Masking Effects Caused by Contralateral Distractors in Participants With Versus Without Listening Difficulties

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Objectives: To examine the effects of distractor sounds presented to the contralateral ear on speech intelligibility in patients with listening difficulties without apparent peripheral pathology and in control participants.

Design: This study examined and analyzed 15 control participants (age range, 22 to 30 years) without any complaints of listening difficulties and 15 patients (age range, 15 to 33 years) diagnosed as having listening difficulties without apparent peripheral pathology in the outpatient clinic of the Department of Otolaryngology-Head and Neck Surgery, Tohoku University Hospital. Speech intelligibility for 50 Japanese monosyllables presented to the right ear was examined under the following three different conditions: "without contralateral sound," "with continuous white noise in the contralateral ear," and "with music stimuli in the contralateral ear."

Results: The results indicated the following: (1) speech intelligibility was significantly worse in the patient group with contralateral music stimuli and noise stimuli; (2) speech intelligibility was significantly worse with contralateral music stimuli than with contralateral noise stimuli in the patient group; (3) there was no significant difference in speech intelligibility among three contralateral masking conditions (without contra-stimuli, with contra-noise, and with contra-music) in the control group, although average and median values of speech intelligibility tended to be worse with contralateral music stimuli than without contralateral stimuli.

Conclusions: Significantly larger masking effects due to a contralateral distractor sound observed in patients with listening difficulties without apparent peripheral pathology may suggest the possible involvement of masking mechanisms other than the energetic masking mechanism occurring in the periphery in these patients. In addition, it was also shown that the masking effect is more pronounced with real environmental sounds, that is, music with lyrics, than with continuous steady noise, which is often used as a masker for speech-in-noise testing in clinical trials. In other words, it should be noted that a speech-in-noise test using such steady noise may underestimate the degree of listening problems of patients with listening difficulties in their daily lives, and a speech-in-noise test using a masker such as music and/or speech sounds could make listening problems more obvious in patients with listening difficulties.

Key words: Auditory processing disorders, Contralateral masking, Dichotic listening, Informational masking, Listening difficulties.

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INTRODUCTION

Patients with sensorineural hearing loss often complain of difficulties in speech perception in a noisy environment. However, even individuals without clinical hearing loss who have no apparent abnormality on routine clinical audiometric testing sometimes also complain of listening problems. That is, in most such individuals, "one-to-one" conversations are usually possible without any problem, but they often experience "listening" problems under the background noise and/or crowded environments in which many people are talking. These listening problems without apparent peripheral pathology have been called auditory processing disorders (APD) (ASHA 2005; AAA 2010; British Society of Audiology (BSA) 2011, 2018). The American Speech-Language-Hearing Association (ASHA) has defined APD as difficulties in the perceptual processing of auditory information in the central auditory nervous system. The ASHA also noted that APD refers to difficulties in the processing of auditory information in the central nervous system as demonstrated by poor performance in one or more of the relatively complex auditory information processing tasks performed in clinical practice in the so-called auditory processing test (APT), such as sound localization, auditory discrimination, temporal masking, auditory performance in competing acoustic signals (including dichotic listening), and auditory performance with degraded acoustic signals, etc. (ASHA 2005). Moreover, the ASHA stated that non–modality-specific cognitive processing and language problems may manifest themselves in auditory tasks (i.e., as "listening" problems), but, the diagnosis of APD requires demonstration of a deficit in the neural processing of auditory stimuli that is not due to higher order language, cognitive, or related factors (ASHA 2005).

However, most tests considered useful in the diagnosis of APD usually involve psychoacoustic measurements, which are basically affected by the pathologies in the entire auditory system from peripheral to central, as well as cognitive functions such as attention and memory (Moore 2018; Dillon & Cameron 2021). This means that there is a limitation to fully differentiate the causative pathology by clinical symptoms and tests such as the APT. In fact, in our daily practice for patients with APD and/or possible APD, patients who could be diagnosed with APD based on APT results often have some problems with attention or other cognitive functions, as many researchers have noted (Gyldenkærne et al. 2014; Sharma et al. 2014; DeBonis 2015; Tomlin et al. 2015; Moore 2018; Roebuck & Barry 2018; Stavrinos et al. 2018; Dillon & Cameron 2021; Petley et al. 2021; Kawase et al. 2022; Obuchi et al. 2023). However, usually, it seems difficult to differentiate whether a patient's difficulty is due purely to problems with the core central auditory system, cognitive problems such as attention, or whether both are involved.

