Aurally presentation technique of virtual acoustic obstacle by manipulation of acoustic transfer function

Takahiro Miura*
Graduate School of Information Science and Technology, the University of Tokyo

Junya Suzuki†
Graduate School of Innovative Life Science, University of Toyama

Teruo Muraoka‡
Research Center for Advanced Science and Technology the University of Tokyo

Tohru Ifukube§
Research Center for Advanced Science and Technology the University of Tokyo

Abstract

The auditory-enhanced blind can localize the existence and distance of obstacle without visual information. Virtual acoustical obstacle can be aurally presented by sound convolved with acoustic transfer function measured under the environment with obstacles. In this study, we discussed whether perceived obstacle distance and obstacle localization certainty is controlled by means of ATF (Acoustic transfer function) manipulation. The group of ATF was measured by dummy-head microphone under the environment with an obstacle. Sound stimuli were generated by means that pink noise was convolved with manipulated ATF whose spectral cues are emphasized. These stimuli were evaluated in terms of perceived distance and localization certainty by the blind. This resulted in nearer perceived distance and higher localization certainty, as increasing emphasis of spectral cues.

Index Terms: H.5.1 [Information Interfaces and Presentation]: User Interfaces—Auditory (non-speech) feedback; H.1.2 [Information Interfaces and Presentation]: User/Machine Systems—Human factors

1 Introduction

Human can perceive the existence and the position of non-sound object (hereafter called as obstacle) auditorily, without visual information. This ability is known as ”auditory obstacle perception” or ”obstacle sense” performed by the blind [6, 9–12]. The factors of this perception may include the impression change of acoustic field caused by the reflected sound from the obstacle [1, 14–16, 18] or sound insulation by the obstacle [17] when background or self-utterance sounds exists. The impression change of acoustical field can be resulted from spectral ripples caused by reflected sound [6, 15, 16] or gain change caused by obstacle's insulation [17].

It is known that sound images on a 3-D environment can be implemented by the presentation of binaural sounds generated by the convolution of head-related transfer function (hereafter called as HRTF) to a sound [2]. HRTF is measured by binaural microphone (e.g. Brüel & Kjær 4101) or dummy head microphone (e.g. Brüel & Kjær 4128 and GRAS 45BM) at the environment of sound source and listening point. HRTF includes the effect of acoustic transmission path and interference by the shapes of torso, head, external ear et al. as well as the characteristics of measurement devices such as microphone and loudspeaker. Meanwhile, as shown in Fig. 1, virtual acoustic obstacle may be presented auditorily by the binaural presentation of the convolved sound to arbitrary sound with the Acoustic transfer function (hereafter called as ATF; the reason this name is used is that the HRTF does not include the effect of obstacle generally) measured by dummy head microphone at obstacle-existed environment. In addition, emphasis of virtual acoustic obstacle can be realized by the manipulation of acoustical factors contained in the ATF. This technique can be applied to the obstacle orientation by the blind, blind mobility aid, and the orientation training environment for the blind.

*e-mail: miura@human.rcast.u-tokyo.ac.jp
†e-mail:suzuki@human.rcast.u-tokyo.ac.jp
‡e-mail:muraoka@human.rcast.u-tokyo.ac.jp
§e-mail:ifukube@human.rcast.u-tokyo.ac.jp

20th International Conference on Artificial Reality and Telexistence (ICAT2010), 1-3 December 2010, Adelaide, Australia
ISBN: 978-4-904490-03-7 C3450

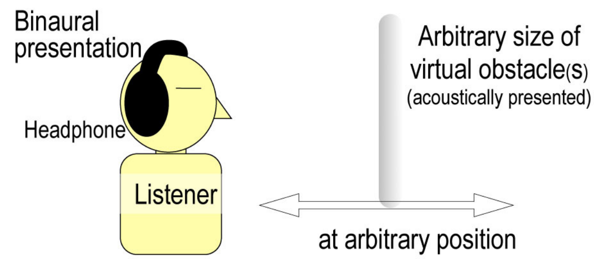

Figure 1: Concept of the technique in this study

In this paper, we discussed the possibility of virtual obstacle presentation by means of convolved sound with manipulated ATF. We firstly explain the measurement of ATF and the principle of generating the sound stimuli. Then, these sound stimuli are evaluated by the blind who can perceive the obstacle existence with auditory information. The evaluation items include localization certainty, localized distance and sound impressions.

2 Technique for generating sound stimuli

As a technique for sound stimuli of virtual acoustic obstacle, this section firstly states the measurement method for acoustic transfer function (hereafter called as ATF) and then explains how to generate the stimuli by convolution of manipulated ATF.

2.1 ATF measurement

Before the measurement, dummy head microphone (Brüel & Kjær 4128, hereafter called as ”HATS” (Head and torso simulator)), obstacle (lumber board) and loudspeaker (TANNOY System 800) were set at the simplified low-reflective room (size: 6.0 m width $\times$6.0 m depth $\times$ 3.0 m height, background noise: 30 dB, reverberation time: 0.181s), as shown in Fig.2.

