Sound perception of children aged 2-6 years with autism spectrum disorder

Jiayu Guo[a], Jian Kang[a,b], Hui Ma[a*]

[a]School of Architecture, Tianjin University, 92 Weijin Road, Tianjin, China

[b]Institute of Environmental Design and Engineering, The Bartlett, University College London, London, United Kingdom

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Highlights

- Loudness, musicality, complexity, spectrum component, and familiarity perceived by ASD children.
- ASD children' sound perception process includes selective listening, cognition and anticipation.
- The sound preference of ASD children was associated with their auditory profile.

Keywords: autism spectrum disorder, preschool children, sound perception, sound preference, grounded theory

Abstract

According to prior research, children with autism spectrum disorder (ASD) process auditory signals differently from typically developing (TD) children. However, their sound perception still needs to be clarified. In this study, an in-depth interview with teachers was carried out to investigate the sound perception dimensions and process of ASD children aged 2-6 years when they were listening to sounds in their daily lives. An experiment was then conducted to explore the sound preference of the ASD and TD children. The following results were obtained: 1) The interview showed that the sound perception dimensions of ASD children included loudness, musicality, complexity, spectrum component, and familiarity. 2) The sound perception process of ASD children included selective listening, cognition, and anticipation. 3) The sound preference of ASD children was associated with their auditory profile rather than psychoacoustic parameters such as tonality, sharpness, and roughness which differed from the situation of TD children. [1]

1 Introduction

*mahui@tju.edu.cn

Environmental sounds have been considered a 'resource' rather than 'waste' in recent years [1]. A high-quality acoustic environment may positively affect human well-being and quality of life [2]. People's sound preferences and how they perceive sounds have lately received great attention [3]. Kidd and Watson used semantic segmentation to investigate the relationship between acoustic properties and audience judgments of sound quality [4]. Subjective evaluation experiments have been used to investigate the structure of personal evaluations of environmental sound [5]. Dellve et al. employed grounded theory to establish preschoolers' relationships with sound through interviews with 36 children [6]. Interviews, subjective evaluations, and behavioral observations are widely used to study the sound perceptions of adults and children.

About 1 in 36 children has been identified with autism spectrum disorder (ASD), according to the Centers for Disease Control and Prevention (CDC) [7]. ASD is a neurodevelopmental disorder with two core symptoms: difficulties in social communication and interaction, as well as showing restricted and repetitive behavior, interests, or activities [8]. A substantial body of research has supported that atypical sensory processing is common to ASD children [9,10], especially in auditory processing [11]. Several investigations have confirmed the atypical auditory processing of ASD [12–15]. Atypical auditory processing of ASD leads to increased difficulty in extracting useful information and communicating effectively in real-life scenarios [16]. Moreover, it leads to many discomforts when processing auditory information, including increasing their attention burden [17], making their brains more prone to fatigue [18], and inducing negative emotions such as anxiety [19]. In a survey of 138 questionnaires, acoustic stress was found to be the primary source of stress for individuals with ASD compared to other factors [20,21]. Due to the atypical auditory processing of ASD, their acoustic environment-deserves more attention.

Behavioral, neuroimaging, neurophysiological, and pathological research has revealed that hearing disorders in the ASD population include atypical sound sensitivity, poor sound localization, and difficulty listening to noise [22,23]. As a result of these hearing disorders, reducing acoustic environmental risk factors has become an important area of research. However, most recommendations have been limited to loudness and reverberation time [24–31], which are insufficient to meet the needs of individuals with ASD regarding indoor sound fields [32]. Conversely, several studies have focused on optimizing acoustic environments for this population [33]. Studies have found that listening to music, either passively or actively, is useful for the ASD population to reduce atypical behaviors associated with auditory [34,35]. A systematic review of the literature identified that increasing the signal-to-noise ratio would help improve the behaviors of ASD, including increased executive power, improved speech recognition, and reduced auditory load [36]. Although previous studies have explored the relationship between ASD's auditory and acoustic environment, it remains unclear how they perceive sound, what they perceive when they hear a sound, and what sounds they prefer. An investigation of sound perception and preferences of the ASD population seems necessary for creating a high-quality acoustic environment for ASD.

Therefore, the sound perception of ASD children aged 2–6 years is a great concern. The research questions in this study were as follows:

1) What are the sound perception dimensions of ASD children when they listen to sounds? 2) what are the sound perception process of ASD children when they listen to sounds? 3) Whether the sound preferences of ASD children are consistent with those of typically developing children.

2 Methodology

The present study comprises two steps: the in-depth interview with teachers (Study I) and the listening experiment for children (Study II). In Study I, the sound perception dimensions and sound perception process of ASD children when they are listening to sound in their daily lives were obtained. Based on the results of Study I, Study II was designed and carried out. In Study II, the children's listening experiment was conducted with the ASD children (the ASD group) and the typically developing children (the TD group). The sound preferences of the ASD and TD children were obtained by the listening experiment.

2.1 Participants

2.1.1. Teachers for ASD children participate in Study I

Due to the lack of structural- and core-language competence, ASD children struggle to express themselves [37]. ASD children were thus not interviewed directly in this study. Teachers and parents can provide crucial informants in comprehending the emotions and behaviors of young children with ASD. Nevertheless, parenting stress, inconsistent standards from multiple informants, and variations in performance across different settings have resulted in discrepancies between teachers' and parents' assessments of these children's emotional and behavioral functioning [38]. Some studies indicate that teachers are more familiar with age-appropriate behaviors, rendering them more tolerant towards certain behavioral issues than parents [39,40]. Other research has identified large class sizes as a key factor associated with lower levels of parent-teacher agreement [41]. In this study, interviewees were needed to be professional and continuous observation experience of ASD children's emotions and behaviors. Teachers with higher education and qualifications are more suitable than parents as interviewees. In addition, interviewed teachers must have professional qualifications and over two years of work experience.

Fifteen teachers from several rehabilitation institutions were recruited for the in-depth interview. The teacher's basic information, such as age, gender, educational background, the entire period of actual operation, and professional qualifications, was collected.

2.1.2. Children participate in Study II

Thirty-one ASD children were recruited from a rehabilitation institution as the ASD group. All the participants were diagnosed with ASD by Grade A Tertiary Children's Hospitals. The diagnosis was in accord with the Child Autism Rating Scale or the Diagnostic and Statistical Manual of Mental Disorders. In total, 22 (70.97%) boys and 9 (29.03%) girls were included. The ASD participants ranged from 2 to 6 years (mean age = 4.13 years, SD = 1.45). The auditory raw scores of the ASD participants were assessed using the auditory processing part of the Short Sensory Profile(SSP) [42]. This score indicates that ASD children's auditory profile differs from TD children [43]. Therefore, in the present study, the auditory raw score was used to characterize the auditory profile of ASD participants.

A total of 53 TD children were recruited from a kindergarten as the TD group. The TD participants included 27 boys (50.94%) and 26 girls (49.06%). The TD participants ranged from 2 to 6 years (mean age = 4.42 years, SD = 1.02).

Additional eligibility criteria for all participants included the absence of any history of auditory abnormalities or medication with psychotropic substances.

