue and body balance control has been investigated since 1970's. The early investigations were related to the auditory-induced illusion (Lackner, 1977)(Lackner, 1978)(Lackner, 1983). It is well known experiments using rotating sound source with 10-20Hz sound pan change of each speaker. Sitting in the environment, the participant can percept that either "I am moving" or "Surround is moving". Extending the illusory phenomenon, researchers investigate the posture perception with multiple rotating sound sources. Following the rotating direction of the sound, the participant percepts illusory posture movement (actually posture does not change).

On the other hand, the clinical approach reports an experiment that gives electrical stimuli to vestibular organ of the human participants. It results that the stimuli absolutely affects to his/her body balance control (Aoki et al., 2000). It is now very hard to perform the experiment with the vestibular stimuli due to the ethical problems. Therefore, clinically the participant is a patient who is in hospital to aid auditory-related diseases.

When we consider applications of the vection or the vestibular stimuli, the *biofeedback* application is one of the interesting directions for attractive utilizations. The biofeedback is a trend word used in the application area of the auditory-induced body balance control. For example, (Dozza et al., 2006), (Giansanti et al., 2009) and (Brunelli et al., 2006) have reported the body balance control using a feedback system to keep a vertical standing posture. We think these research projects are going to the frontline of the research regarding auditory cues with sound pan changes that affect the right and the left bias of posture. The research is focused on the static posture control with the healthy sighted, the blindness, and some Parkinson's disease participants. However, we are going to focus on the body balance control against auditory cues of the blindness and the sighted people under a walking situation. Under such an active environment, the mechanisms of the auditory-induced body balance control has not been clearly explained in the previous researches because the experiments had been focused on illusions occurred at a static posture.

Regarding the Parkinson's patients, a biofeedback system called *Walkmate* has been developed by the researches (Miyake, 2009) (Hove et al., 2012). The Walkmate generates rhythmic pacing sequences to the Parkinson patients using nonlinear limit cycle oscillators. The rhythmic pacing timings are generated by feedforwarded the timings taken from a pressure sensor put in the patient's foot. The system induces self-walking from the potential characteristics of the disease. Therefore, this type of application using auditory cues during active body balance control can be treated as one of special cases. Therefore, we want to try to find how the auditory and the body balance control of physically healthy persons are involved during active movements like walking.

As we discussed above, it is not well-known that the cognitive response from vection to the body balance regarding physically healthy people. The vection is recognized as an internal psychological and cognitive perception. Therefore, the body balance might be influenced by the vection in a dynamic body balance control such as during walking, running or hard sports activity. However, the research regarding the vection is still under progress in the static body balance control or self-cognitive issue due to the complex relation to the sight. Thus, although the space perception of human in a dynamic body balance control would be related to the vection and the vision, it is not explored that the dynamic body balance control relates to the auditory stimuli. Finally the new findings will be utilized in sports trainings, new society design to eliminate dangerousness induced by acoustic illusion, and engineering applications such as a novel rehabilitation system using a sound guide.

In this paper, we focus on exploring influences to the space perception regarding the dynamic body

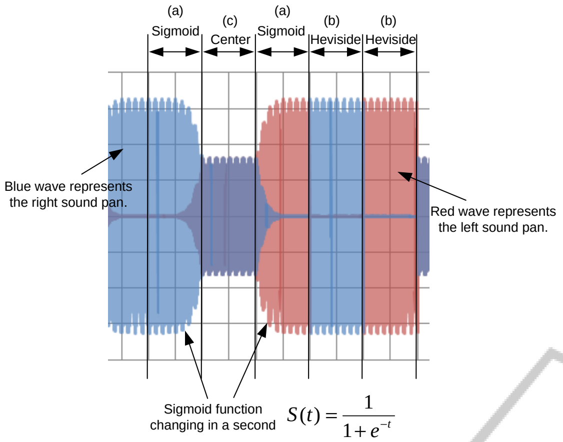



Figure 1: Sound pan change waves when the Heviside and the Sigmoid function are applied. The blue part is a sound pan from right side. The red part is the one from left side. (a) shows the pan change with the Sigmoid function. (b) is the one with the Heviside. The center pan is shown in (c). The sound volume was adjusted to be felt in the same among (a), (b) and (c). Therefore, the range of sampling data during the center pan is half of the right or left sound pan.

balance control induced by the auditory cues. We have questions for the perception: 1) If human can follow auditory cues and walk the expected direction with/without vision or not. 2) If the sight is not related to the space perception when we follow the acoustic cues or not. And 3) if we have any difference in the response time from the acoustic cues to the dynamic body balance with/without the sight or the sound type of the cues or not. Thus, we report the experiments to explore answers of the questions above and discuss the semantics of the results.

# 3 METHODS AND HYPOTHESIS

## 3.1 Methods and Experimental Setup

To investigate the space perception regarding the dynamic body balance control induced by the auditory cues, we use a quite simple method following the steps; 1) a walking participant hears auditory cues that change the sound pans among right, center and left, 2) the participant chases the sound pan direction, 3) congenital, acquired blindness and sighted people with/without an eye mask perform the same steps of 1) and 2). According to the steps, we observe the response time from the beginning of the cues, the rotation amount of body and the walking direction.