Furthermore, hidden hearing loss (HHL) due to cochlear synaptopathy, a peripheral pathology with normal hearing, can also cause hearing problems in noisy environments, as well as poor performance in the speech-in-noise test and decreased intelligibility for distorted speech materials (Kujawa & Liberman 2009; Schaette & McAlpine 2011; Liberman 2015; Liberman et al. 2016; Liberman & Kujawa 2017). Therefore, in addition to the

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functional pathology in the brain, it is also necessary to consider and differentiate the presence or absence of a subclinical peripheral pathology with normal hearing and its influence on the individual patient's listening problems. Indeed, it has been reported that subclinical peripheral pathology can be a factor exacerbating the symptoms of APD (Petley et al. 2021). Cochlear synaptopathy can exist as an early lesion of acoustically induced and/or age-related cochlear pathology, and it can be differentiated by objective measurements such as ABR and the acoustic reflex in animal experiments (Kujawa & Liberman 2009; Sergeyenko et al. 2013; Valero et al. 2018). Unfortunately, however, the differential diagnosis of cochlear synaptopathy in humans is currently difficult by clinical audiological examinations and other means (Bramhall et al. 2019; Dias et al. 2024).

Given this background, several researchers have proposed "listening difficulties" rather than APD as an umbrella term (Moore 2018; Dillon & Cameron 2021). Unlike the term APD originally defined by the ASHA (2005), this term appears to conceptually not exclude the possibility of listening problems due to problems other than with the core central auditory processing system in the brain (such as cognitive and/or language deficits) and/or subclinical peripheral pathology comorbid with APD (Moore 2018; Dillon & Cameron 2021).

In daily clinical practice, cases that present with listening problems may have experienced various acoustic exposures, even at low levels, during the course of their growth, and possible subclinical peripheral pathology cannot necessarily be ruled out by clinical examination. In addition, it is often found that no small number of patients have some cognitive problems. However, the clinical examinations, including the APTs, that are currently being performed often do not clearly differentiate the primary and/or associated lesions involved in each case that are causing the auditory processing problem. Thus, in the present article, the term "listening difficulties" is used instead of APD as a more inclusive term to refer to the listening problems without clinical hearing loss in which some abnormalities are identified by APTs.

One of the typical complaints of patients with listening difficulties is poorer speech intelligibility in a background with many distracting sounds (distractors), even though there is no apparent peripheral pathology to cause hearing loss. That is, they are more likely to be masked by distractors (maskers) than those without listening difficulties. The masking phenomenon is sometimes discussed from the viewpoint of two factors: energetic masking and informational masking (Leek et al. 1991; Brungart 2001; Kidd et al. 2003, 2008, 2016; Best et al. 2020). Energetic masking is caused mainly by physical interactions between a signal and a masker. In contrast, informational masking is a masking phenomenon that occurs primarily through central mechanisms that cannot be explained by energetic masking mechanisms, and it is broadly defined as a degradation of auditory detection or discrimination of a signal embedded in a context of other similar sounds (Leek et al. 1991). Considering that there is basically no obvious pathology in the periphery in both subjects with and without listening difficulties, it may be inferred that the differences in masking properties between the two groups may be due, even if only partially, to factors related to the masking mechanism in the central nervous system, rather than peripheral energetic masking.

The background mechanism of the central masking phenomenon has not yet been fully clarified. However, in addition to the informational masking mechanism, as well as the energetic masking mechanism due to the possible overlap of neural excitations induced by maskers and signals in the central auditory pathway, it seems possible that the effect of distracting sounds on cognitive functions such as "attention" and "memory" may be one of the contributing factors related to the background mechanism of the central masking phenomenon, considering the similar inhibitory effects of distracting sounds seen in the phenomena of "irrelevant sound effect" and/or "inattentional deafness" (Colle & Welsh 1976; Salame & Baddeley 1982, 1989; Ellermeier & Zimmer 1997, 2014; Macdonald & Lavie 2011; Dalton & Fraenkel 2012; Koreimann et al. 2014; Molloy et al. 2015; Best et al. 2020; Utz et al. 2023). The irrelevant sound effect is a phenomenon in which short-term memory performance could be disturbed while listeners are being exposed to acoustically structured stimuli, such as speech and/or music (Colle & Welsh 1976; Salame & Baddeley 1982; Ellermeier & Zimmer 1997, 2014). Typically, the memorization of visually presented material, such as lists of letters or digits, is known to be substantially impaired by the presence of background speech and/or music stimuli, but it is not disturbed by the presentation of steady stimuli such as continuous noise (Colle & Welsh 1976; Salame & Baddeley 1982, 1989; Jones et al. 1992; Ellermeier & Zimmer 1997, 2014; Nittono 1997; Tremblay et al. 2000). Of the cognitive functions, the irrelevant sound effect is thought to have a greater impact on the memory process (Colle & Welsh 1976; Salame & Baddeley 1982; Ellermeier & Zimmer 1997, 2014), but another possible mechanism involved in masking by music and/or speech stimuli may be an attention-related effect, known as "inattentional deafness," in which auditory perception and/or responses are affected by perceptual and/or cognitive load from the auditory and visual stimuli (Macdonald & Lavie 2011; Dalton & Fraenkel 2012; Koreimann et al. 2014; Molloy et al. 2015; Causse et al. 2016; Utz et al. 2023).