2.2 Sound stimuli

A caregivers' questionnaire survey determined the sound stimuli used in the experiment for study II to ensure the sound stimuli were acceptable to the participants. A total of 43 caregivers of ASD children who participated in the survey were asked to fill out the questionnaire based on the living environment of their ASD child. The caregivers judged the sounds in the questionnaire as 'common,' 'uncommon,' or 'indeterminate.'

The primary caregivers were recruited from a rehabilitation institution for ASD children. There were no limitations on the gender and age of caregivers, but those who spent the most time caring for the child were identified. As a result, most identified caregivers were mothers, while others were grandmothers, fathers, and grandfathers.

A total of 25 sounds listed in the questionnaire were evaluated. A score of 1 was given for 'common,' -1 for 'uncommon,' and 0 for 'indeterminate' in the questionnaire. Firstly, the five lowest-scoring sounds were excluded. Second, the 20 sounds were subdivided and supplemented to ensure the sound stimuli contained different sound classifications [44]. Moreover, recognizable differences in sounds within the same sound classification are required to ensure the richness of the sound stimuli. For example, the 'Song' was subdivided into 'The lilting singing of children' and 'The soothing singing of children.'

The sound stimuli were recorded in familiar locations for the ASD children as described by caregivers in Tianjin, China. A series of 15s sound stimuli were recorded using a Sony PCM-D50 audio recorder. Four psychoacoustic parameters- fluctuation strength, sharpness, roughness, and tonality- were calculated for each sound stimulus to identify the acoustic characteristics of the sounds. The psychoacoustic parameters were calculated by ArtemiS software (HEAD acoustics) as an average of over 15 seconds.

2.3 Procedure

2.3.1. The in-depth interview (Study I)

The interview aims to investigate the sound perception dimensions of ASD children and their sound perception process. A semi-structured in-depth interview for teachers was designed based on the narrative research approach, and an interview outline (Table 1) was established before the interview. The interview recording would be collated into a transcript and then coded.

As shown in Table 1, the interview was mainly divided into three parts. First, The teachers' basic information was collected, including age, gender, educational background, and teaching experience. The teachers were asked to recall the teaching environment they had worked in and identify the sounds that appeared in the environment. Questions about the ASD students and environment were helpful for the teachers to recall the scene when the child listened to the sound. Then, the teachers were asked to describe the scene when a child listened to a sound in detail. Finally, the teachers were asked to express their opinions on the sound perception and preferences of ASD children.

Table 1.

Interview outline for the teachers in-depth interview.

Category	Question
Basic information about the teachers	Age, gender, educational background, the entire period of actual operation, professional qualifications
	The number of children currently in charge, the number of children once in charge
	The sounds heard in the teaching environment
The objective situation observed by the interviewees	Please describe the scene when the ASD child listens to a sound, including the characteristics of the sound, the child's actions, expressions, and reactions to the sound.
The subjective opinions of the interviewees	Based on your observations, do you think there are commonalities or regularities in sound perception among ASD children?
	Regarding the content of this interview, do you have anything to explain or add?

It should be noted that the outline suggested was only used as a guide, and more detailed questions were asked during the interview. The interviewer made detailed inquiries to help the teachers describe the scene when the child listened to the sound more accurately. Interviews and coding were conducted concurrently, with coding performed after every two to three interviews. The interview outline was continuously expanded based on the coding results. After interviewing 12 participants, it became evident that the agreed-upon coding results could explain most of the interview data. Furthermore, new interviewees began repeating content similar to previous participants, indicating that theoretical saturation had been reached in the interview. Additional interviews were then conducted, as suggested by Bowen [45] to confirm saturation; however, no new labels or categories emerged during coding, leading to the termination of further interviews [46,47]. The survey was conducted from October 2020 to March 2021. Each interview lasted 30–60 minutes. The complete interview recordings were eventually compiled into a 12,000-word text.

2.3.2. The listening experiment (Study II)

The listening experiment aims to compare the sound preference of ASD and TD children. In the listening experiment, 22 sound stimuli were played, and children were asked whether they liked the sound.

The listening experiment was conducted in the rehabilitation space used in daily educational activities. The ambient temperature was 22–26℃, and the humidity was 30–50%. The background noise level in the rehabilitation space was less than 45 dB(A).

The experimenters of the ASD group were their teachers to ensure that the ASD group's state was consistent with their daily lives. In addition, the teachers observed the ASD group throughout the experiment to ensure they were free from any discomfort. The experimenter of the TD group was one of the researchers. Before the experiment of the TD group, the researcher was introduced to the TD group, and there was enough time for the TD group to become familiar with the researcher.

A tiny Bluetooth speaker box was selected as the playback device in the experiment. The speaker box was compact and lightweight, and was commonly used by participants daily. The speaker box was calibrated before the listening experiment. According to the measurement of 12 occupied classrooms, the range of SPL observed was from 53.6 dB(A) to 69.6 dB(A), with a median value of 64.1 dB(A). Previous research suggests that the typical SPL threshold for ASD children falls between 55 dB(A) and 65 dB(A) [48–51]. Therefore, a SPL of 60 dB(A) was chosen for the experimental stimulus. When the player was positioned at the center of the desktop, it produced a sound pressure level of approximately 60 dB(A) at the participants' head position. To avoid burdening the participants, the listening experiment was designed to mimic participants' daily music-listening scenario. Two communication cards were prepared for the participants who had language deficits. One of the cards represented 'like,' and the other represented 'dislike.' A pre-experiment was conducted to confirm that all participants could understand the experiment completely and finish the experiment smoothly.

In the formal experiment, each stimulus was played for 15 seconds, and the participants were subsequently asked to use cards or words to indicate whether they liked or disliked the sound. The completion time was adjusted according to each participant's individual needs. The sound stimuli were played randomly.

Ethical clearance to conduct the Study Ⅰ and Ⅱ were obtained from the School of Architecture, Tianjin University. The teachers voluntarily signed the informed consent form, agreeing to participate in the recorded interview. The guardians of the participants voluntarily signed the informed consent form and agreed to participate in the experiment. All participants were informed of their confidentiality rights, anonymity, and the right to withdraw from the study at any time. All aspects of the research conformed to the tenets of the Declaration of Helsinki.

Figure 1. Photo of a rehabilitation space with participant performing the experiment.

2.4 Data analysis

2.4.1. The in-depth interview (Study I)

The Grounded Theory (GT) approach allows for considerable data and in-depth insights using systematic data collection and analysis procedures [52]. Although a sociological method, GT has been employed to explore people's understanding of the acoustic environment [53,54]. Therefore, GT was used to perform Study I.

A multistep analysis technique [55] was employed. The qualitative analysis software encoded the transcript of the interview. The steps were as follows:

In the open coding, the transcript was broken down into labels. Conceptualized data were then developed by comparing similarities between the labels. Specifically, descriptors for sounds and behaviors were encoded as individual labels. Similar labels were then grouped into the same conceptualized data. For example, the labels 'very loud' and 'loudly' were grouped into the 'loud.' Moreover, the labels 'looked to the rehabilitator,' 'pointed to others with hands,' and 'said what he had heard' were grouped into 'interacting with others.'