We prepared the experimental environment for the methods above in gymnasiums. Let us explain the

Table 1: Participants attended in the experiment.

| Participant | Visibility | Sex | Age |
|---|---|---|---|
| A | Congenital blindness | Male | 27 |
| B | Aquired blindness | Male | 41 |
| C | Aquired blindness | Female | 38 |
| D | Sighted | Female | 37 |
| E | Sighted | Female | 27 |
| F | Sighted | Female | 24 |
| G | Sighted | Female | 20 |
| H | Sighted | Male | 58 |
| I | Sighted | Female | 40 |
| J | Sighted | Male | 62 |

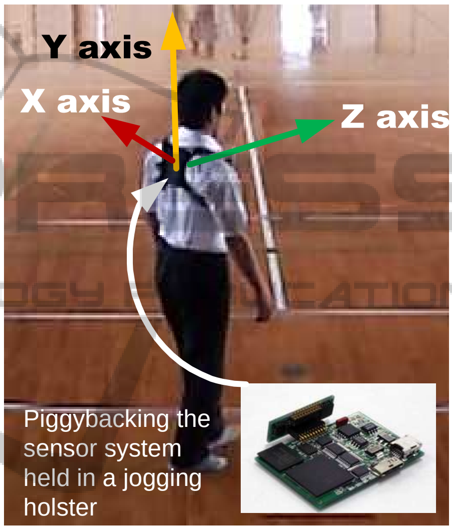



Figure 2: Magnetic sensor axis of the integrated sensor system piggybacked by participants during the experiment.

materials, the places and the participant selection concept listed below:

- *Place for Experiment:* We have prepared empty and silent gymnasiums in Kochi University of Technology and in the Blind School in Kochi Prefecture in Japan where the walking length by the participant almost equals to the one of the goal-to-goal in a basketball court. The air temperature in the gymnasiums was about $10-20\,^{\circ}$C without any wind during autumn season. The floor made of wood keeps flat without inclination.
- *Auditory Cues used in the Experiment:* The sound pattern including the auditory cues consists of three types of tones. The first one is the starting trigger for the participants that indicate the starting point of the experiment. It is constructed by 880Hz sin wave with 16 bit sound resolution. This trigger sound is outputted in the center pan. The subsequent sound stimuli organize a right-to-left or a left-to-right pan change constructed by 440Hz sin wave with 16 bit sound resolution as illus-

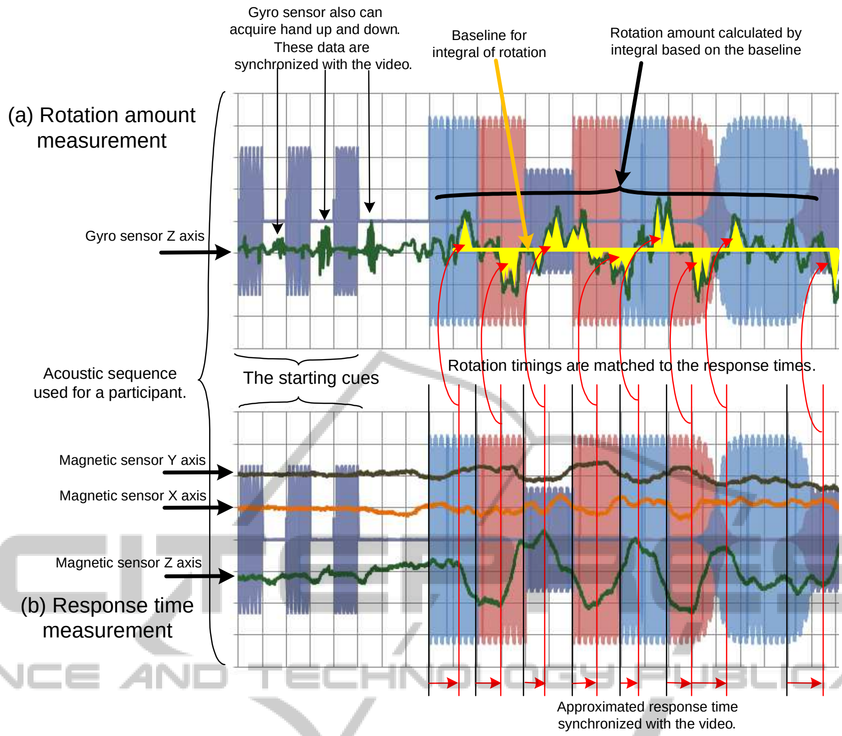





Figure 3: Measurement methods of the approximated response times and the rotation amounts at the body balance controls against the acoustic cues. The response time is measured from the beginning of the sound pan recognized by the magnetic sensor data. The rotation amount is measured by the integral of the gyro sensor data corresponding to the changing timings of the response time.