HATS are placed at the center of the room. The loudspeaker was set at 3.0 m from the back of HATS. Obstacles were 3 kind of 70 cm (height) $\times$ 1.0 cm (thickness) wooden boards whose width were 10,15, 20, 40 and 100 cm and were placed in front of the HATS, as the center height of obstacle was equals to that of HATS head. These width represent the near values of human head width (15 cm) and its $\pm$ 5 cm value (10 and 20 cm) and of human body width (40 cm), and large wall comparing to human body (100 cm).

Measurement signal for obtaining frequency responses was swept-sine (also known as TSP) [7, 8, 13, 19] whose TSP points was

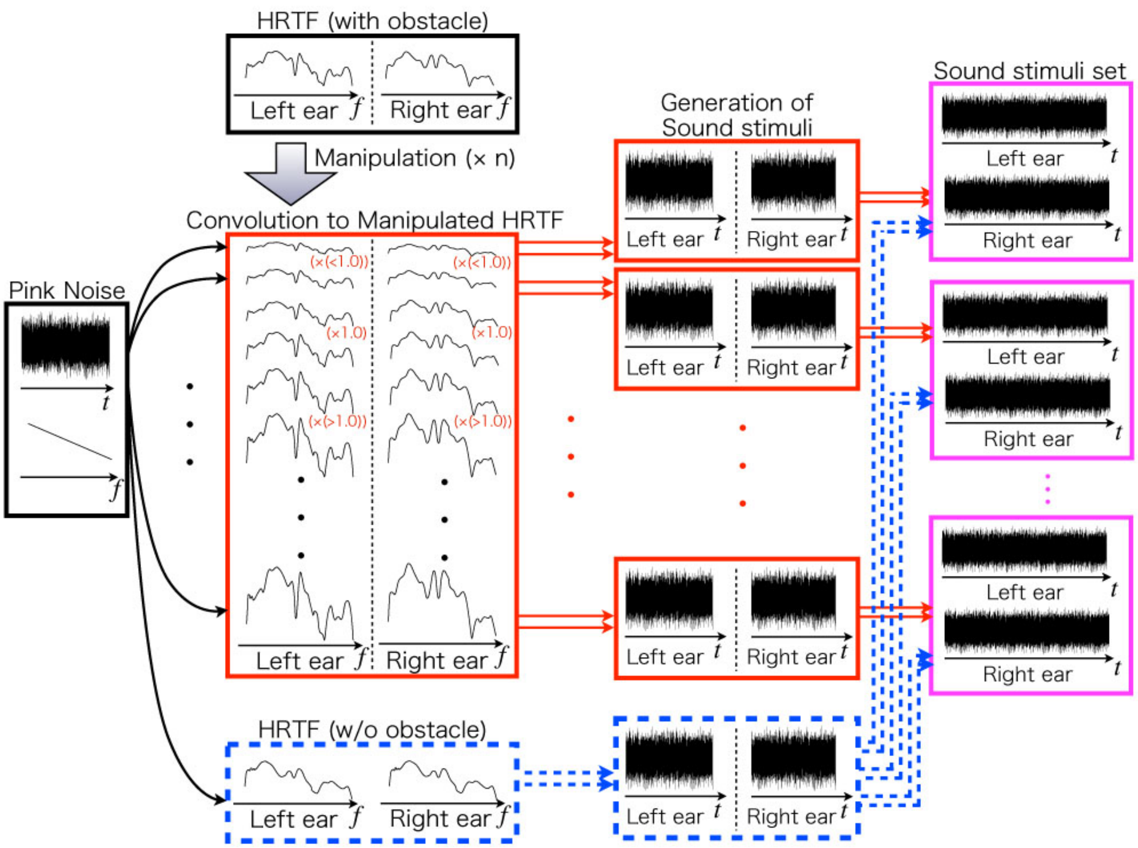

Figure 3: The technique of generating sound stimuli set

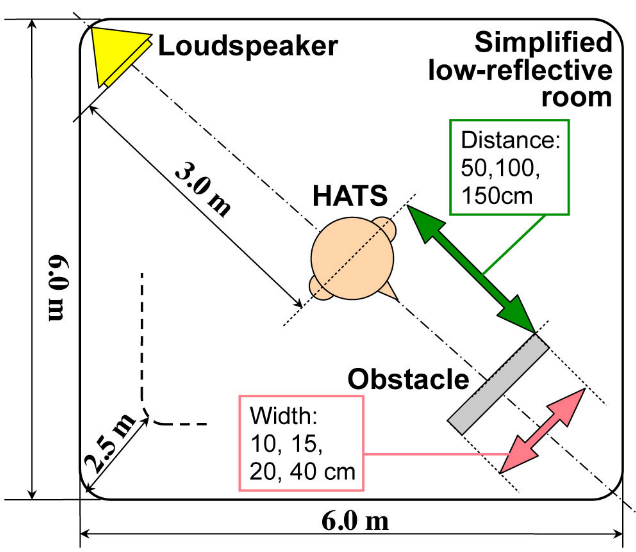

Figure 2: Measurement environment of ATF

65536 and was generated by Matlab (Mathworks), as was 44.1kHz in the sampling frequency. This signal was generated from aforementioned loudspeaker after D/A conversion (quantization bit rate: 16 bit) by audio unit (Edirol FA-66) and amplification by power amplifier (Timedomain YA1). Output signal from the loudspeaker was captured by the microphones at the both ear of HATS simultaneously and then was recorded in laptop computer after AD conversion (sampling frequency: 44.1 kHz, quantization bit rate: 16 bit) by audio unit (Edirol FA-66). Then transfer functions at the both ear was calculated by means of the circular convolution of recorded signals and inverse signal of original swept-sine and Discrete Fourier Transform. The repeat count of swept-sine was 3 times and the average transfer functions of 3 times measurements at each ear are employed as ATF.

ATF measurement was carried out when the obstacle distance was positioned at 50, 100 and 150 cm from HATS, as shown in Fig.2. In addition, the same measurement without obstacle was examined.

2.2 Sound stimuli for evaluation experiment

The outline of generating sound stimuli is illustrated by Fig. 3.

Only one pattern of pink noise series was used for convolution. This pink noise was convolved with manipulated ATF. As the specific ATF manipulation, spectral amplitudes of ATF was firstly multiplied by arbitrary value (hereinafter called as "manipulation ratio"), and then was secondly calculated by the normalization with the value of maximum spectral amplitude of non-manipulated ATF. ATF-convoluted pink noise was normalized in time domain by the maximum value of maximum amplitude of pink noise. The sound generated by this order is named as manipulated sound stimuli. In the evaluation experiment, manipulated ratio was 10 patterns: aside from 0.6∼2.0 every 0.2, 0.5 and 3.0 was set. The reason that these simple manipulation was employed was resulted from the consideration of brief calculation and computing speed. Except the manipulated sound stimuli, convoluted pink noise with ATF without obstacle called non-manipulated sound stimuli was also generated.