In the axial coding, associations between conceptualizing data were identified to rationalize the classification of the categories. Specifically, associations were made for categories based on the meaning they represented. For example, the conceptualizing data 'loud,' 'noisy,' 'intense,' 'high volume,' and 'low volume' were categorized as 'loudness.'

In the selective coding, core categories were identified. Categories with the same attributes were grouped into the same core category. Specifically, ‘loudness,’ ‘musicality,’ ‘complexity,’ ‘spectrum component,’ and ‘familiarity’ are different sound dimensions perceived by ASD children. Therefore these five categories were classified as ‘sound perception dimensions.’

Table 2 presents excerpts from the open, axial, and selective coding processes that involve memos, labeling, and conceptualizing data, categories, and core categories. In Table 3, the three labels ‘loud,’ ‘loudly,’ and ‘louder’ were used as examples to illustrate how they were encoded.

Table 2. the excerpts of the coding process.

Memos	Labeling	Conceptualizing Data	Categories	Core categories
("Please describe the scene when the child listen to the sound, including the kind of sound, the child’s actions, expressions, and reaction to the sound.") "He loves the sound of the ambulance siren and every time an ambulance passes on the road downstairs he would say: it’s the ambulance. Then he would run to the window to look for this car." "When he hears music that he likes, he dances. The music he likes has a very strong rhythm." "He doesn’t like sudden noises that appear out of nowhere, interrupt what he is doing and can make him unhappy. Common sounds are acceptable to him, such as the sounds	a1 Play music very loudly a2 He doesn't like loud sounds ... a15 When many children play noisily together, he will cover his ears a16 He loved the hat with ear-pads, especially especially in noisy places ... a64 He can hum along to the melody of the music a65 She likes soothing melodies ... a219 Only sounds that interest him attract his attention a220 He was interested in cars, so he cared about the sound of cars ... a259 He would look for the source of the sound. ... a275 He had been frightened by dogs, so he was	aa1 loud (a1-a14) aa2 noisy (a15-a20) aa3 intense (a21-a36) aa4 high volume (a37-a54) aa5 low volume (a55-63) aa6 melody (a64-a107) aa7 cheerful (a108-a123) aa8 rhythmic (a124-a149) aa9 soothing (a150-a172) aa10 clamour (a173-a177) aa11 chaotica (a178-a180) aa12 complicated (a181-a182) aa13 pure (a183-a184) aa14 simple (a185-a186) aa15 cluttered (a187) aa16 composite (a188) aa17 sharp (a189-a193) aa18 shrill (a194-a196) aa19 harsh (a197-a199)	Aa1 loudness (aa1-aa5) Aa2 musicality （aa6-aa9) Aa3 complexity (aa10-aa16) Aa4 spectrum component (aa17-aa23) Aa5 familiarity (aa24-aa26) Aa6 selective listening (aa27-aa28) Aa7 cognition (aa29-aa30) Aa8 anticipation (aa21-aa33)	A1 Sound perception dimensions (Aa1-Aa5) A2 Sound perception process (Aa6-Aa8)

in the classroom where he receives therapy, and he seems to be used to them. But if a sound comes up that has never been there before, it can cause him to have an emotional breakdown." "He loves music that is played by a single instrument, but does not like music that is played by a combination of instruments. When he hears the former, he stares at the player all the time; when he hears the latter, he pushes it away and even asks me to turn it off." ...	frightened when he heard barking ...	aa20 high frequency (a200) aa21 rough (a201) aa22 raspy (a202) aa23 muffled (a203) aa24 learned (a204-a210) aa25 common (a211-a3215) aa26 known (a216-a218) aa27 interest-oriented (a219-a241) aa28 ignoring uninterested sounds (a242-a258) aa29 attention to the sound source (a259-a274) aa30 attention to the connotation (a275-a284) aa31 resisting the unexpected (a285-a295) aa32 familiar surrounding increase tolerance (a296-a300) aa33 anticipate the sound (a301-a303)

Table 3. An example of the coding process.

Labeling	Conceptualizing Data	Categories	Core categories
a1 Play music very **loudly** a2 He doesn't like **loud** sounds a3 ... a5 He wants me to play the music **louder** a6 Child A does not like child B because B often cries **loudly**. Whenever B cried, A would stay away from him ...	aa1 loud (a1-a14) aa2 noisy (a15-a20) aa3 intense (a21-a36) aa4 high volume (a37-a54) aa5 low volume (a55-63)	Aa1 loudness (aa1-aa5) Aa2 musicality （aa6-aa9) Aa3 complexity (aa10-aa16) Aa4 spectrum component (aa17-aa23) Aa5 familiarity (aa24-aa26)	A1 Sound perception dimensions (Aa1-Aa5)

Notes: The transcript was broken down into labels.	Notes: Similar labels were then grouped into the same conceptualized data. For example, the labels ‘loud’, ‘louder’ and ‘loudly’ were grouped into the ‘loud. ’	Notes: Associations were made for categories based on the meaning they represented. For example, the conceptualizing data ‘loud,’ ‘noisy,’ ‘intense,’ ‘high volume,’ and ‘low volume’ were categorized as ‘loudness.’	Notes: ‘loudness,’ ‘musicality,’ ‘complexity,’ ‘spectrum component,’ and ‘familiarity’ are different sound dimensions perceived by ASD children. Therefore these five categories were classified as ‘sound perception dimensions.’

2.4.2. The listening experiment (Study II)

Statistical analysis was performed using SPSS 22.0. Participants’ preference for sound stimulus was recorded as ‘1’ or ‘0’, with ‘1’ indicating a ‘like’ and ‘0’ indicating a ‘dislike.’ For each sound and sound classification, a Pearson chi-square test was used to compare the differences in sound preferences between the ASD and TD groups. In addition, a nonparametric Spearman rank correlation matrix was created to investigate the relationship between psychoacoustic parameters, the auditory profile of the ASD group, and the sound preference of the ASD and TD groups.

3 Results

3.1 Sound perception dimensions (Study I)

Five sound perception dimensions of ASD children were identified from Study I. According to teachers’ descriptive words, five sound perception dimensions were identified: *loudness* (Aa1), *musicality*(Aa2), *complexity*(Aa3), *spectrum component*(Aa4), and *familiarity*(Aa5). Dimensions was sorted by the number of labels each contains. As shown in Figure 2, the first dimension with the highest number of labels was “*loudness*,” consisting of *loud*, *noisy*, *intense*, *high volume*, and *low volume* (aa1-5). Loudness perception was most reported in ASD children. For example, they could detect faint sounds that are hard for teachers to notice, and they could sense whether the music player is at their preferred volume level. Moreover, their perception of loudness had different orientations. Some children liked loud sounds and even closed their ears to the sound source, while others resisted any sound beyond their acceptable range. “*musicality*” dimension was explained by *melody*, *cheerful*, *rhythmic*, and *soothing* (aa6-9). ASD children’s perception of musicality includes rhythm and melody. They perceived changes in the rhythm and melody of sounds and music, and clapped and swayed to the rhythm and melody. Similar to the loudness perception, the musicality perception of ASD children also has different orientations. Some children prefer soothing rhythms and melodious melodies, while others prefer cheerful and passionate ones. C*lamour*, *chaotic*, *complicated*, *pure*, *simple*, *cluttered*, and *composite* (aa10-16) contributed to the “*complexity*” dimension. Complexity is the third sound perception dimension of ASD children. ASD children had the same orientation in their perception of complexity. They all dislike complex sounds, such as sounds with multiple sound sources and chaotic sounds with many changes. In addition, *sharp*, *shrill*, *harsh*, *high frequency*, *rough*, *raspy*, and *muffled* (aa17-23) were placed within "*spectrum components*." ASD children also had different orientations in their perception of spectrum components. Their attitudes towards the honking, alarm, and screaming varied from delighted to disgusted. As for "*familiarity*," *learned*, *common*, and *known* (aa24-26) became contributors. In addition to perceiving the physical properties of sounds, children also perceived the familiarity of sounds. They had chosen songs they listened to more often and paid more attention to familiar songs.

