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Original article

Exploring a method for evaluation of preschool and school children with autism spectrum disorder through checking their understanding of the speaker's emotions with the help of prosody of the voice

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Abstract

Purpose: We attempted to evaluate the ability of 125 preschool and school children with autism spectrum disorder (ASD children) to understand the intentions of those speaking to them using prosody of the voice, by comparing it with that of 119 typically developing children (TDC) and 51 development-age-matched children with attention deficit hyperactivity disorder (ADHD children), and to explore, based on the results, a method for objective evaluation of children with ASD in the early and later periods of childhood.

Methods: Phrases routinely used by children were employed in the task administered to the children, with the prosody of the voice speaking these phrases changed to express the four emotions (acceptance, rejection, bluff and fooling).

Results: The percentage of children with ASD who could correctly identify the emotion of "fooling" was significantly lower than that of TDC, at each developmental age (corresponding to middle kindergarten class to sixth year of elementary school). On the other hand, in the children with ADHD, while the correct answer rate for identifying the emotion of "fooling" was significantly lower than that in the TDC and higher than that in the ASD children at development ages corresponding to the early years of elementary school, it did not differ significantly from that in the TDC and was higher than that ASD children at development ages corresponding to the later years of elementary school.

Conclusion: These results indicate that children with ASD find it particularly difficult to understand the emotion of fooling by listening to speech with discrepancy between the meaning of the phrases and the emotion expressed by the voice, although the prosody of the voice may serve as a key to understanding the emotion of the speakers. This finding also suggests that the prosody of the voice expressing this emotion (fooling) may be used for objective evaluation of children with ASD.

Keywords: Autism spectrum disorder; Preschool and school children; Prosody of the voice; Understanding of the speaker's emotions; Screening test

1. Introduction

During speech, while a speaker's intention may be transmitted through the literal meaning of phrases, the speaker can also convey a different meaning through

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using prosody of the voice. For example, the phrase "you are splendid" may be interpreted as an applause (identical to its literal meaning), or actually as an ironical exclamation for a failed person if the appropriate prosody of the voice is used. Even among young children, the verbal or nonverbal expressions sometimes differ from their true emotions. For example, when receiving a gift that disappoints, children aged 3 or 4 years may give an embarrassed smile, hiding their displeasure, and children aged 6 years may say "thank you," suppressing their real emotion [1,2]. Thus, young children sometimes use a fooling or tease to promote communication [3,4] or call a bluff or express a lie to suppress their real emotions [1,2]. This means that even young children can speak while hiding their real emotions and transmit an intention different from their emotions.

Understanding of a speaker's emotion through the prosody of voice (intonation, loudness, height, etc.), particularly when the literal meaning is discrepant from the intended emotion (e.g., cynical speech), is sometimes difficult even for adults. It has been reported that when children in the early years of elementary school hear spoken words whose literal meanings are discrepant from the speaker's emotions expressed by prosody of the voice, only 50–60% can actually understand the intentions of the speaker [5,6]. In a study of young children, Berman et al. presented the phrase "Let's look at the doll" in two different manners by prosody of the voice and asked the children to answer whether the speaker meant the broken doll or the new doll [7]. This study revealed that even young children attempt to identify the intention of the speaker based on the voice-expressed features of the speaker. In another study, Friend [8], Morton, et al. [9] exposed young children and elder children to sentences such as "My soccer team just won the championship" with varying prosody patterns (expressing the emotions of happiness, anger or grief) and asked them to judge the speaker's emotion. The results indicate that children begin to understand the meanings of the sentences taking into account also the voice characteristics by the age of 10 years.