The duration of sound stimuli set in evaluation experiment was 7 seconds in one task. This composed by that 3-second manipulated sound stimuli was inserted by the two part of 3-second non-manipulated sound stimuli with 1-second cross-fading between the connection part of different stimuli, as shown in Fig.3.

3 Evaluation experiment

3.1 Subject

Four congenitally blind subjects and two acquired blind subjects of ages 22-42 years (average: 30.1) participated in the experiment. All of them were totally blind. All of the subjects were male and had normal hearing (20 dB HL in quartation method), that is, within normal limits in pure tone audiometry.

3.2 Experimental procedure

Experiment was carried out in soundproof chamber (Rion AT-81). Before starting experiment, the subject was asked to wear the open-type headphone (STAX SRM-1/MK2 and SR-Λ) and then to adjust the sound intensity at the comfortable level (45 ∼ 60 dB SPL). First, the 7-second sound stimuli stated at section 2.2 was binaurally presented to the subject. After that, the subject was asked to respond orally by following three items.

Localization certainty was evaluated the subjective presence of obstacle by 6-scale. The subject was instructed that scales 5, 4, ... and 1 were corresponding to 100 ∼ 80%, 80 ∼ 60%, ... and 20 ∼ 0%, respectively, in the case of localizing obstacle presence. Scale 0 should be answered only when they didn't perceive the existence of obstacle completely.

"Insulation or reflection" which indicated whether the reflected sound from the obstacle or the sound as if the sound source were insulated by the obstacle can be heard.

Localized distance represented the perceived obstacle distance between the subject and was evaluated by cm unit.

The subject were asked not to utter sound such as voice or footsteps during stimuli presentation. In addition, when the subject answers 0 in localization certainty, the other two items should not be answered.

The experiment was consisted of the trial session composed by 10 tasks and the main session composed by 320 tasks (= 5(obstacle width) × 4 (obstacle distance (3 condtions) and without obstalce (1 condition)) × 10 (manipulation ratio) × 2 (repeat count)). The main experiment was carried out separately by 80 times, with fixing the condition of obstacle width.

4 Result

4.1 Localization certainty

Localization certainty (hereinafter called LC) as a function of management ratio is illustrated by Fig. 4. These graphs are plotted by every obstacle width and lines in the graphs represent obstacle distance.

LC when the obstacle is not existed was little differences in every conditions of obstacle width. Thus the consistent tendency of LC when the obstacle are not existed was obtained, in the case the subject responded to two comparative patterns of stimuli: the no-obstacle sound stimuli and the obstacle sound stimuli whose obstacle width is varied, though the obstacle width is comparatively changed.