Given the possible involvement of the central masking mechanism in the listening problems of patients with listening difficulties, it would be worthwhile to compare the effects of distractors on listening comprehension via a central masking mechanism between subjects with and without listening difficulties. In daily life, signal and distracting sounds (maskers) enter the ipsilateral ear at the same time. Therefore, the ipsilateral masking condition seems a more natural condition to examine. However, in the ipsilateral masking condition, the signal could be greatly affected by the distracting sounds via an "energetic masking" mechanism in the periphery, and it may be difficult to evaluate the effects of central masking separately from the effects of peripheral masking. It is known that the central masking phenomenon caused by the above mechanisms, that is, informational masking, energetic masking due to overlapping of neural excitation in the central nervous system, and inattentional deafness, etc., can be observed with contralateral masking condition, in which the effects of peripheral energetic masking are basically avoided except for the possible effects of the contralateral masker due to cross-talk (Zwislocki 1972, 1978; Brungart & Simpson 2002; Kidd et al. 2003; Shirakura et al. 2021; Takai et al. 2023). It may be meaningful to observe central masking by contralateral presentation to minimize the effects of energetic masking in the auditory periphery, though it may be an unusual sound presentation condition in everyday life.

Thus, in the present study, to compare the effects of distractors on listening comprehension via a contralateral masking mechanism between subjects with and without listening difficulties, the effects of contralaterally presented distractors on intelligibility of speech sounds presented to the ipsilateral ear (i.e., dichotic listening condition) were examined in subjects with and without listening difficulties. The present study condition can be regarded as observing the negative effects of distracting sound presented to the contralateral ear on cognitive functions, such as selective attention to the signal sound. As distracting sounds, the effects of steady noise, which is usually considered to have relatively weak effects on cognitive function, and of music stimuli with lyrics, which is expected to have a greater effect, since it contains both word sounds and music, were observed (Colle and Welsh 1976; Salame & Baddeley 1982, 1989; Ellermeier & Zimmer 1997, 2014; Macdonald & Lavie 2011; Dalton & Fraenkel 2012; Koreimann et al. 2014; Molloy et al. 2015; Best et al. 2020; Utz et al. 2023).

MATERIALS AND METHODS

Participants

This study examined and analyzed 15 healthy control participants without complaints of listening difficulties (12 men, 3 women; mean age, 23.6 years; age range, 22 to 30 years) and 15 patients (3 men, 12 women; mean age, 22.3 years; age range, 15 to 33 years) who had been diagnosed as having "listening difficulties without apparent peripheral pathology" in the outpatient clinic of the Department of Otolaryngology-Head and Neck Surgery, Tohoku University Hospital.

Control participants without complaints of listening difficulties were recruited from undergraduate and graduate students enrolled at Tohoku University. After normal hearing ability was confirmed by routine audiograms (thresholds at 125, 250, 500, 1000, 2000, 4000, and 8000 Hz: equal to or better than 20 dB HL) and speech audiograms (maximum speech intelligibility for 20 Japanese monosyllables (67-S word lists, Japan Audiological Society): equal to or better than 90%), the absence of listening difficulties was also confirmed through an interview with the researcher (T.K.) and the same questionnaire on listening problems (Obuchi & Kaga 2020) used for patients. This questionnaire consisted of 16 items, including the 12-item version of the Speech, Spatial and Qualities of Hearing scale (SSQ-12) (Noble et al. 2012, 2013) translated to Japanese plus four questions assessing the psychological aspects of patients with listening problems from another questionnaire (Questionnaire on hearing) (Suzuki et al. 2002). Each item had a score scale ranging from 0 to 10, corresponding to responses such as "not at all" and "perfect"; the total score ranged from 0 to 160. According to the previous report examining scores on this questionnaire in subjects with and without listening difficulties, the estimated cutoff line was 109 points (sensitivity: 93.9%, specificity: 82.9%) (Obuchi & Kaga 2020). Moreover, considering that the present tasks involved the evaluation of selective attention with different distractor sounds under a dichotic listening condition, the same dichotic listening test as performed on the patient group was administered. Dichotic listening (separation) was assessed using 20 four-mora words adopted from the Familiarity-controlled Word Lists 2007 (FW07), which consist of 4 groups of lists ranked according to word familiarity: low familiarity, lower-middle familiarity, upper-middle familiarity, and high familiarity (Kondo et al. 2008; Speech Resource Consortium). The 20 words used were selected from the word list with upper-middle familiarity. A pair of two four-mora words uttered by a female speaker was presented binaurally (dichotic) at the same time using the headphone system, and the participants were instructed to listen and distinguish between the words presented in their right and left ears, paying separate attention to each ear (i.e., participants were instructed to listen to the words presented on the right side [left side] while focusing their attention on the words presented on the right side [left side] and ignoring the words presented on the left side [right side]). A-weighted sound pressure levels of test words were around 62 dB. Each pair of test words was presented four times and the percentage of correct answers was assessed. The combination of words used and the order of presentation were fixed, that is, the same stimuli were used for all subjects. Cases with a history of possible chronic and/or loud noise exposure and those over 40 years of age were excluded to avoid the possible involvement of HHL due to cochlear synaptopathy as much as possible (Kujawa & Liberman 2009; Sergeyenko et al. 2013).