Subsequently, we conducted a study designed to examine the ability of children of understanding the speaker's emotions expressed through prosody of the voice, regardless of the literal meanings of the spoken phrases, using phrases not requiring high linguistic capabilities (i.e., phrases used during routine communication among children). To put it concretely, we conducted the study in typically developing children (TDC) using test phrases containing emotional expressions such as "I don't like it" [10]. The study demonstrated that the minimum age at which the children acquired the ability to understand the speaker's emotions on the basis of the prosody of the voice differed depending on a combination of two factors: (1) whether the literal meanings of the phrases were positive or negative, and (2) whether the emotion expressed by the voice was positive or negative. When the literal meaning of the spoken phrases was consistent with the emotion expressed by the voice, and both were positive in nature, almost a 100% of the TDC (at age equivalent to middle kindergarten class) exhibited a level of understanding identical to that of adults. When both the literal meaning and the emotions expressed by the voice were negative in nature, about 90% of the TDC at age equivalent to elder kindergarten class were able to understand the intention of the speaker based on the prosody of the voice. However, when the literal meaning was discrepant from the verbally expressed emotion (particularly when the literal meaning was negative and the verbally expressed emotion was positive, i.e. [fooling]), the percentage of children that was able to understand it was on the order of 7–60% preschool age and more than 90% school age. Thus, the age at which the ability to understand this type of emotion based on prosody of the voice was found to be higher than that for other types of emotions.

Conventionally, the diagnosis of autism spectrum disorder (ASD), which is characterized by difficulty in interpersonal communication, was based on subjective evaluation by the examiner on the basis of behavioral observation and questionnaires designed referencing DSM-5 [11] or ICD-10 [12]. Such a diagnostic approach is, however, possible only for well-experienced experts. We thus considered that it would be useful to develop an indicator that would be easier to evaluate. Because the scenarios in which ASD children face difficulties in personal communication often involve failure of mutual understanding of feelings between the child and his/her friend, we attempted to create a new indicator through evaluation of the ability of ASD children to understand the emotions of friends from the prosody of the voice used during conversation.

The present study was designed to investigate the prosody of the voice not allowing easy understanding of the speaker's emotions, and the developmental age until acquisition of the ability to understand the speaker's emotion in the case of prosody of the voice allowing understanding of the speaker's emotions, in children with developmental disorder (particularly ASD), who are known to have problems in recognizing a speaker's prosody (a factor needed for communication) [13–17] and in whom acquisition of the ability to understand other's minds tends to be delayed [18]. We expected that the ability to understand emotions expressed by the voice may serve as an objective indicator for evaluation of the personal communication ability of ASD children, and could add value to the existing means of evaluation of these children (behavioral observation and questionnaire).

Table 1
Four types of literal meanings and emotions expressed by voices and spoken phrases (number of samples) (correct answer rate by 25 adults).

		Emotion expressed by voice							
		Positive Acceptance(6)				Negative Bluffing(6)			
Literal meaning	Positive	I give this to you	(100)	I understand it	(100)	I give this to you	(100)	I understand it	(100)
		Ok	(100)	Let's play	(100)	Ok	(100)	Let's play	(100)
		Let's go	(100)	Let's do it	(100)	Let's go	(100)	Let's do it	(100)
	Negative	Fooling(6)				Rejection(6)			
		I don't know	(92)	I can't do it	(100)	I don't know	(100)	I can't do it	(100)
		I don't understand	(96)	Stop it	(100)	I don't understand	(100)	Stop it	(100)
		I hate it	(100)	No	(100)	I hate it	(100)	No	(100)

2. Methods

2.1. Creation of literal meaning judging tasks

To create tasks involving understanding of the speaker's emotions by young children, we collected, through interviews of nursery teachers, utterances in conversations routinely used among children in scenes likely to result in misunderstanding of the friend's speech and problematic behaviors to friends. A total of 12 phrases selected by 5 nursery teachers as being used frequently by young children were adopted as the literal meaning judging tasks, consisting of 6 phrases with positive literal meanings and 6 phrases with negative literal meanings (Table 1).

In a preliminary study, the positive or negative meaning of each of the phrases used in the literal meaning judging tasks was judged correctly by all of 25 adult university students.

2.2. Creation of emotions expressed by the voice judgment tasks

Tasks for judging the speaker's emotions from the prosody of the voice were prepared as follows. On each of the 6 phrases with a positive literal meaning adopted above, two voice patterns, i.e., prosody of positive emotion [acceptance] and prosody of negative emotion [bluffing], were created (12 tasks in total). For example, the phrase "I give this to you," which has a positive literal meaning was expressed in a voice pattern suggestive of positive emotion ("I really want to give it" [acceptance]) and a voice pattern suggestive of negative emotion (discrepant from the literal meaning; "I am forced to give it" [bluffing]). Similarly, each of the 6 phrases with a negative literal meaning was expressed in two voice patterns, a voice pattern suggestive of a positive emotion [fooling] and a voice pattern suggestive of a negative emotion [rejection] (12 tasks in total) (Table 1).