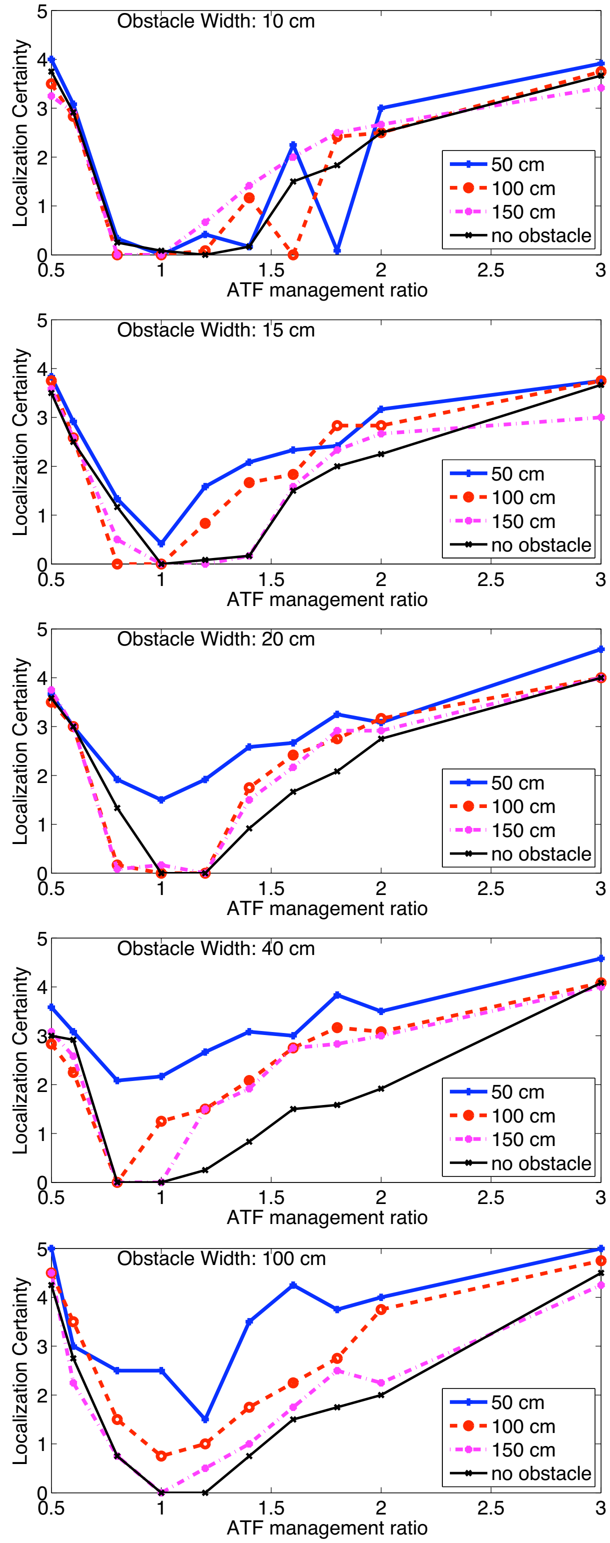

Figure 4: Localization certainty as a function of ATF management ratio.

LC when the obstacle is existed tends to be decreased as the distance increases, in all conditions of obstacle width and manipulation ratio. It is observed that this tendency increased as the obstacle width is larger. As shown in the lines of LC as a function of manipulation ratio, the lines of the case with obstacle approaches the line of the case without obstacle as increasing the obstacle distance. However, particularly when the obstacle width is 10 cm, in the case of 1.0∼1.4 in manipulation ratio, LC in the case of 50 cm obstacle distance is smaller than those of 100 or 150 cm.

Regarding the LC corresponding to the manipulation ratio, 1.0 of manipulation ratio (no manipulation) results in least localization certainty. In addition, LC is larger as increasing or decreasing the manipulation ratio. When the manipulation ratio is 1.0, LC of all obstacle distance condition is near to zero in the case of 10 cm in obstacle width. However, in the case of 15 or 20 cm in obstacle width, LC of 50 cm in obstacle distance is larger than that of 10 cm in obstacle width, and furthermore those of 150 cm rose to approximately 1.0 in the case of 40 and 100 cm in obstacle width.

The percentage of 0 responses in LC (hereafter ZRLC), as a function of management ratio is shown in Fig. 5. As well as Fig. 4, these graphs are plotted by every obstacle width and lines in the graphs represent obstacle distance.

ZRLC of no obstacle in 1.0 manipulation ratio is the highest, and ZRLC decreases as increasing or decreasing the manipulation ratio. This tendency is almost the same in the cases with or without obstacle, and gets stronger as the obstacle width is larger. Particularly when obstacle width is 100 cm, sum of ZRLC is largest in the case without obstacle. ZRLC is smaller when the obstacle distance is smaller, and especially in the case of 100 cm in obstacle width, ZRLC becomes 0% regardless of manipulation ratio when obstacle distance is 50 cm. Below 0.6 or over 2.0 manipulation ratio result in 0 % ZRLC in both the case with or without obstacle.

4.2 ” Insulation or reflection ”

” Insulation or reflection ” as a function of management ratio is illustrated by Fig. 6. These graphs are plotted by every obstacle width and lines in the graphs represent obstacle distance. Note that the part of 0%-ZRLC as shown in Fig.5 is not plotted because of the impossibility to calculate.