The patient group diagnosed as having "listening difficulties without apparent peripheral pathology" was recruited from patients attending Tohoku University Hospital. When recruiting, an effort was made to recruit as many patients as possible who were at least 18 years old, rather than underage subjects. As for the patients under 18 years old, they were allowed to participate in the study if they were at least 15 years old, and if they and their parents or guardians wished and agreed to their participation in the present study. After confirming the absence of apparent abnormalities on eardrum inspection, pure-tone audiograms, and speech intelligibility for 20 Japanese monosyllables ("67-S" lists, Japan Audiological Society), listening problems of patients with listening difficulties were confirmed by an interview with the researcher (T.K.) and/or a "questionnaire on listening problems" developed by Obuchi and Kaga (2020), as well as by an APT routinely executed in the outpatient clinic. Patients who participated in the present study had at least two abnormal findings (equal to or less than the mean value minus 2 SDs in normal controls) on an APT, such as the dichotic listening test, natural fast speech perception test, gap detection test, speech-in-noise test, speech perception in multiple talker test, etc. Cases with a history of possible chronic and/or loud noise exposure and those over 40 years of age were also excluded to avoid the possible involvement of HHL as much as possible. Based on the medical history in the medical record, comorbid conditions included a diagnosis of developmental disorder in 2 patients (1 with ADHD/ASD and 1 with ASD) and depression in 1 patient (in addition to these 3 cases, there were 5 other cases in which a developmental disorder had been suspected and investigated in the past, and some developmental problem and/or some cognitive weakness had been suggested in the past, although not a condition that could be clearly diagnosed as a developmental disorder).

Averaged audiograms and maximum speech intelligibility, as well as the results for the questionnaire (questionnaire on listening problems) score and a dichotic listening test of the participants, are shown in Figure 1. Audiograms (Fig. 1A) and maximum speech intelligibility (Fig. 1B) were in the normal range for both the controls and the patients with listening difficulties, with no significant differences between the two groups or between the left and right ears on two-way repeated-measures analysis of variance (ANOVA) performed with a