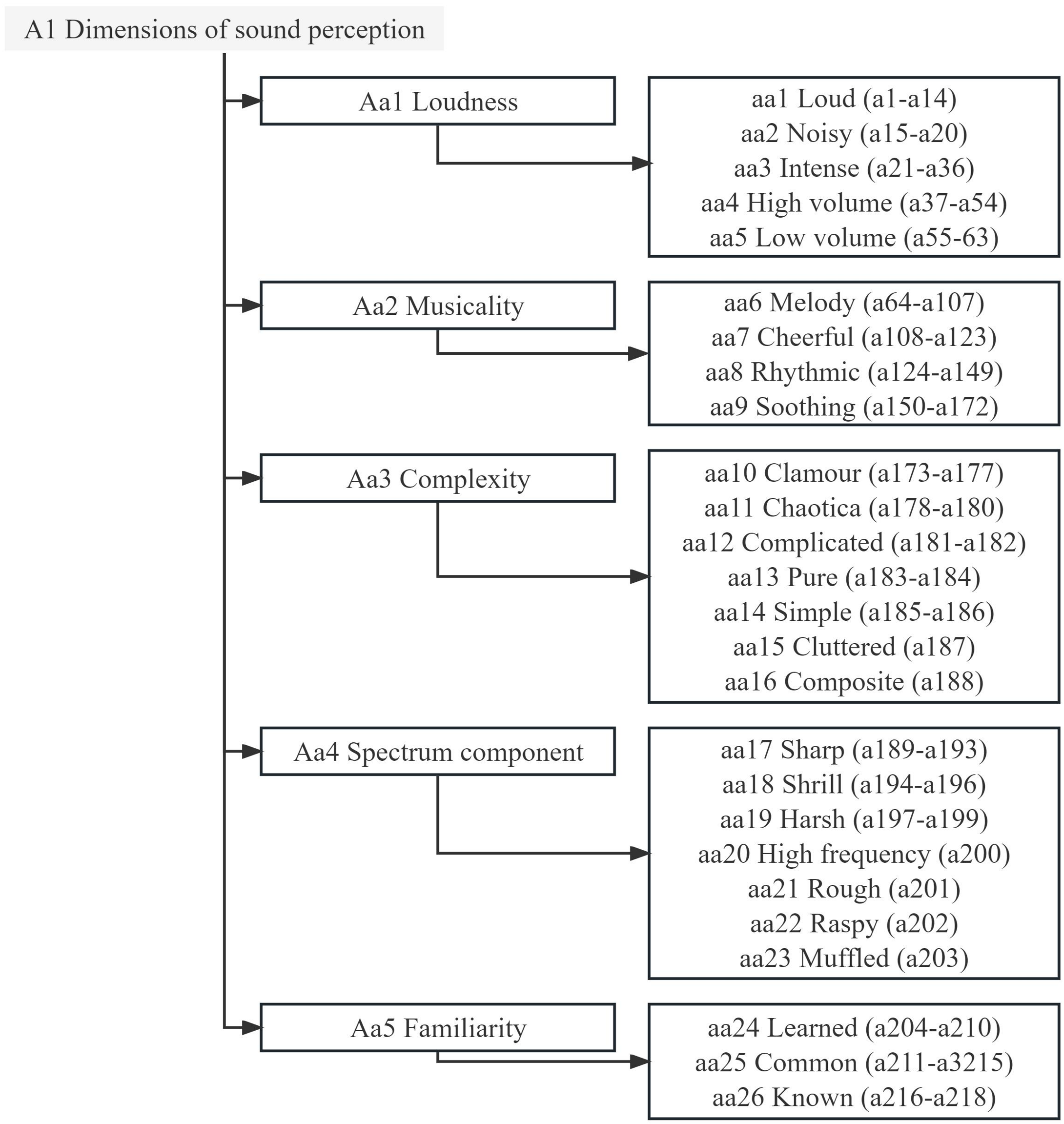

Figure 2. The sound perception dimensions.

Therefore, among the five sound perception dimensions, children with ASD had different orientations to *loudness*, *musicality*, and *spectral component*.

3.2 Sound perception process (Study I)

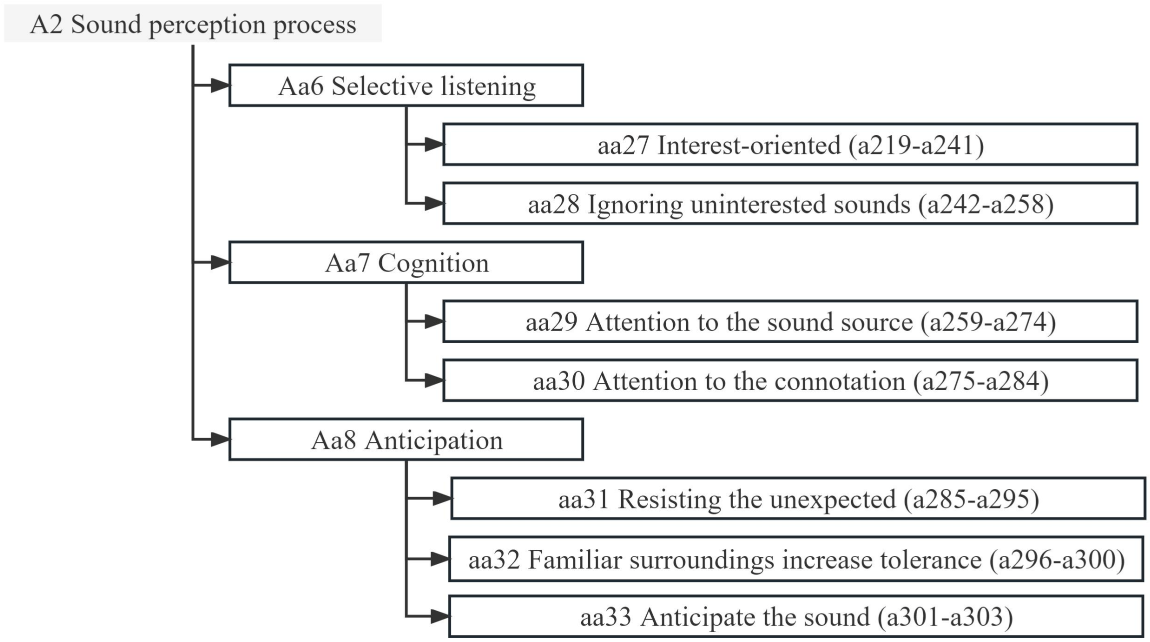

Figure 3. The sound perception process.