Regardless of obstacle width, lower manipulation ratio than 0.8 induced the higher response of ”insulation” while higher manipulation ratio than 1.2 causes the higher response of ”reflection”. As increasing the obstacle width, the response of ”reflection” was increasing in the case under 0.8 of manipulation ratio. Particularly in the case of 100 cm of obstacle width, 0.5 manipulation ratio resulted in nearly 50% (chance level) of the response as ”reflection”.

4.3 Localized distance

Localized distance (hereinafter called LD) and the ratio between localized and obstacle distances (hereinafter called RLD) as a function of management ratio are illustrated by Fig. 7 and 8, respectively. These graphs are plotted by every obstacle width and lines in the graphs represent obstacle distance. Note that the part of 0%-ZRLC as shown in Fig.5 is not plotted because of the impossibility to calculate.

LD became lower as the obstacle width enlarged regardless of the manipulation ratio and the obstacle distance. There was little difference of LD change related to obstacle distance when the obstacle width is below 20 cm. Whereas, in the case over 40 cm in obstacle width, LD was likely to decrease as the obstacle distance decrease. Particularly when obstacle width was 40 cm, the difference between LDs of 100 and 150 cm in obstacle distance were little. Meanwhile, when obstacle width was 100 cm, LD were likely to increase as the obstacle distance became smaller. In every obstacle width, LD tended generally to be farther during the non-obstacle condition.

When obstacle width is 50 cm, the line of LDR as a function of manipulation ratio formed highest value envelope and separated

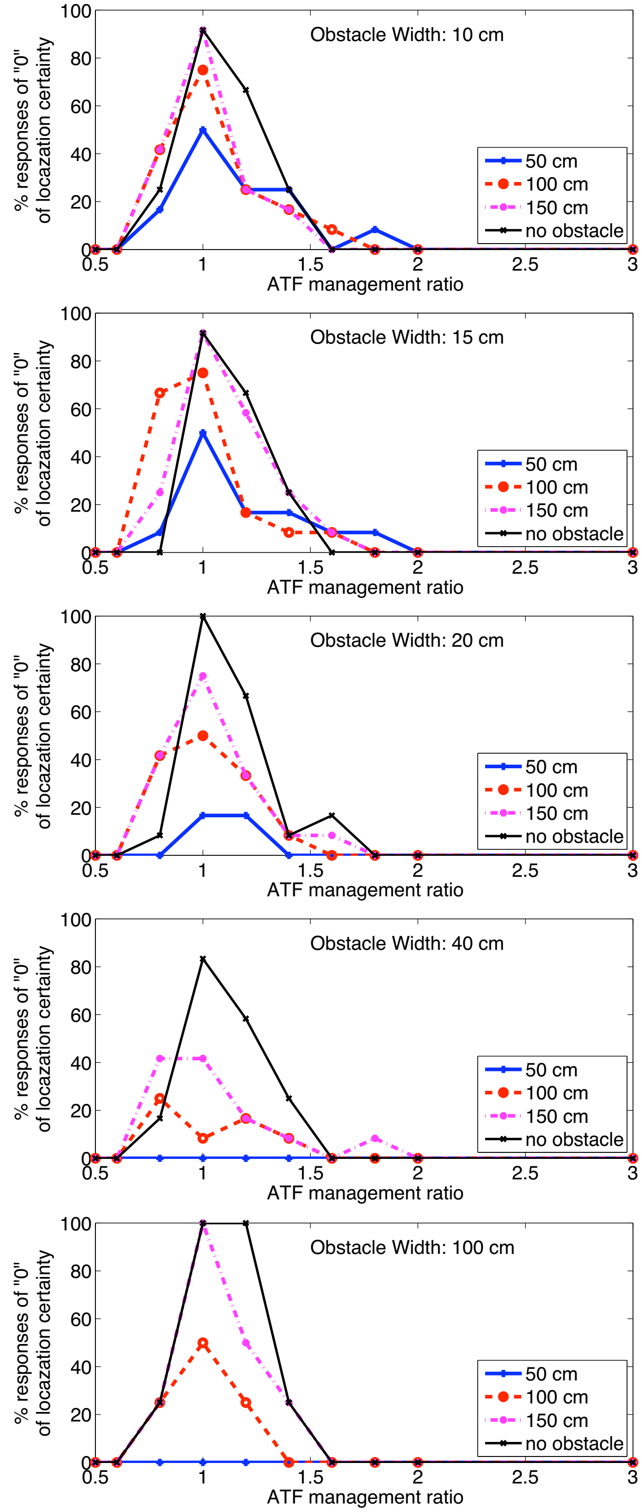

Figure 5: Percentage of response of ”0” in localization certainty, as a function of ATF management ratio. Legends display the conditions of obstacle distance.

from the presented distance. This tendency was weakened as obstacle width extended. In the case of 150 cm in obstacle distance, LDR decrease related to obstacle width change was not observed.