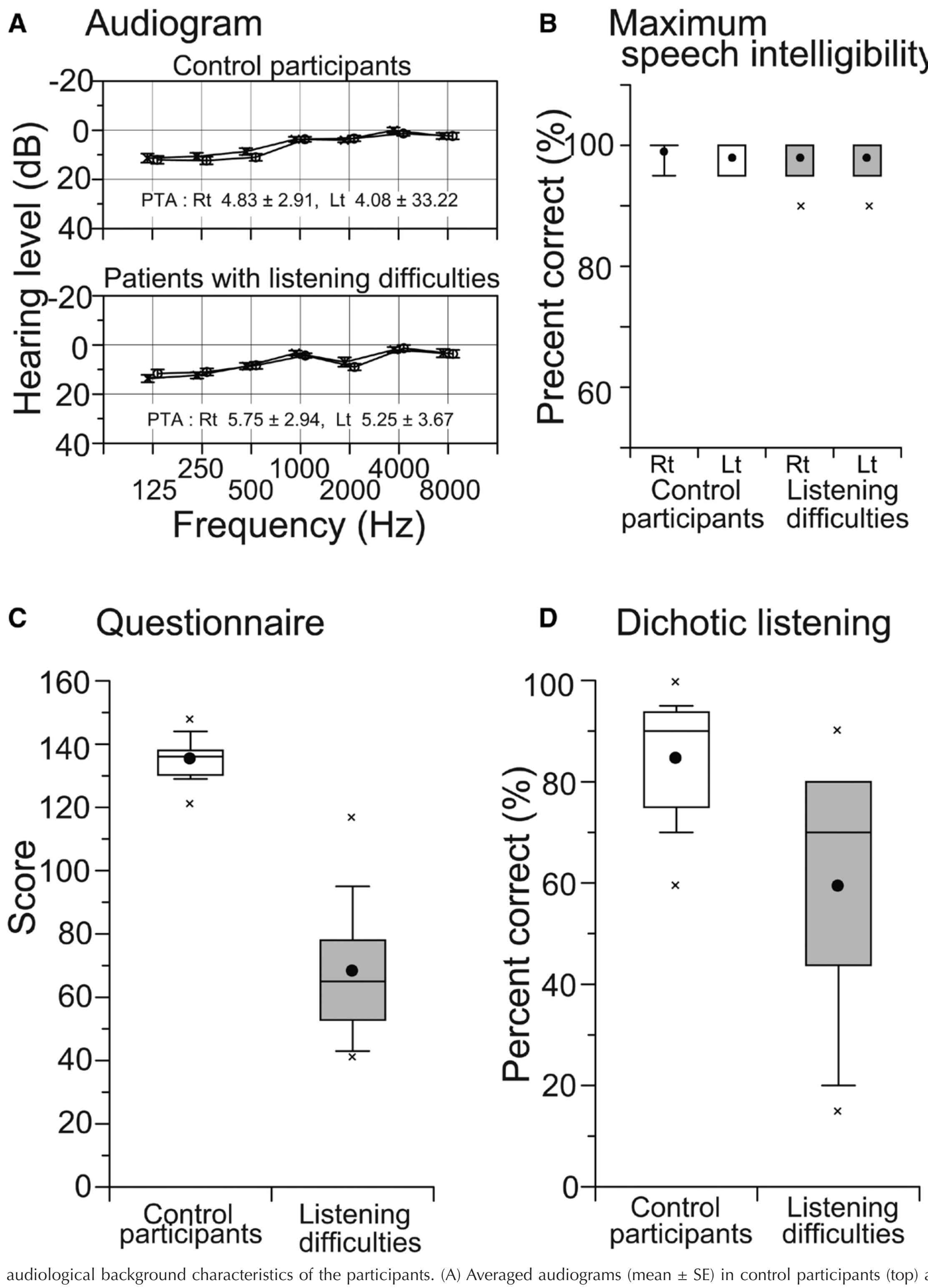

Fig. 1. Basic audiological background characteristics of the participants. (A) Averaged audiograms (mean ± SE) in control participants (top) and in patients with listening difficulties (bottom) (PTA: pure tone average); (B) Box-and-whisker plot of maximum speech intelligibility for 20 Japanese monosyllables (67-s word lists, Japan Audiological Society) in control participants and in patients with listening difficulties (mean value with SE); (C) Box-and-whisker plot of the questionnaire (questionnaire on listening problems) score; (D) Box-and-whisker plot of the results for dichotic listening. Box-and-whisker plot showing the 90/10th percentiles at the whiskers, the 75/25th percentiles at the boxes, and the median in the center line. Filled circles in the box plots indicate mean values. The crosses above the lines are outliers, that is, individual data values that fall outside the 10/90th percentile range.

between-group factor (control participants and patients) and a within-group factor of ear (right and left ears). In contrast, both questionnaire scores (Fig. 1C) and the percent correct in the dichotic listening test (Fig. 1D) were significantly better in the control group than in the patient group on the Student's *t* test.

This study was approved by the ethics committee of the Tohoku University Graduate School of Medicine (#2020-1-641: principal investigator, T.K.) and was performed in accordance with the guidelines of the Declaration of Helsinki. According to the research protocol approved by the ethics committee, written informed consent was obtained from the study participants after explaining the details of the study using an explanatory document. For participants under 18 years of age, written informed consent was also obtained from their parents or guardians at the same time.

Apparatus and Stimuli

The present study was conducted in a soundproof room at Tohoku University Hospital. The digital sound sources of the speech stimuli to assess speech intelligibility, as well as the contralateral distractor stimuli (masker), were played on a personal computer and presented through a headphone system (LCD-1; Audeze, Santa Ana, CA, USA).