According to the teachers' description, in addition to identifying which dimensions of sound ASD children perceive, the sound perception process was also identified: *selective listening* (Aa6), *cognition* (Aa7), and *anticipation* (Aa8). As shown in Figure 3, the first aspect with the highest number of labels was "*selective listening* (Aa6)," consisting of *interest-oriented* (aa27) and *ignoring uninterested sounds* (aa28). Despite hearing all sounds, they perceived only the sounds they were interested in and completely ignored other sounds as if they did not hear. This result suggests that sound perception in ASD children is interest-oriented, with a greater frequency of attention towards preferred sounds rather than resistance towards disliked sounds. Moreover, "cognition (Aa7)" was explained by attention to the sound source (aa29) and attention to the *connotation* (aa30), which means that when perceiving a sound, ASD children tried to understand and recognize it. The cognitive involvement of sound perception in ASD children explains the subjective dimension of 'familiarity' in sound perception. As for "*anticipation*," *resisting the unexpected* (aa31), *familiar surrounding increase tolerance* (aa32), and *anticipating the sound* (aa33) became contributors. ASD children would prefer predictable environmental sounds (Aa8). They disliked sudden sounds and were more sensitive to sounds in unfamiliar environments. Even more, ASD children were trying to learn the patterns of sounds to be ready for the next sound. The *anticipation* is consistent with the familiarity dimension of sound perception, which reflects the ASD children's insistence on environmental consistency, suggesting a desire to reduce auditory stimuli.

3.3 Sound preference (Study II)

3.3.1. Sound preference of ASD children and TD children

The preference of ASD children for different sound stimuli ranged from 38.71% to 90.32%. The preference of TD children in different sound stimuli ranged from 43.4% to 94.34%. The sound preferences of the ASD and TD groups are shown in Figure 4. For the ASD group, their most preferred sound was the *lilting singing of children*, with 90.32%. In comparison, the sound preference for *the soothing singing of children* was less, at 70.97%, even though the two sound stimuli were the same sound classification. The *cat meow* and the *frogs croaking* were the second most preferred sounds (80.65%). The least preferred sound was the *fountain sound*, with only 38.71%.

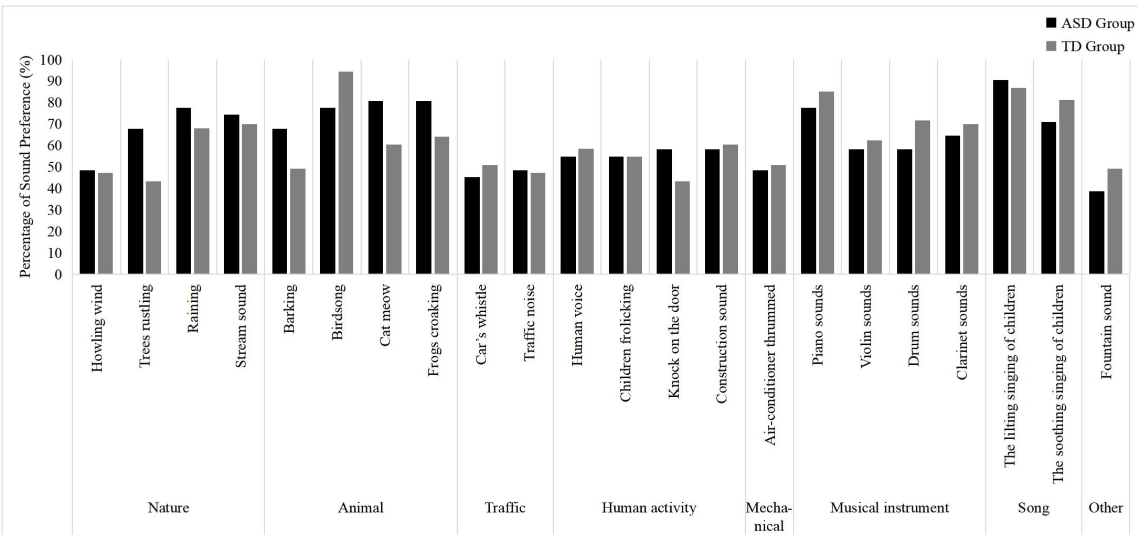

Figure 4. Sound preferences of the ASD and TD groups.

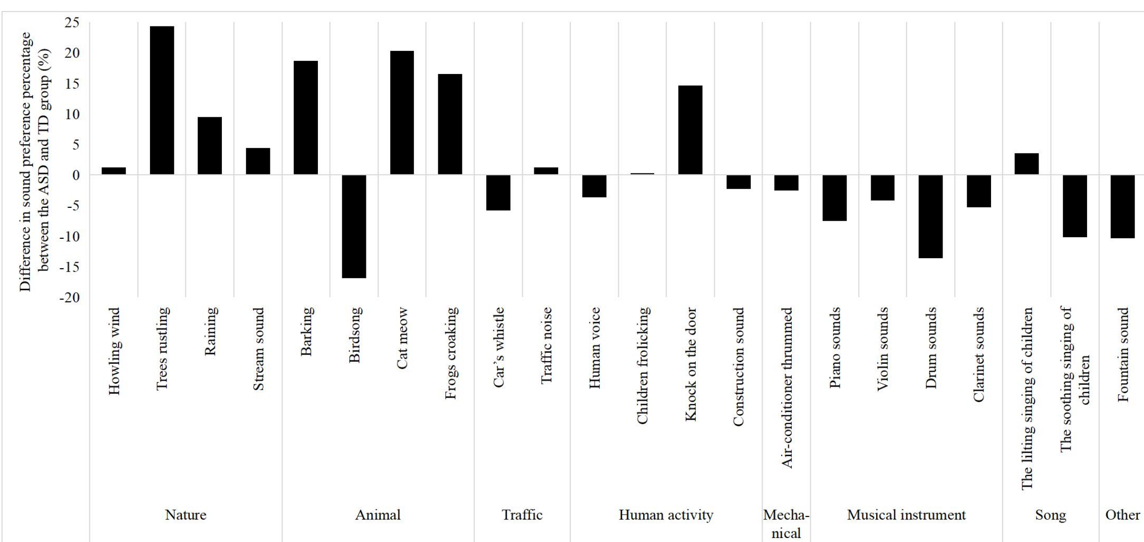

Figure 5. Difference in sound preference percentage between the ASD and TD group.

The difference in preference between the ASD and TD groups for the same sound is shown in Figure 5. The largest difference was the sound of *Trees rustling*, which was preferred by ASD children more than TD children. At the same time, ASD children preferred both nature and most animal sounds more than TD children and were less attracted to human-created sounds, even if the sounds were music. However, their preference for birdsong and knock on the door was opposite to other sounds in the same classification.