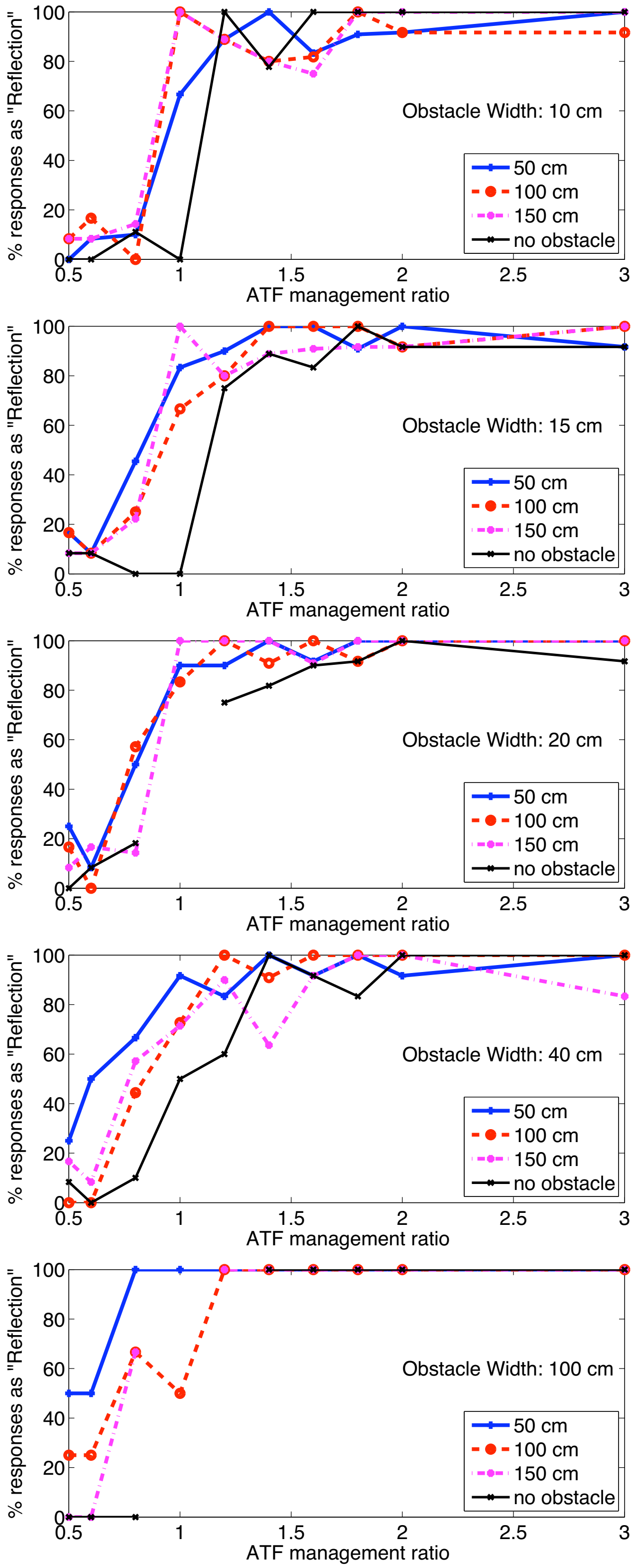

Figure 6: Percentage of responses as "Reflection", as a function of ATF management ratio. Legends display the conditions of obstacle distance.