trated in Figure 1, which dynamic range varies in $-16384 < s < 16384$ where $s$ is the sample value. These indicate the walking direction to the participant. The pan change uses two functions: *Heviside* and *Sigmoid*. The Sigmoid function changes the sound pan smoothly. The changing time from one side to another takes a second and the same sound pan is also kept for a second (Figure 1(a)). Totally during two seconds one of the sound pans is outputted. But the Heviside one changes the sound pan suddenly. The length is two seconds for the same sound pan (Figure 1(b)). The last type is the center sound pan that is constructed by 440Hz with 16 bit sound resolution, which the dynamic range is varied in $-8192 < s < 8192$ for the sample value $s$ (Figure 1(c)). The (a), (b) and (c) are randomly appears during the experiment as the auditory cues for guiding the direction. The participant follows the direction of the sound pan. We just requested them to turn to the direction as they recognized. In the case of the center sound pan, we just requested the participants to walk in straight. We have prepared five sequences with the auditory cues for the experiment, in which the total time of a sequence is 56 seconds. Each participant tried these five sequences, where the sighted participant wears an eye mask for the experiments. Finally the sighted participant also attended in an additional 6th experience without the eye mask using another acoustic cue sequence.

- *Measurement of the Body Balance Control during the Experiment:* A sensor system originally equipped with a 400 dps 3D gyro sensor (InvenSense IDG-400 $\times$ 2), a 2.5G 3D accelerometer (Freescale MMA7261QT) and a 3D magnetic sensor (Aichi Steel AMI602) was introduced to the experiment. All sensors can achieve up to 200Hz sampling rate and have 12bit resolution (Texas Instruments TLV2553IPW) for each data. Therefore, the experiment applies 5 msec to the sampling time resolution. The data of accelerometer illustrates the timings of legs' movement during the walking of participant. The gyro sensor measures the rotation amount of participant's body using the absolute value from the channel of the vertical axis against body. The magnetic sensor outputs the direction data of the body that represents the starting or the ending timings of rotating the body against the auditory cues. Data measurement timings from all axes of all the sensors are synchronized by the microcontroller (Microblaze at 48MHz) implemented on a Xilinx Spartan3E FPGA. If participant walking in straight, the data from the magnetic sensor keeps the same value.

- *Participants attended in the Experiment:* Totally ten participants including a mentally healthy congenital and two mentally healthy acquired blindness persons and seven healthy sighted persons attended in the experiment as summarized in Table 1. Participant wear cotton thick socks to eliminate cognitive effect from the floor. As shown in Figure 2, participant piggybacked the sensor and an iPod nano put into a small jogging holster, and heard the sound pan changes from the iPod nano via a noise canceling headphone (Sony MDR-NC100D). The sound volume was adjusted as the participant comfortably and clearly can hear the sound.

We took videos of the experiment with two cameras from the back and the front of each participant. The video was used to synchronize the data from the sensors compared with the participant's movement. We noted that this method did not have enough accuracy for the response time from an acoustic cue because it was impossible to record the acoustic cues heard by the participant. Therefore, regarding the response time from an acoustic cue to the body balance control, we request to participants to move their hands up and down during the starting cues, and then we synchronize the movement from the video as the starting point of the acoustic cue sequence. Moreover, because the hand movement was recorded in the sensor data (especially in the accelerometer data), we synchronized the movement confirmed by the video approximately with the sensor data (Figure 3(b)). Finally we used the rate of the *approximate response time* where one of the response times was used as the base time. We explained the detail of this calculation in the next section using the realistic cases.

On the other hand, we also focus on the rotation amount to measure the dynamic volume of body balance controls induced by the acoustic cues. We integrate the area more than or less than the baseline related to the behavior of the response time as shown in Figure 3(a). This integral regions represent the rotation amount induced by the acoustic cues without time dependency.

### 3.2 Hypothesis for the Expected Results

Measuring the approximated response time and the rotation amount by the experiment, we expect that seven hypotheses can be approved as enumerated below:

1. The response time differs depending on the changing function of the sound pan: Changing the sound pan with the Heviside function induces faster response to body balance control than the Sigmoid one.
2. Training the body balance control by the sound pan change affects to the response time: The number of sequences in the experiment that a participant tried affects to his/her response time against the sound pan change.
3. The response time differs depending on participant's age: Age affects to the response time from the pan change recognition to the body balance.
4. The response time of blindness people becomes shorter than the one of the sighted: the blindness promotes keen auditory sense and induces shorter response time from the sound pan change to the body balance control than the sighted.
5. There exists left or right bias with respect to the hypothesis 1: The response time differs depending on participant's dominant arm/leg.
6. Rotation amount induced by the sound pan change differs between the Heviside and the Sigmoid function: The body balance control induces larger rotation amount when the Heviside function is used for the sound pan change than the sigmoid function or vise versa.
7. The center pan is misunderstood after the previous sound pan is changed from right or left: The sound pan sequences in the order of right, left and center or in the one of left, right and center induce misrecognition of the center pan perceived by the participant.
8. Vision influences the response time against the sound pan change: When the sighted people use their vision, their response times against the sound pan change with the Heviside or the Sigmoid function differs from the ones without sight.

The hypotheses 1-5 and 8 are related to the response time against the sound pan. These hypotheses can be analyzed by the approximate response time compared with the rates calculated by the division with the one of the compared response times. The hypothesis 6 is analyzed by using the rotation amount measured by the gyro sensor. It is available to evaluate the rates calculated by the division of the comparing rotation amount with the compared rotation amount. Thus, we performed the experiment and analyzed the acquired data applying the methods mentioned above. Thus the next section will show the results and investigate the hypotheses.