For the sound source of the speech stimuli, "57-S monosyllable lists" of 50 monosyllables uttered by a female speaker, which were distributed by the Japan Audiological Society (Tokyo, Japan), were used to assess speech intelligibility. The sound lists consist of 5 sets of the same 50 Japanese monosyllables with different orders, which consist of 5 short vowels (/a/,/i/,/u/,/e/,/o/) and 45 consonant-vowel (CV) syllables (/ji/,/ho/,/wa/,/ka/,/ga/ - - - etc.). These monosyllable lists are distributed as digital sound sources on CD with a 1-kHz pure tone for calibration. The sound pressure levels of the speech stimuli were adjusted so that the level of 1-kHz tone for calibration was 60 dB A-weighted sound pressure level using a measuring amplifier (type 2610; Brüel & Kjær, Nærum, Denmark). Speech stimuli were presented every 3 sec to the right ear.

Continuous white noise and music stimuli were presented to the left ear as a contralateral masking noise. A sound clip of continuous white noise, digitally generated using signal generation software (AcousticCore 8, Arcadia, Minoo, Japan), was presented at 60 dB A-weighted sound pressure level through the headphone. As the music stimulus, popular Japanese pop music with lyrics ("Yoru-ni-kakeru" by YOASOBI) was used by playing a music clip published on the YouTube channel of the artist (Ayase/YOASOBI 2019). The sound pressure level of the music clip was adjusted so that the average A-weighted sound level for the first 20 seconds of the music stimulus was 60 dB using a measuring amplifier (type 2610, Brüel & Kjær). This music piece was chosen because it is a very popular song (over 260 million views on YouTube) that is widely known in Japan (in fact, all participants indicated that they had heard this music piece before), with many transitions in intensity, rhythm, and pitch. The durations of the noise clip and the music clip were 7 min and 4 min 36 sec, respectively, long enough to present 50 monosyllables in 1 session.

Procedure

After the practice period to familiarize the participants with the test procedure, speech intelligibility under the 3 different conditions (without contralateral stimuli, with contralateral music, and with contralateral noise), was measured (3 conditions) using the 3 different monosyllable lists consisting of the same 50 monosyllables. In each measurement session, participants were instructed to write down which monosyllables were perceived on an answer sheet during the time after each monosyllable was presented and before the next stimulus was presented.

Considering the possibility of an order effect, the measurement order of the three different conditions was adjusted so that the orders of the test conditions and monosyllable lists used for the measurements were counterbalanced among the three measurement conditions. When speech intelligibility was measured with contralateral stimuli, continuous contralateral stimuli started a few seconds before the start of presentation of monosyllables. The timing when each monosyllable was presented with respect to the music stimulus was not exactly the same for each measurement, but the presentation of all monosyllables was completed during the presentation of the music stimulus. All measurements, including practice sessions and breaks, typically took about 20 to 25 minutes.

Analysis and Statistics

The data obtained for intelligibility (percent correct) measured in three different conditions were analyzed based on the converted data using the arcsine square root transformation (Sokal & Rohlf 1995), which is often used to compare data presented as percentages.

Statistical analysis was performed using SPSS ver. 26 software (IBM Corp., Armonk, NY, USA). Two-way repeated-measures ANOVA with post hoc analyses Bonferroni-corrected for multiple comparisons was also performed to test the effects of group (between-subject factor) and contralateral masking conditions (within-subject factor) on speech intelligibility. Values of $p < 0.05$ were considered significant, and the Greenhouse–Geisser correction (Geisser & Greenhouse 1958) was used if Mauchly's test of sphericity (Mauchly 1940) indicated that the assumption of sphericity was violated.

RESULTS

Speech intelligibility results of the control group and patients with listening difficulties under three different contralateral masking conditions, that is, without contralateral stimuli, with contralateral noise stimuli, and with contralateral music stimuli, are shown in Figure 2. To compare data presented as percentages, values for speech intelligibility are presented after performing an arcsine square root transformation (by this transformation, 0, 20, 40, 60, 80, and 100% are transformed to 0, 0.46, 0.68, 0.89, 1.11, and 1.57 rad, respectively).

Differences in speech intelligibility assessed by two-way repeated-measures ANOVA performed with a between-group factor (control participants and patients) and a within-group factor of contralateral masking condition (without contra-stimuli, with contra-noise, and with contra-music) showed a significant main effect for group [$F(1,28) = 13.339$, $p < 0.01$, partial $\eta^2 = 0.323$], reflecting significant differences in speech intelligibility between the control group and the patient group with listening difficulties, a significant main effect for masking condition [$F(2,56) = 22.778$, $p < 0.001$, partial $\eta^2 = 0.449$], reflecting a significant difference in speech intelligibility among the three different contralateral masking conditions, and significant interaction effects between "group" and "contra-masking condition" [$F(2,56) = 4.691$, $p < 0.05$, partial $\eta^2 = 0.143$]. Post hoc analyses showed that speech intelligibility in patients with listening difficulties was significantly worse with contralateral music stimuli and noise stimuli than without contralateral stimuli, and that speech intelligibility was significantly worse with contralateral