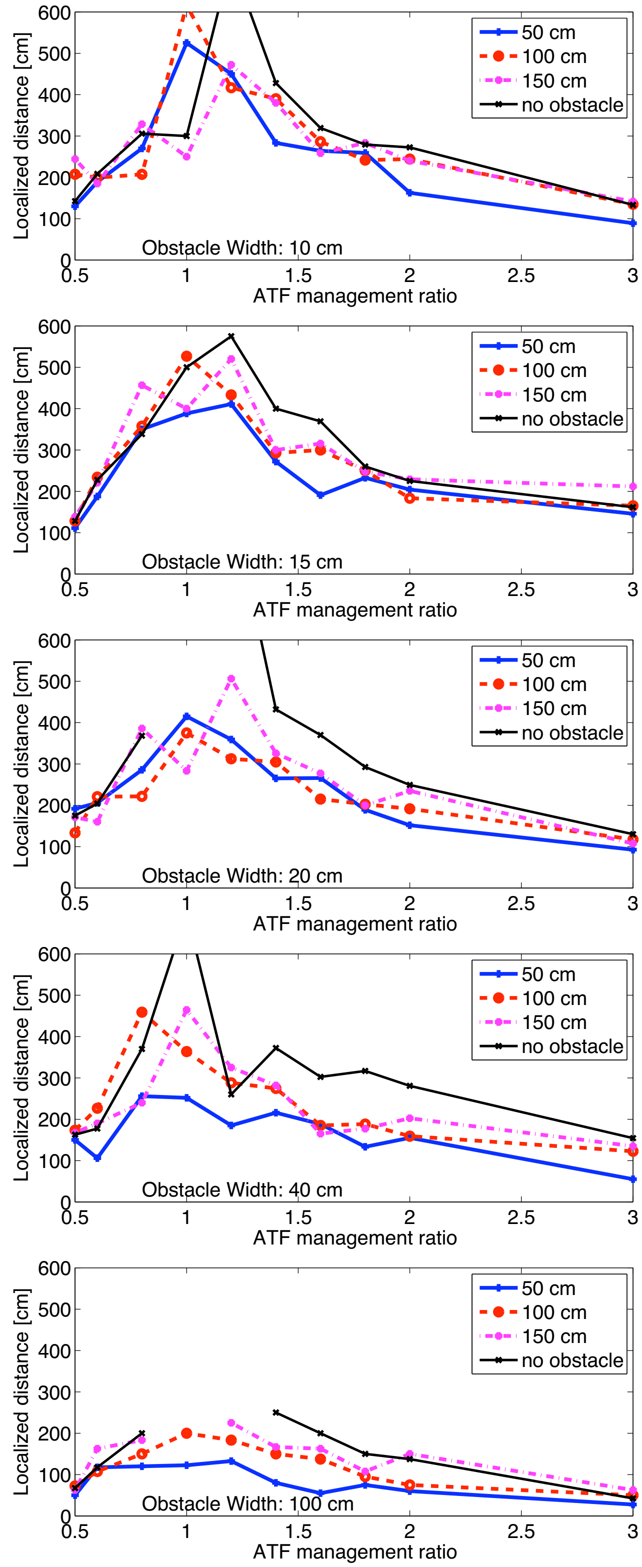

Figure 7: Localized distance as a function of ATF management ratio. Legends display the conditions of obstacle distance.

LD and LDR were largest regardless of obstacle width when ma-

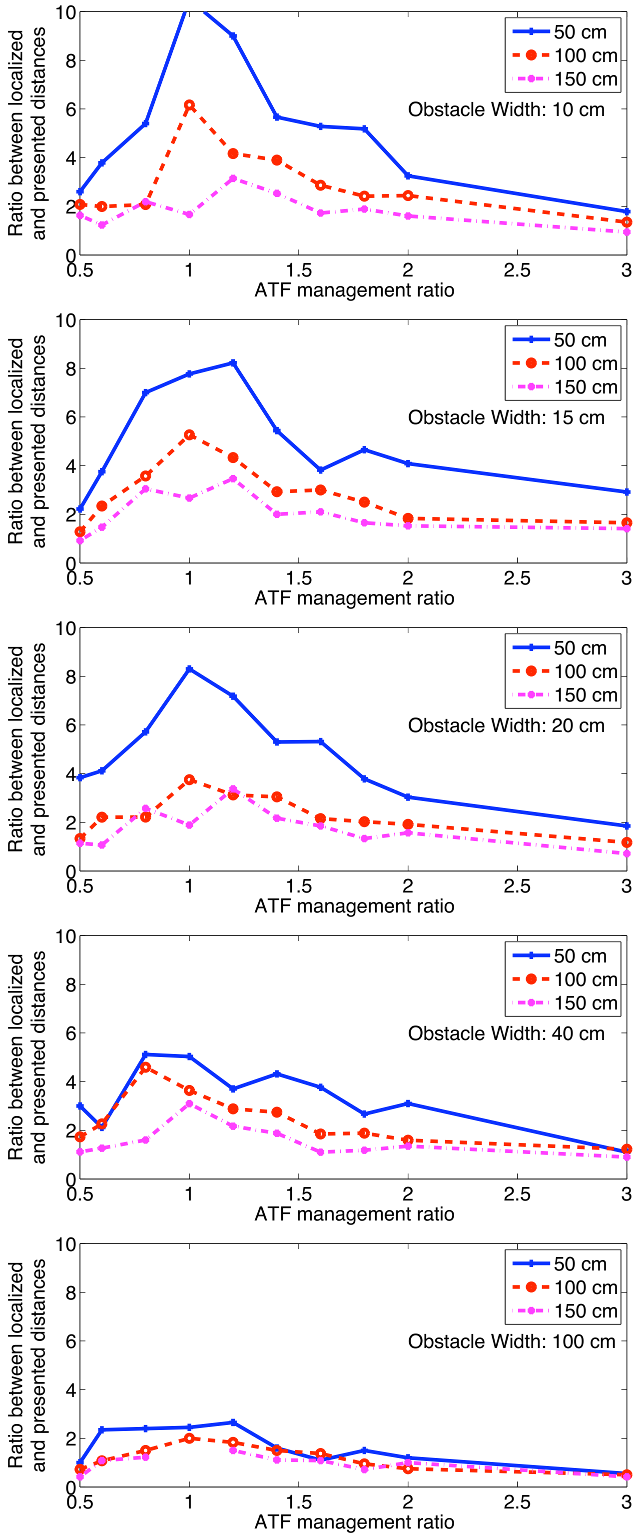

Figure 8: Localized distance as a function of ATF management ratio. Legends display the conditions of obstacle distance.