# 4 RESULTS

## 4.1 Found Fundamental Knowledge

Regarding the hypothesis 2, 3 and 5, we compared the approximated response times and the rotation amounts among blindness/sighted, ages, sex, dominant hand/leg of all participants and the number of trials. The comparison is performed under these conditions; 1) the approximated response times and the rotation amounts are compared based on every experiment in five trials, 2) we compared results among the sound pan change patterns categorized into four patterns; Heviside or sigmoid function and the sound pan change of right-to-left or left-to-right, and 3) we compared the normalized rates by the right-to-left pattern with Heviside function. However, we were not able to find any relation among all data. The data is randomly spread and independent in each participant. Therefore, we conclude that the hypothesis 2, 3 and 5 were not found.

According to this conclusion regarding these failures of the hypotheses, we apply new conditions below to evaluate other hypotheses 1, 4, 6-8:

1. Due to the failure of the hypothesis 2 regarding effect for multiple trials, we can use the average data (mean) from the five trials of a participant's experiment for comparing with other participants' results.
2. Due to the failure of the hypothesis 3 regarding effect of age of participant, we can compare data among different ages of participants.
3. Due to the failure of the hypothesis 5 regarding effect of dominant direction of participant, we can directly compare both data regarding the sound pan change patterns of right-to-left and left-to-right without considering participant's dominant hand/leg.

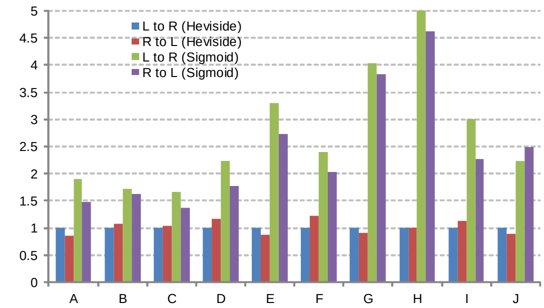
According to the fundamental knowledge discussed above, the comparisons of the sensor data will be performed regarding four categories of observations: 1) the response time, 2) the rotation amount, 3) the auditory-space perception and 4) the interference of vision. Let us discuss the observations respectively.

## 4.2 Observations regarding Response Time

First, let us focus on the difference of changing sound patterns. We have found that the difference of changing patterns regarding sound pan change among the Sigmoid and the Heviside functions influences the body balance control, which confirms the hypothesis 1. Especially we confirm the truth that the sound pan change with the Heviside function induces shorter response time than the one with the Sigmoid.

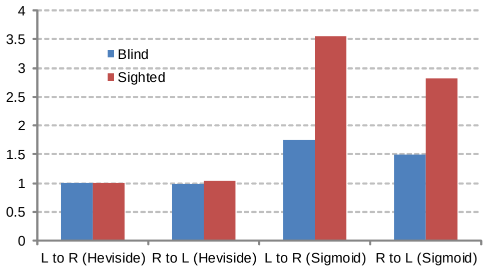
We first categorized the sound pan change patterns into four types; 1) left-to-right change with Heviside function, 2) right-to-left one with Heviside function, 3) left-to-right one with Sigmoid function and 4) right-to-left one with Sigmoid function. Applying the condition 1 in section 4.1, we have calculated the means of the response times regarding the four sound pan change types in five time trials per participant including all the blindness and the sighted with eye mask. Figure 4 shows rates normalized by the type 1) of the means of the response times categorized to each participant. Note that A, B and C are the blindness people and others are the sighted. Every participant begins to turn their body at the sound pan change with Sigmoid function in a longer response time than the one with Heviside function. Thus, we confirm that the smooth pan change induces slow response to the body balance control.

Next, regarding the response time to the sound pan change with the Sigmoid function, we have found that




| Part. | L to R (Heviside) | R to L (Heviside) | L to R (Sigmoid) | R to L (Sigmoid) |
|---|---|---|---|---|
| A | 1.000 | 0.857 | 1.909 | 1.477 |
| B | 1.000 | 1.069 | 1.716 | 1.626 |
| C | 1.000 | 1.035 | 1.655 | 1.360 |
| D | 1.000 | 1.166 | 2.238 | 1.767 |
| E | 1.000 | 0.877 | 3.300 | 2.734 |
| F | 1.000 | 1.229 | 2.393 | 2.039 |
| G | 1.000 | 0.902 | 4.039 | 3.835 |
| H | 1.000 | 1.009 | 7.717 | 4.614 |
| I | 1.000 | 1.127 | 2.997 | 2.274 |
| J | 1.000 | 0.899 | 2.228 | 2.491 |

Figure 4: Comparison of the response time rates among all participants normalized by the 1) left-to-right sound pan change for investigating the hypothesis 1. Any participant responses against the sound pan changes with Sigmoid function more slowly than the one with Heviside because the means of the sound pan change types 2), 3) and 4) become larger than 1.00.




| Part. | L to R (Hev.) | R to L (Hev.) | L to R (Sig.) | R to L (Sig.) |
|---|---|---|---|---|
| Blindness | 1.000 | 0.987 | 1.760 | 1.488 |
| Sighted | 1.000 | 1.030 | 3.559 | 2.822 |

Figure 5: Comparison of the rate of the response times among blindness and sighted participants to investigate the hypothesis 4. The means are normalized by the case of the sound pan change from left to right with Heviside function. Focusing on the rates of Sigmoid function, we confirm that the rates of blindness participants are smaller than the ones of the sighted. This means that the blindness people has a keen space perception from the sound and also can be induced by the acoustic cue to the fast body balance control.

the blindness people are induced by the sound pan change in shorter time than the sighted people when the sighted people do not use their vision (shutting out the vision with eye mask).