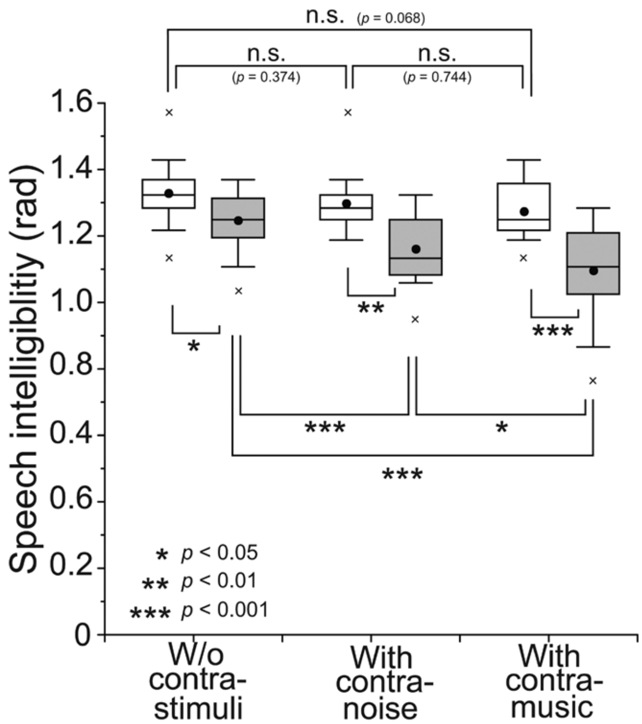

Fig. 2. Box-and-whisker plot of speech intelligibility of control participants and patients with listening difficulties under three different contralateral masking conditions: without contralateral stimuli (w/o contra-sound), with contralateral noise stimuli (contra-noise), and with contralateral music (contra-music). Box-and-whisker plot showing the 90/10th percentiles at the whiskers, the 75/25th percentiles at the boxes, and the median in the center line. Filled circles in the box plots indicate mean values. The crosses above the lines are outliers, that is, individual data values that fall outside the 10/90th percentile range.

music stimuli than with contralateral noise stimuli. However, there was no significant difference in speech intelligibility among three contralateral masking conditions (without contra-stimuli, with contra-noise, and with contra-music) in the control group, though average and median values of speech intelligibility tended to be worse with contralateral music than without contralateral stimuli (p = 0.068). Speech intelligibility in all three contralateral conditions (without contra-stimuli, with contra-noise, and with contra-music) was significantly worse in patients with listening difficulties than in the control group in all conditions. Moreover, changes in speech intelligibility relative to those without contralateral stimuli caused by the contralateral noise and music (=magnitude of the effect of contralateral sound), calculated from the data shown in this figure, were also significantly greater in patients with listening difficulties than in control participants (contra-noise effect: $p < 0.05$; contra-music effect: $p < 0.01$ by the Mann–Whitney U test).

DISCUSSION

Different Effects of Distractors Presented to the Contralateral Ear Seen in Patients With and Without Listening Difficulties

One of the typical complaints of patients with listening difficulties without clinical hearing loss is poorer speech intelligibility in a background with many distracting sounds than persons without listening difficulties, despite no apparent peripheral pathology to cause hearing loss. The present results showed that the people with listening difficulties are more susceptible to contralateral masking than the controls, especially (but not only) when the contralateral masking contains informational masking.

Although "informational masking" usually indicates masking phenomena that cannot be explained in terms of energetic masking, the underlying mechanism that causes informational masking is not fully understood (Leek et al. 1991; Brungart 2001; Kidd et al. 2003, 2008, 2016; Best et al. 2020). However, larger effects of contralateral distracting sounds seen in patients with listening difficulties may be explained as an attention-related phenomenon observed in patients with listening difficulties who are often reported to have some kind of cognitive problems in the attention mechanism, such as fluctuating attention levels, inattentive tendencies, and deficits in sustained and divided attention (Moore et al. 2010; Gyldenkærne et al. 2014; Sharma et al. 2014; DeBonis 2015; Tomlin et al. 2015; Moore 2018; Roebuck & Barry 2018; Stavrinos et al. 2018; Dillon & Cameron 2021; Kawase et al. 2022; Obuchi et al. 2023). That is, in the present study, speech stimuli and distractor stimuli were presented to the right and left ears, respectively (i.e., dichotically), and participants were asked to focus their attention on the speech stimuli and to write down which speech stimuli they heard. That is, from the viewpoint of the assessment of auditory selective attention under dichotic listening conditions (Cherry 1953), stimuli presented contralaterally can be interpreted as stimuli that interfere with selective attention to the stimuli to be paid attention to presented ipsilaterally. Thus, the present results may be interpreted as showing that selective attention to the speech sound was significantly more interfered with in the patient group with attentional weakness than in the control group by the distractors presented to the contralateral ear, resulting in a greater reduction in speech intelligibility. However, whether the reduction in apparent selective attention by the patient group is a consequence of reduced executive attention, reduced effectiveness in communication between the hemispheres, or reduced efficiency in analyzing complex signals like speech that become more apparent in the context of masking, cannot be determined from this experiment.