nipulation ratio is 1.0. They were likely to decrease, regardless of obstacle width, as the manipulation ratio becomes larger or smaller

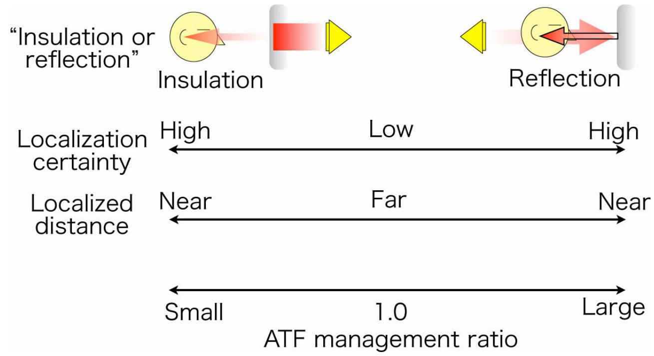

Figure 9: Tendency of localization certainty, localized distance and "insulation or reflection" as a function of ATF management ratio

than 1.0.

4.4 Summary

Tendency of change in localization certainty, localized distance and "insulation or reflection" as the change of ATF management ratio can be summarized as Fig. 9. As ATF management ratio becomes farther from 1.0, localization certainty increases while localized distance decreases. When ATF management ratio is much smaller or larger than 1.0, subjects recognizes insulation or reflection by the obstacle, respectively.

5 Discussion

As shown in Fig. 4, LC as a function of manipulation ratio was smallest when manipulation ratio was 1.0, regardless of obstacle width and distance. In addition, manipulation ratio over or under 1.0, corresponding to the emphasis or suppression of spectral cues, resulted in the higher responses of "reflection" or "insulation", respectively (as illustrated by Fig.6). LD decreased as the manipulation ratio separate larger from 1.0 (Fig.7). Therefore the impressions of obstacle sound reflection or insulation can be emphasized by increasing or decreasing manipulation ratio. The reason of this cause may be discussed by the comparison of spectral cues between ATF with the manipulation and ATF measured at obstacle-existed environement.

It is observed LC can be increased by the manipulation of non-obstacle ATF (Fig. 4). This fact suggest that even if ATF measured at non-obstacle environment has to be used, simple manipulation to ATF and convolution to arbitrary sound can realize the acoustic virtual obstacle presentation. This can be analyzed by the comparison between the difference of ATFs measured at non-obstacle or obstacle-existed environment and the difference whether non-obstacle ATF is manipulated.

The method of ATF manipulation in this study enables the emphasis of acoustic virtual obstacle existence as a result of relative amplification of spectral cues by means of multiplying arbitrary value to ATF. More effective technique of virtual obstacle presentation may be realized by the emphasis of only obstacle-induced spectral cues. This approach enables to precise presentation of virtual obstacle due to dealing separately with head-related and obstacle-related acoustical factors. However, it will take longer computing time by this method. On the other hand, simple ATF manipulation stated by this paper does not need preliminary measurements of individual ATF with or without obstacles and takes shorter calculation time. This method can be applied to the wider range of computers such as mobility assistive devices with miniature or micro computers, in particular blind mobility aid such as ultrasonic mobility aid [4]. Conventional blind mobility aid which presents obstacle distance auditorily informs the blind by the acoustic cues which is different from the cues blind people does not use [3]. Thus the information presented by those mobility aid conflicted with auditory obstacle perception of the blind. Application of proposed acoustic presentation to blind mobility aid may enable the blind to promote their ability of auditory obstacle perception.

ATF in this study is not subject-intrinsic ATF but ATF measured by the HATS. Individualized ATF should be used in the case of more precise presentation of acoustic virtual obstacle. However, ATF in this study which measured at the environment with obstacle could induce the impression of obstacle existence, to some extent. In addition, the emphasis of spectral cues enable to manipulate the obstacle presence and localization distance. This may be because of preferentially-perception of gain or spectral ripple changes caused by the emphasis or suppression of ATF, with comparison to the acoustic difference caused by head difference. This study did not evaluate the unnaturalness of presented sound caused by not convolving subject-intrinsic ATF. However, training of auditory sound localization enabled to the higher performance of localization even in the case of head shape changes such as chronic unilateral earplugging [5], or the case of using nonindividualized ATF [20]. Accordingly, brief presentation technique in this study can be efficient enough to a certain level e.g. only a presentation acoustic virtual obstacle.

6 Conclusion

As a preliminary study for the presentation technique of acoustic virtual obstacle, we first carried out the measurement of ATF at the environment with or without an obstacle. Then spectral amplitudes of ATFs were multiplied by arbitrary value (manipulation ratio), and then convoluted to a pink noise for generating sound stimuli. Furthermore, these stimuli were evaluated by totally blind subjects.

The result suggested that the relative emphasis of spectral cues enabled to induce the obstacle presence even if ATF measured at the environment without an obstacle was used. Besides, the emphasis or suppression of spectral cue can induce the perception as reflected sound from the obstacle or as sound insulation by obstacle, respectively.

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