To confirm this hypothesis, as shown in the Figure 5, we have calculated the means of the rates used for the analysis in the hypothesis 1 comparing among the blindness and the sighted participants. Although both participants have the potential delay against the sound pan change types with Sigmoid function due to the hypothesis 1, the rates of the sighted participants of Sigmoid function become larger than the one of blindness participants in both cases of the types 1) and 3) or 2) and 4). This confirms the hypothesis 4. Thus, we have confirmed that the blindness people are able to perceive the beginning of smooth pan change keener than the sighted ones.

## 4.3 Observation regarding Rotation Amount

We have found that the rotation amount of body balance control induced by the sound pan change with the Heviside function is larger than the one with the Sigmoid, which confirms the hypothesis 6.

According to the condition 1 and 2 in section 4.1, we calculated the means of the rotation amounts as explained in section 3.1 and analyzed the rates of the Sigmoid cases normalized by the Heviside one as shown in Figure 7. The values in the columns of the Sigmoid cases of left-to-right/right-to-left sound pan changes are normalized by the ones of the same sound pan change with Heviside function. The almost all mean values in the graph are less than 1.0. Although the right-to-left case of the participant E and the left-to-right case of the participant I show larger values than 1.000, it is still less than 1.1, which is less than 10% difference. This means that the rotation amounts of the Heviside cases become larger than the ones of the Sigmoid. Thus, the sudden sound pan change induces larger rotation at the body balance control than the smooth sound pan change.

## 4.4 Observation regarding Auditory-space Perception

We have a question that if the change of sound pans can guide the precise direction of the participant under a dynamic body balance control such as walking. Now, regarding the hypothesis 7, we have found that the blindness people, especially congenital blindness, are able to have more precise space perception to detect the sound direction by the acoustic cues than the acquired blindness and the sighted people without vision. Moreover, the congenital blindness people are able to induce the body balance control to the correct direction.

We focused on the sound pan change sequences in the order of left-right-center or right-left-center, and counted the number of times when a) participant walked straightly following the center sound pan, b) participant turned to wrong direction, and c) participant ignored the center sound pan (i.e. he/she turns to the previous sound pan direction before the center pan) as shown in Table 2. The table shows the percentages of the types a), b) and c) against the total number of times of the focused sound change sequences appeared in the five trials of the experiment. In the sound pan change sequences include 4 times per whole experiment trial. A participant should receive 20 times of the sound pan change sequence including the center sound pan in an experiment trial. According to the table, we confirm that the congenital blindness has 95% of the correct recognition to the center sound pan direction and controls their body balance in front. This shows that they have a very keen space perception when they construct their space imagination using the acoustic cues.

On the other hand, the acquired blindness people have recognized the center pan correctly only for 20%. The sighted participants without vision have behaved in just 2% for the correct recognition of the center sound pan, and also misunderstood the center sound pan returned from a side as it is changing to the opposite sound pan direction from the previous sound