Similarly, the chi-square test showed no significant differences in sound preferences between the ASD and TD groups for most sounds except for the sounds of *trees rustling* and *birdsong*, as shown in Table 3.

Table 4. Differences in sound preference between the ASD group and the TD group.

Sound classification	Sound	Asymp Sig. (2-sided)	Asymp Sig. (2-sided)
Nature	Howling wind	0.914	0.074
	Trees rustling	**0.031**	
	Raining	0.353	
	Stream sound	0.668	
Animal	Barking	0.096	0.062
	Birdsong	**0.050**	
	Cat meow	0.055	
	Frogs croaking	0.111	
Traffic	Car’s whistle	0.609	0.775
	Traffic noise	0.914	
Human activity	Human voice	0.744	0.695
	Children frolicking	0.991	
	Knock on the door	0.194	
	Construction sound	0.835	
Mechanical	Air-conditioner thrummed	0.821	0.821
Musical instrument	Piano sounds	0.387	0.142
	Violin sounds	0.704	
	Drum sounds	0.201	
	Clarinet sounds	0.616	
Song	The lilting singing of children	0.630	0.583
	The soothing singing of children	0.283	
Other	Fountain sound	0.358	0.358

Items with the significant differences data (above 0.5) are indicated with a bold front

3.3.2. Correlation of preferred sounds with psychoacoustic parameters and auditory profile

In addition, correlation analysis showed that sound preference in the TD group was positively correlated with the sound's fluctuation strength, tonality, and sharpness (Table 4). Meanwhile, sound preference in the ASD group was correlated with the auditory raw scores of the ASD participants and the fluctuation strength of the sounds.

Table 5. Correlation between the results of sound preference of the ASD and TD group and the fluctuation strength, tonality, sharpness, roughness, and the auditory profile of ASD group.

	ASD		TD	
	r	*p*	*r*	*p*
Fluctuation strength	**0.099***	0.010	0.136**	0.000
Tonality	-0.010	0.652	0.094**	0.003
Sharpnes	0.017	0.797	0.086**	0.002
Roughness	-0.045	0.244	-0.029	0.316
Auditory raw scores	**-0.089***	0.020	-	-

$^{**}p < 0.01$
$^{*}p < 0.05$

4 Discussion

Sound perception in ASD children differs from that of typically developing children. First, to typically developing children, frequency characteristics may be more noticeable than changes in intensity [56,57]. However, the study I found that ASD children reported the most loudness perception. Secondly, typically developing children's attention is more strongly directed toward (and so more likely to report on) sound features that they perceived as most unpleasant [56]. However, as per the results of Study I, sound perception in ASD children was interest-oriented, with a greater frequency of attention towards preferred sounds rather than resistance towards disliked sounds. Finally, the sound perception of ASD children is heterogeneous, which differs from those of typically developing children. It was found in study I that although ASD individuals share the same perception dimensions, they have different orientations in *loudness*, *musicality*, and *spectral component*. In research on soundscape perception of preschool children with typical development, these dimensions were labeled as peacefulness, which was confirmed to be involved in predicting soundscape preference[58]. Thus, for typically developing children, there is a consistent orientation toward *loudness*, *musicality*, and *spectral components* of sound. It could be assumed that the sound perception of ASD children differs from that of TD children, and the sound perception of ASD children is heterogeneous.

The auditory profile is noteworthy in the study of sound perception in ASD children. Study II found a significant correlation between the sound preferences of ASD children and their auditory profiles. Thus, the auditory profile may be an important factor affecting sound preference. The results are still controversial regarding the perception and attentional preferences of different sounds in children with ASD. Some authors pointed out that ASD children have some fundamental differences from TD children's perception and attentional preferences for different sounds[59,60]. However, other studies do not support these findings [61]. Few previous studies have considered the heterogeneity of children's auditory profile. This controversy could be attributed to differences in the auditory profile of children with autism.

Sound perception in ASD children is consistent with the Restricted and Repetitive Behaviors (RRBs). RRBs are part of the core criteria for ASD and include atypical sensory behaviors such as hyper/hypo-reactivity to sensory input or unusual interests in sensory aspects of the environment, and an insistence on sameness in the environment [8]. The selective perception of sound by ASD children expressed their unusual interest, while the tendency towards familiarity and stability of their environment expressed their insistence on sameness. Overall, the sound perception of ASD children was consistent with their restricted and repetitive behaviors. Although the results are less conclusive and need examination through more research, they may imply that more attention should be given to the auditory needs and acoustic environment of children with autism.

The sound preference of ASD children is heterogeneous. The study Ⅱ found that the sound preference of ASD children had no significant correlation with tonality, sharpness, and roughness. In psychoacoustics, tonality represents whether a sound is composed of tonal components of a certain frequency or broadband noise, sharpness reflects the harshness of a sound, and roughness is a psychoacoustic parameter that describes the feeling of noise, rough and aggressive. Similarly, study I found different orientations of loudness, musicality, and spectral components in the sound perception dimensions of ASD children. The result of Study 1 suggests that ASD children have inconsistent preferences for these perception dimensions. Moreover, loudness, musicality, and spectral components were described similarly to the meanings of psychoacoustic parameters such as tonality, sharpness, and roughness. Therefore, the result of Study I that ASD children have different orientations for loudness, musicality, and spectral component is consistent with the result of Study II that the sound preference of ASD children had no significant correlation with tonality, sharpness, and roughness. The results of sound perception dimensions and sound preference all showed that the sound preference of ASD children is heterogeneous in multiple acoustic indicators. This result provides evidence for the sub-type research on sound preference of ASD children.

This research result will hopefully serve as some information for improvements for the study of perception and attentional preferences in children with ASD. The sensory profile of ASD, including the auditory profile, has four patterns of seeking (seeker), avoiding (avoider), sensitivity (sensor), and registration (bystander) [43]. Future research on the sound perception of preschoolers with ASD could focus on categorizing subject groups to contribute to ASD children's experience and well-being. Although this study found heterogeneity in sound perception among children with autism, further investigation is needed to explore differences among children with different types of ASD. Therefore, the sample size should be further increased, and different sensory types should be grouped in subsequent studies to increase the pertinence of the research and the application value of the research results. In addition, it is necessary to explore whether the results of this study apply to other age groups with autism.

5 Conclusion

The present study included an in-depth interview with the teachers (Study I) and a listening experiment for the ASD and TD children (Study II). Through these studies, the sound perception dimensions and sound perception process of ASD children when they perceive sound were clarified, and the differences in sound preferences between the ASD and TD children were identified. The main findings were as follows:

1. The sound perception dimensions of ASD children included loudness, musicality, complexity, spectrum component, and familiarity. Moreover, although ASD individuals share the same perception dimensions, they have different orientations in loudness, musicality, and spectral component dimensions.

2. The sound perception process of ASD children included selective listening, cognition, and anticipation.

3. There were no significant differences in sound preferences between ASD children and TD children in most sounds, except for the trees rustling and birdsong. However, differently from TD children, the sound preference of ASD children was only associated with their auditory profile and the fluctuation strength of sound.

While sound perception was established in this study regarding inclusive environments, targeted investigations are needed to address the different needs of children with autism to make design recommendations that can be applied to functionally specific built environments.