Different Contralateral Effects Between Noise and Music Stimuli

As mentioned at the beginning, based on previous reports of informational masking and/or irrelevant sound effects (Colle & Welsh 1976; Salame & Baddeley 1982, 1989; Leek et al. 1991; Jones et al. 1992; Ellermeier & Zimmer 1997, 2014; Nittono 1997; Tremblay et al. 2000; Brungart 2001; Kidd et al. 2003, 2008, 2016), music with lyrics and noise stimuli were chosen for this study, expecting different magnitudes of effects on intelligibility, that is, the former with greater saliency would have a greater suppressive effect on intelligibility than the latter. Therefore, the greater effect of music stimuli presented to the contralateral ear compared with noise, which was observed in the patient group, may be, in a sense, expected. From the perspective of attention mechanisms, the relatively larger effects of music stimuli compared with noise stimuli can be attributed to the different powers of noise and music to interfere with selective attention to the speech stimuli, which may be related to differences in "saliency" between these two contra-stimuli (Kaya & Elhilali 2014, 2017); one would expect the saliency of music stimuli (which has large fluctuations in frequency and sound level components on the time axis) to be much larger than that of continuous noise. In addition, in terms of the general concept of informational masking, music with lyrics presented to the contralateral ear may have caused some degree of "informational masking" due to similarities in some physical properties, such as the temporal envelope and/or due to the semantic content of a music masker with meaningful lyrics (Brungart 2001; Tun et al. 2002; Shi & Law 2010; Başkent et al. 2014). Moreover, it is also possible to speculate that the difference between the energetic masking effect in the central nervous system due to continuous white noise and that due to musical stimuli with many transitions in intensity, rhythm, and pitch may also contribute to the difference in the contralateral effects of noise and music stimuli.

Based on the present study, it is not possible to clarify to what extent any of the effects described earlier contribute to the different effects between noise and music stimuli observed in the patient group, but the greater masking effect obtained with stimuli that contained informational masking, that is, music with lyrics, may be important in understanding the listening problems that patients with listening difficulties experience in their daily lives.

In addition, from the viewpoint of clinical testing, the present results may have important implications in relation to the test conditions of the speech-in-noise test. In patients with listening difficulties without clinical hearing loss, it is often found that the results of the speech-in-noise test with a headphone system using steady noise, which is routinely performed in our ENT outpatient clinic, were not as poor as their self-reported listening problems. (Musiek & Baran 2002; American Academy of Audiology 2010; Kawase et al. 2022). Considering that the present results appear to indicate the possible important role of masking effects other than the peripheral energetic masking mechanism in patients with listening difficulties without clinical hearing loss, it may be possible that a speech-in-noise test using a masker such as music and speech sounds, etc. could make listening problems more obvious in patients with listening difficulties.

Limitations of the Present Study

It should be noted that the results of the present study were obtained under limited testing conditions. In other words, this is an effect of a specific level of white noise and specific music on a specific level of speech listening, and the overall picture of the effects of contralateral sound has not yet been clarified. It may be necessary to further clarify under which conditions (type of disturbing sound, sound level, etc.) the effects of the contralaterally presented sound observed in the control and patient groups in the present study would be larger (or smaller).

CONCLUSION

Significantly larger masking effects of a contralateral distracting sound observed in patients with listening difficulties without apparent peripheral pathology may suggest the possible involvement of masking mechanisms other than the energetic masking mechanism occurring in the periphery in these patients. In addition, it was also shown that the central masking effect is more pronounced under real environmental sounds, such as music and/or speech stimuli, than under continuous steady noise, which is often used as a masker for speech-in-noise testing in clinical trials. In other words, it should be noted that a speech-in-noise test using such steady noise may underestimate the degree of listening problems of patients with listening difficulties in their daily lives, and a speech-in-noise test using a masker such as music and/or speech sounds could make listening problems more obvious in patients with listening difficulties.

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