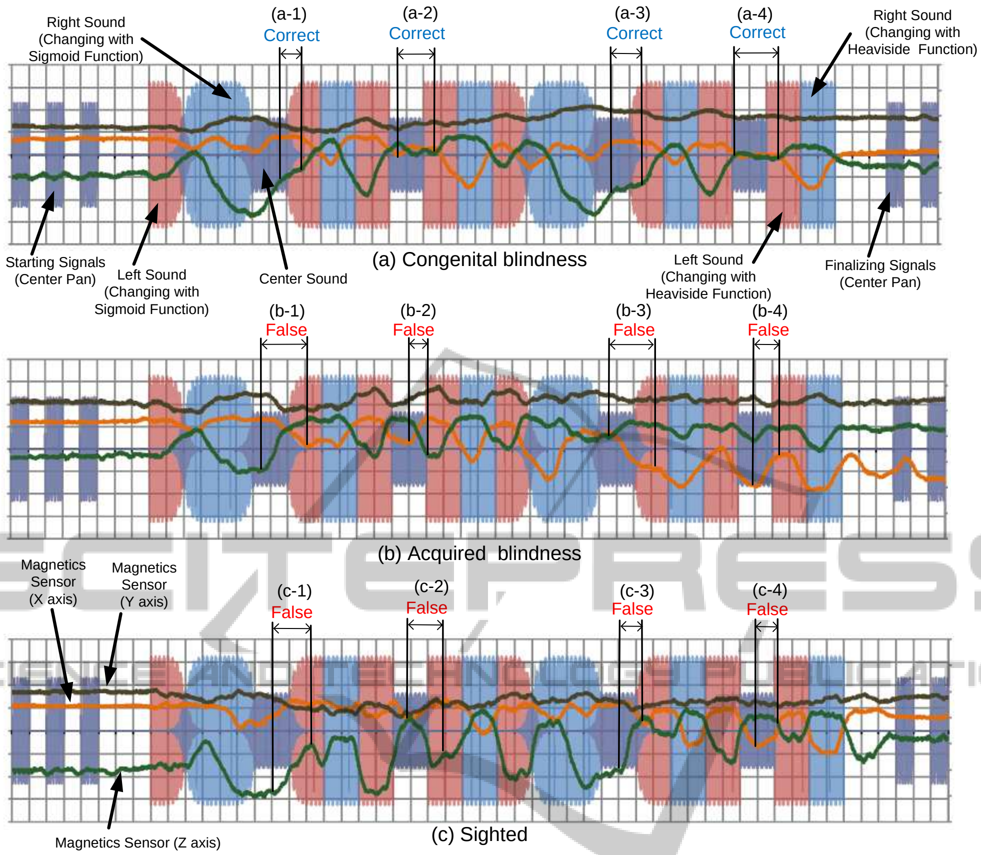



Figure 6: Comparison of the three-axis magnetic sensor data synchronized with the sound pan change timings among (a) congenital, (b) acquired blindness, and (c) the sighted participants to investigate the hypothesis 7. This comparison shows an experiment trial. The congenital blindness participant perfectly perceives the center pan after the left-to-right acoustic cues. However, the acquired blindness and sighted participants fails to perceive the center pan.



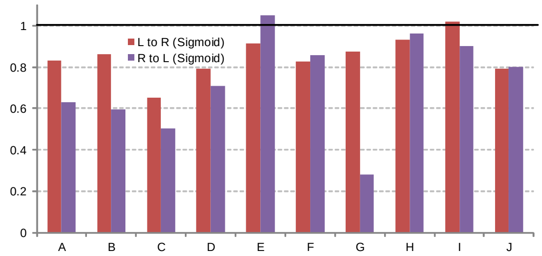
pan. This means that the sight is somehow involved to recognize the space perception created by the acoustic cues even if the sight has been acquired for a long time after we have experienced *visible*.

Figure 6 shows one of the experiment sequence tried by the participant A (congenital blindness), the participant B (acquired blindness) and the participant D (sighted without vision). Lines in the graphs of the figure show three axes of the magnetic sensor. While the participants continue to turn their body direction during the sound pan change, the sensor data of the axes are changing. Regarding the sound data in the graph, there are three starting cues in the center pan at the beginning, the left sound pan of red part and the right one of blue part. The purple part in the graph is the center pan. The triangle shaped purple part in the graph is the mixing timing of the Sigmoid function. Let us explain an significant case when the congenital blind participant perceives the center pan precisely after right-to-left sound pan change shown in Figure 6(a-2). The corresponding timings of the acquired blindness and the sighted as shown in Figure 6(b-2) and (c-2) respectively show that both participants misunderstood the sound pan direction to their right side. Thus, we have confirmed that the space perception by acoustic cues of the participants who have experienced the sight in their life was weakened due to somehow influences of their memory of vision.

## 4.5 Interference of Vision

Finally, we have found that the sighted people responses faster against the sound pan change with Sigmoid function when their vision is available.

After the five time experiment trials of the sighted participants without vision, we performed an additional experiment without eye mask. In the experiment, the participant can use their vision and follows the same instructions for the experiment as the one without vision. We measured the response times and calculated the rates as considered as the evidences of the hypothesis 1. When we calculated the subtractions of the rates in the case with vision from the one without vision, all the subtractions become positive values (i.e. $rate\ without\ vision - rate\ with\ vision > 0$) as shown in Figure 8. Thus, the response time rates normalized by the Heviside case without vision always become larger than the ones with vision. This means that the perception of the sound pan direction change with vision in the case of Sigmoid function induces body balance control in a shorter time than the perception without vision. As well as the hypothesis 7, the vision involves somehow the space perception by the acoustic cues and also influences auditory-induced body balance control.




| Part. | L to R (Sig.) | R to L (Sig.) |
|---|---|---|
| A | 0.832 | 0.629 |
| B | 0.862 | 0.593 |
| C | 0.654 | 0.505 |
| D | 0.793 | 0.709 |
| E | 0.914 | 1.050 |
| F | 0.829 | 0.860 |
| G | 0.878 | 0.282 |
| H | 0.932 | 0.962 |
| I | 1.022 | 0.904 |
| J | 0.791 | 0.800 |

Figure 7: Comparison among rates of rotation amounts of all participants divided by the ones with Heviside functions of the left-to-right sound pan change to investigate the hypothesis 6. The rate values in the graph show that the Sigmoid case induces less body rotation than the Heviside one.