CRediT authorship contribution statement

Jiayu Guo: Conceptualization, Methodology, Validation, Formal analysis, Investigation, Data curation, Writing - original draft, Visualization. Jian Kang: Conceptualization, Methodology, Validation, Writing - review & editing, Supervision. Hui Ma: Validation, Resources, Writing - review & editing, Supervision, Project administration, Funding acquisition.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Conflicts of Interest

The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

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Appendices

Tabel A.1 Information for child participants with ASD.

Participants	Age	Gender	score of auditory raw
1	2	Male	18
2	2	Male	12
3	2	Male	18
4	2	Male	5
5	2	Male	0
6	2	Female	11
7	3	Male	19
8	3	Male	10
9	3	Male	6
10	3	Male	7
11	3	Female	11
12	3	Female	20
13	4	Male	14
14	4	Male	16
15	4	Male	13
16	4	Female	6
17	5	Male	16
18	5	Male	16
19	5	Male	11
20	5	Male	16
21	5	Female	11
22	5	Female	9
23	5	Male	12
24	5	Female	19
25	6	Female	14
26	6	Male	22
27	6	Male	4
28	6	Male	9
29	6	Male	6
30	6	Male	6
31	6	Female	11

Notes: Within the ASD participants, based on parent reports, 13 participants (41.9%) had an ADHD diagnosis, 6 participants (19.4%) had an anxiety diagnosis, 3 participants (9.7%) had a gastrointestinal tract disease diagnosis, 3 participants (9.7%) had a somnipathy diagnosis, 1 participant (3.2%) had a tic diagnosis.

658 **Table A.2** Description, recording location and mean values of psychoacoustics
659 characteristics of 22 sound stimuli.

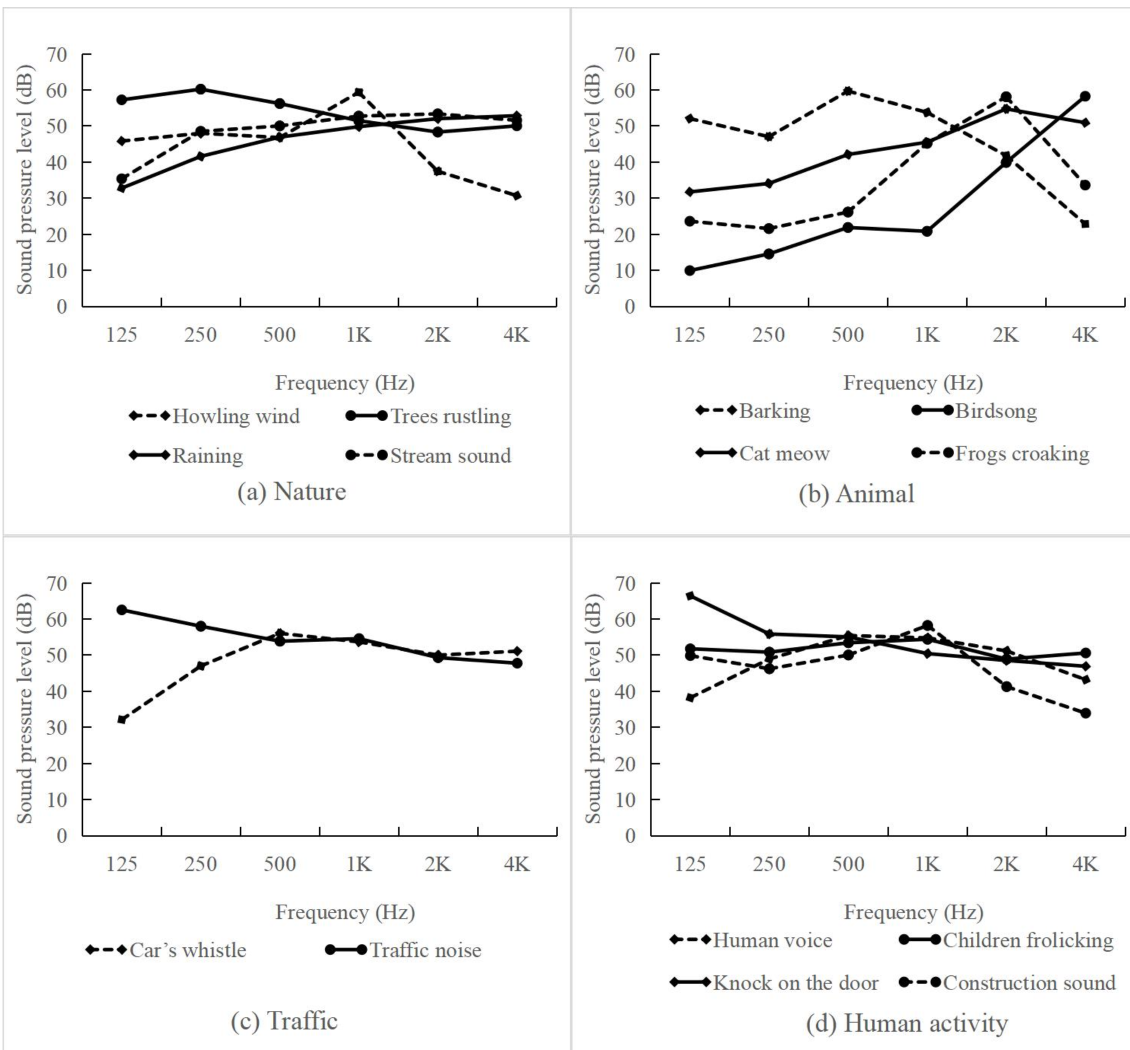
Sounds	Description of the sounds	Recording location	Fluctuation strength (vacil)	Tonality (tu)	Sharpness (acum)	Roughness (asper)
Howling wind	The whistling of the gale	Park	0.0217	15.870	1.62	1.59
Trees rustling	Leaves blowing in the wind	Park	0.0229	0.004	3.04	2.93
Raining	Rain hitting plants and ground	Park	0.0229	0.023	4.36	3.48
Stream sound	The stream flows slowly	Park	0.0241	0.022	3.86	4.11
Barking	Barking of a medium sized dog	Park	0.174	0.018	1.16	1.95
Birdsong	A few birds chirping lightly	Park	0.269	1.100	4.56	2.01
Cat meow	A cat meowing peacefully	Park	0.106	15.140	2.43	1.22
Frogs croaking	A few frogs chirping by a quiet pond	Park	0.241	0.028	2.18	4.34
Car’s whistle	A few cars staggered their horns	Park	0.152	29.760	2.92	2.25
Traffic noise	Lots of cars passing fast on the road	Roadway	0.0232	2.970	2.72	2.68
Human voice	Lots of people talking in the mall	Shopping mall	0.0362	0.016	2.37	3.19
Children frolicking	A few children playing and laughing in the outdoor playground	Park	0.0307	0.157	2.50	2.84
Knock on the door	Knock on metal entry door of residences	Residence	0.153	6.580	1.08	1.54
Construction sound	Hammering on wood during renovation	Residence	0.403	3.300	1.51	3.26
Air-conditioner thrummed	Sound when air conditioner is running	Residence	0.0856	4.860	3.75	3.08
Piano sounds	“To Elise” played on the speaker	Rehabilitation institution	0.0864	19.420	1.03	1.28
Violin sounds	“Butterfly Lovers” played on the speaker	Rehabilitation institution	0.0631	30.490	2.60	1.45
Drum sounds	“Upbeat drumming” played on the speaker	Rehabilitation institution	0.403	6.320	2.89	3.80
Clarinet sounds	“The Polka” played on the speaker	Rehabilitation institution	0.23	17.060	2.81	2.41
The lilting singing of children	Jingle Bells by Children” played on the speaker	Rehabilitation institution	0.215	27.690	3.00	1.98
The soothing singing of children	“Grandmother’s PengHuWan” played on the speaker	Rehabilitation institution	0.137	36.050	3.06	1.60
Fountain sound	A fountain that is spouting water at a constant rate	Park	0.016	0.057	3.76	3.97