## 5 DISCUSSION

Let us summarize the results and discuss the findings explored during the previous sections. We summarize the findings again regarding the hypotheses:

1. A sudden sound pan change induces fast response to both blindness and sighted people according to the hypothesis 1.
2. A sudden sound pan change induces large rotation of body balance control to both blindness and sighted people according to the hypothesis 6.
3. Blindness people perceive smooth sound pan change keener than the sighted people according to the hypothesis 4.
4. Congenital blindness people perceive sound pan direction correctly according to the hypothesis 7.
5. The vision promotes quick response for auditory-induced body balance control due to the hypothesis 8.

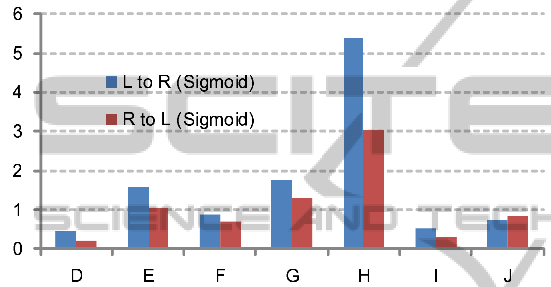
These findings are considerable to be applied to engineering application and society design. Due to the findings 1 and 2 above, we can use it for engineering application such as the biofeedback system based on sound guide. The different types of the auditory cue change such as Heviside and Sigmoid made by the feedback system will induce different effect to body balance control. When a fast body balance control and a large body rotation are required for correcting the balance control by a feedback system, we can apply the findings 1 and 2 to induce those potential body balance controls with different speed. For example, during the training of skiing to perform a beautiful *Wedeln* with the correct timing of the parallel turns, this feedback system using the findings 1 and 2, which feedbacks the rhythm of the turns sensed by accelerometer, will become valid for mastering high level skill. Thus the outcomes from the experiment in this paper are clearly applicable and important in realistic engineering field and the sports sciences applications that can modify the future body balance control correctly by acoustic cues.

On the other hand, we have found that blindness people have superior ability to perceive the space than the sighted people due to the findings 3 and 4. The blindness people seem to have their stable origin of their axes defined at their center of body. Moreover the origin of the axes is stably fixed to the defined place even if the body balance control is influenced by the acoustic cues. The finding 4 shows the evidence of the space perception ability of blindness people, which can be said as an *affordance* of blindness. Surprisingly although congenital blindness people have clearly the ability, the acquired ones do not. We can draw an inference that if any people have experienced vision in their life, memory of vision influences somehow the origin of the axes placed in the center of body by the acoustic cues. The space perception of the acquired and the sighted people is dulled by their subliminal vision image, and thus the matching between their space perceived by the acoustic cues and the perception of center of their body is distorted.

Finally the finding 5 means that the vision promotes the correct space perception and quick body balance control induced by the acoustic cues. It has not been explored the reason why the vision induces the quick response. However the experimental result implies that the vision accelerates somehow the quick response against the auditory cues. The sighted peo-

Table 2: To investigate the hypothesis 7, comparison of response types and the number of times in each type when the center pan appears in the experiment trials among congenital and acquired blindness, and the sighted participants without vision. The types are; a) correctly perceiving the center sound pan and walking without rotation (straightly), b) incorrectly perceiving the center sound pan and rotating the body to the opposite direction of the previous sound pan, and c) continuing the previous rotating movement without perceiving the center sound pan.

| Part. | Type a | Type b | Type c | Total times |
|---|---|---|---|---|
| Congenital | 95% | 5% | 0% | 20 |
| Acquired | 20% | 80% | 0% | 40 |
| Sighted | 2% | 94% | 4% | 140 |




| Part. | L to R (Sig.) | R to L (Sig.) |
|---|---|---|
| D | 0.431 | 0.182 |
| E | 1.573 | 1.060 |
| F | 0.879 | 0.697 |
| G | 1.756 | 1.305 |
| H | 5.395 | 3.027 |
| I | 0.530 | 0.301 |
| J | 0.739 | 0.851 |

Figure 8: Regarding the sound pan change patterns with Sigmoid function, comparison among sighted participants with subtracting the calculated response time rates with vision (without eye mask) from the one without vision (with eye mask) to investigate the hypothesis 8. The subtraction is performed between the Heviside and the Sigmoid cases corresponding to the same sound pan change patterns that are the left-to-right and the right-to-left ones respectively. All data in this graph show positive values. This means that the participants with vision perceive the sound pan change with Sigmoid function in shorter time than the one without vision.

ple would control their body balance with their eyeball movements simultaneously to exploit their quick responses against auditory cues.

Considering the finding 3,4 and 5, let us discuss some meanings of the findings in the society. In the conventional training on gymnastics, it is not good method to exploit the gymnast's potential ability by disabling his/her vision with eye mask if he/she is not a congenital blindness because the space perception by the auditory stimuli around him/her becomes uncertain. We can say that much better method to exploit the sighted gymnast's potential ability should be the training technique validating their vision with being aware of sounds in the environment. This method will induce quickly to master correct body balance control. Another example is to go to the tunnel with driving a car. We need to have much attention to detect the driving direction because our eyes are fixed to the front of the car as the same situation of the experiment mentioned in this paper with eye mask. However, the sounds are coming all around the car due to the reflections of the sounds from the wall of the tunnel. The driver would lose his/her space perception from the acoustic stimuli surrounding the car without dynamic vision.

In the society design, we warn troublesome caused by the situations where the acoustic cues influence the body balance control related to the findings 3, 4 and 5. For example, we can meet the situation where an old person or a child stands on Median of a large road. The body balance control of the person is influenced to the opposite side against the vision because the acoustic cues are moving on the opposite side of the cars running in front of the person. Thus it is very important to eliminate this kind of dangerous environments where the changing direction of acoustic cue is opposite to the vision stimuli. Moreover, recently we can easily see the people who walk with operating a smart phone in a street. They are trying to perceive the environment surrounding him/her from the acoustic stimuli. However, as we confirmed by the experiments in this paper, this activity is very dangerous because their vision is disabled by focusing on the screen on the phone. This accelerates unstable space perception due to dulling their origins of axes recognized by the acoustic stimuli. Additionally the condition to percept the space has become worse in these days due to wearing headphone to listen to music from the phone. While he/she with a headphone walks in a street with making an email sentences on a phone, if a car is passing in front of him/her, he/she should delay to respond to the sound of the car and will have an accident. Thus, not only the vision, it should be very important to design the society or the products considering the auditory effects considering both the vision and the auditory.

## 6 CONCLUSIONS

This paper investigates the influence to the space perception when acoustic cues are inputted to blindness and sighted people during walking. We performed experiments to investigate eight hypothesis and found that the five hypotheses are confirmed: 1) The speed for body balance control is affected by the sound pan change type. 2) The rotation amount for body balance control is affected by the sound pan change type. 3) The blindness people has keener perception for the auditory cues than the sighted. 4) The congenital blindness people has a very stable axes that is not moved by the acoustic cues. And finally 5) the sighted people responses quicker against a smooth sound cue with vision than without vision.

These findings outcome the relations among the acoustic stimuli and the auditory-induced body balance control during a dynamic movement because the vection was only the cognitive and psychological matter which is detected internally in the participants on a stable posture. Our findings can be applied to engineering applications and the social design to warn the dangerousness when the sighted people lose the vision. Recently we meet such situations in many places. We warn to improve our life style to use vision with acoustic as much as possible. However, it is not sure that the absolute reasons such as the related brain parts and the psychological affects to the response quickness or the misperception of the center sound pan. Therefore, expecting an electroencephalograph or a small fMRI used in a walking situation, we will continuously explore the main reason why the findings in this paper occur so far.

## ACKNOWLEDGEMENTS

We thank to teachers of blind school in Kochi prefecture, especially to Prof. Iida who accepted our offer for the experiments. This research is partially supported by the KAKENHI No. 23650409 of Grant-in-Aid for Challenging Exploratory Research, and No. 20240060 and 24240085 of Grant-in-Aid for Scientific Research (A) funded by Japan Society for the Promotion of Science (JSPS) and also is partially supported by the JST PRESTO program and Tateisi Science and Technology Foundation.

## REFERENCES

Aoki, M., Thilo, K., Burchill, P., Golding, J., and Gresty, M. (2000). Autonomic response to real versus illusory motion (vection). *Clinical Autonomic Research*, 10(1):23–28.

Blake, R. and Sekuler, R. (2005). *Perception*. McGraw-Hill Humanities/Social Sciences/Languages.

Brunelli, D., Farella, E., Rocchi, L., Dozza, M., Chiari, L., and Benini, L. (2006). Bio-feedback system for rehabilitation based on a wireless body area network. In *Fourth Annual IEEE International Conference on Pervasive Computing and Communications Workshops, 2006*.

Dozza, M., Chiari, L., Hlavacka, F., Cappello, A., and Horak, F. (2006). Effects of linear versus sigmoid coding of visual or audio biofeedback for the control of upright stance. *Neural Systems and Rehabilitation Engineering, IEEE Transactions on*, 14(4):505–512.

Giansanti, D., Dozza, M., Chiari, L., Maccioni, G., and Cappello, A. (2009). Energetic assessment of trunk postural modifications induced by a wearable audio-biofeedback system. *Medical Engineering & Physics*, 31(1):48–54.

Hove, M. J., Suzuki, K., Uchitomi, H., Orimo, S., and Miyake, Y. (2012). Interactive rhythmic auditory stimulation reinstates natural 1/*f* timing in gait of parkinson's patients. *PLoS ONE*, 7(3):e32600.

Lackner, R. J. (1977). Induction of illusory self-rotation and nystagmus by a rotating sound-field. *Aviation, Space, and Environmental Medicine*, 48(2):129 – 131.

Lackner, R. J. (1978). Handbook of sensory physiology. *Some Mechanisms Underlying Sensory and Postural Stability in Man*, 8:805 – 845.

Lackner, R. J. (1983). Handbook of sensory physiology. *Influence of Posture on the Spatial Localization of Sound*, 31(9):650 – 661.

Miyake, Y. (2009). Interpersonal synchronization of body motion and the walk-mate walking support robot. *Robotics, IEEE Transactions on*, 25(3):638 –644.

Valjamae, A. (2009). Auditorily-induced illusory self-motion: A review. *Brain Research Reviews*, 61(2):240 – 255.