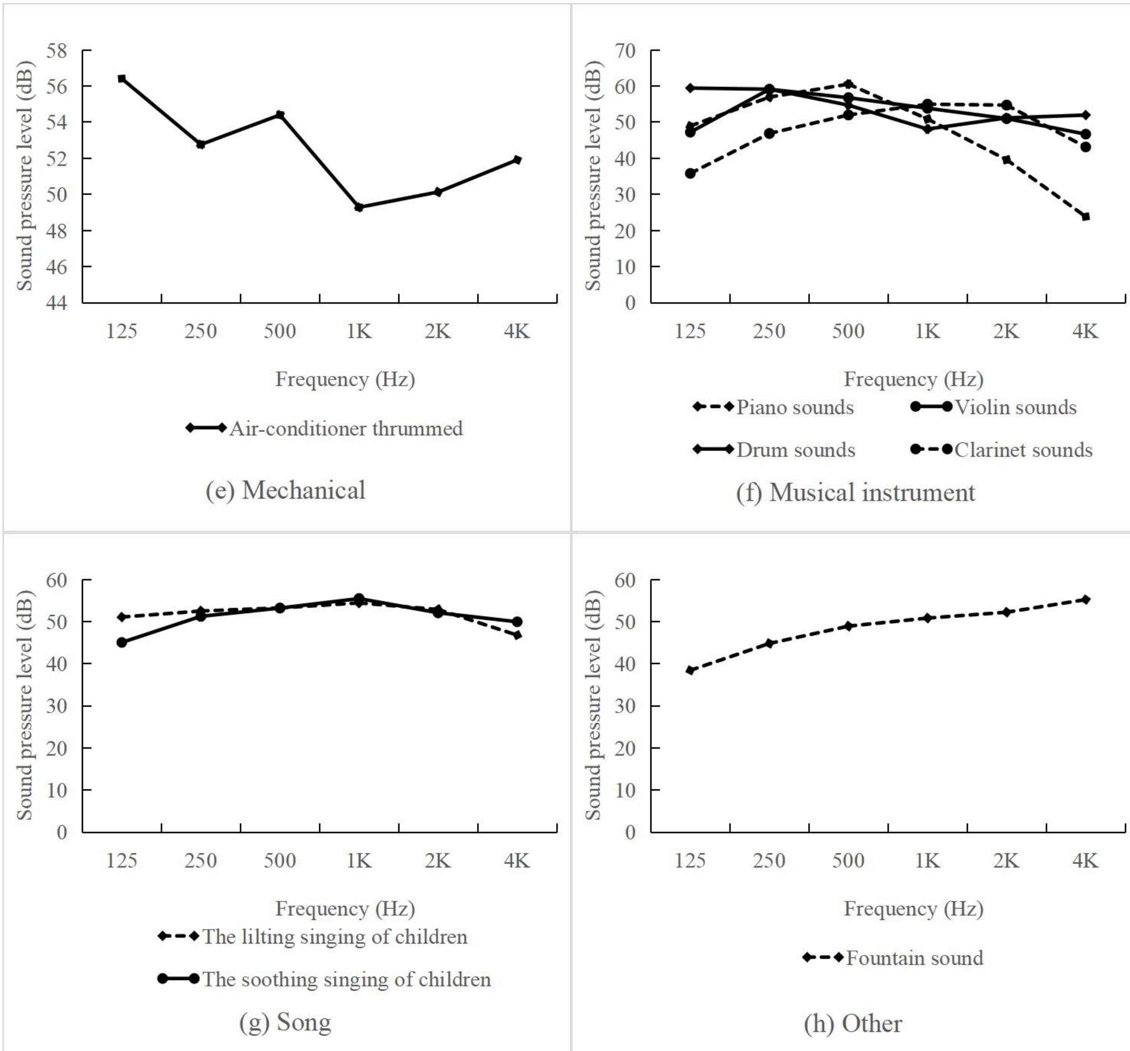
Table A.3 The percentages of sound preference for the ASD and ND groups.

Sound stimuli		ASD	TD
Howling wind	like	48.39%	47.17%
	dislike	51.61%	52.83%
Trees rustling	like	67.74%	43.40%
	dislike	32.26%	56.60%
Raining	like	77.42%	67.92%
	dislike	22.58%	32.08%
Stream sound	like	74.19%	69.81%
	dislike	25.81%	30.19%
Barking	like	67.74%	49.06%
	dislike	32.26%	50.94%
Birdsong	like	77.42%	94.34%
	dislike	22.58%	5.66%
Cat meow	like	80.65%	60.38%
	dislike	19.35%	39.62%
Frogs croaking	like	80.65%	64.15%
	dislike	19.35%	35.85%
Car’s whistle	like	45.16%	50.94%
	dislike	54.84%	49.06%
Traffic noise	like	48.39%	47.17%
	dislike	51.61%	52.83%
Human voice	like	54.84%	58.49%
	dislike	45.16%	41.51%
Children frolicking	like	54.84%	54.72%
	dislike	45.16%	45.28%
Knock on the door	like	58.06%	43.40%
	dislike	41.94%	56.60%
Construction sound	like	58.06%	60.38%
	dislike	41.94%	39.62%
Air-conditioner thrummed	like	48.39%	50.94%
	dislike	51.61%	49.06%
Piano sounds	like	77.42%	84.91%
	dislike	22.58%	15.09%
Violin sounds	like	58.06%	62.26%
	dislike	41.94%	37.74%

Drum sounds	like	58.06%	71.70%
	dislike	41.94%	28.30%
Clarinet sounds	like	64.52%	69.81%
	dislike	35.48%	30.19%
The lilting singing of children	like	90.32%	86.79%
	dislike	9.68%	13.21%
The soothing singing of children	like	70.97%	81.13%
	dislike	29.03%	18.87%
Fountain sound	like	38.71%	49.06%
	dislike	61.29%	50.94%

Figure A.1 Spectrogram of 22 sound stimuli.




Sound pressure level (dB)
Frequency (Hz)
125
250
500
1K
2K
4K
Air-conditioner thrummed
(e) Mechanical
Piano sounds
Violin sounds
Drum sounds
Clarinet sounds
(f) Musical instrument
The lilting singing of children
The soothing singing of children
(g) Song
Fountain sound
(h) Other