Four females whose jobs involved contact with children or who had acting experience spoke the phrases (emotions expressed by the voice judging tasks) to 25 adult university students in 4 voice patterns, with prosodies, that are usually used among young children expressing different emotions. The voice of one of these females who obtained the highest correct answer rate (99.5%) in the task expressed by the voice was adopted for administering the tasks to the children.

Table 1 shows the correct answer rate to each voice judging task among adult subjects.

2.3. Task implementation method

2.3.1. Literal meaning judging tasks

In the literal meaning judging tasks, the recorded voice by the speaker without emotion in Japanese was reproduced to the children, asking them to answer whether the speech sounded good or bad to them by selecting either the laughing face and ○ or the angry face and ✗ on the illustration. If the child was unable to give any answer for 10 s or more, the child was guided to select "I don't know."

2.3.2. Emotions expressed by the voice judging tasks

In the emotions expressed by the voice judging tasks, the recorded voice in Japanese was reproduced to the children, asking them to select one of the two alternatives fitting the voice just reproduced, i.e., one from the laughing face and angry face shown in the illustration to the task involving the emotions of [rejection] and [fooling], and one from the laughing face and sad face shown in the illustration of the tasks involving the emotions of [acceptance] and [bluffing], similar to the way that was adopted for the literal meaning judging tasks. The option of "I don't know" was included in these tasks also.

2.3.3. Evaluation of the age of acquisition of the ability

To eliminate the influence of intellectual development on the ability to understand the speaker's emotions from the prosody of the voice, comparison at each developmental age was made among the ASD children, TDC

and children with another type of developmental disorder (i.e. attention deficit hyperactivity disorder: ADHD).

Evaluation of developmental ages of the children with ASD or ADHD was carried out using the Japanese version of WISC-IV [19] or a new version of the Kyoto Scale of Psychological Development [20]. Similar evaluation of the TDC was carried out using the Japanese version of Raven's Colored Progressive Matrices [21], to confirm absence of any delay in intellectual development.

2.4. Survey 1: Comparison between development-age-matched ASD children and TDC

The time-course of development of the ability to understand emotions expressed by the voice was compared between development-age-matched ASD children and TDC.

This survey was carried out in 125 children diagnosed as having ASD in Japan, whose native language was Japanese (97 boys and 28 girls). Of these 125 children, 12 were in middle kindergarten class, 15 were in the elder kindergarten class, 17 were in the first year of elementary school class, 18 in the second year of elementary school class, 16 in the third year of elementary school class, 16 in the fourth year of elementary school class, 18 in the fifth year of elementary school class, and 13 in the sixth year of elementary school class. The developmental ages of these ASD children were calculated and the ASD children were divided by the developmental ages into groups corresponding to the school years of the TDC as follows; early kindergarten group (9 ASD children), middle kindergarten group (20 ASD children), elder kindergarten group (21 ASD children), first year of elementary school group (21 ASD children), second year of elementary school group (16 ASD children), and third to sixth years of elementary school group (38 ASD children). Children diagnosed as having both ASD and ADHD were counted as ASD children and not as ADHD children. That is, in the present study, children having the characteristics of any other disease besides ASD were also counted as ASD children, as long as they had the characteristics of ASD. The 119 TDC who served as the control group (59 boys and 60 girls) were children who were attending kindergarten (nursery school) or elementary school (20 in the early kindergarten class, 21 in the middle kindergarten class, 25 in the elder kindergarten class, 21 in the first year of elementary school class, 32 in the second year of elementary school class), and none of the children showed any delay in intellectual development. We obtained informed consent from children/guardians. Table 2 shows the age distribution and IQ profile of the ASD children and TDC.

The correct answer rates in the literal meaning judging tasks and the tasks for judging the 4 emotions expressed by the voice of [acceptance], [rejection], [bluffing], and [fooling] were compared between development-age-matched ASD children and TDC by Mann-Whitney's U test. From the early kindergarten group to the second year of elementary school group, comparison was made at each developmental age. Because the level of understanding in the TDC showed a ceiling effect in the early years of elementary school, investigation of the TDC was limited to the age corresponding to the second year of elementary school class, the ASD children between the third and sixth year of elementary school group were compared with the TDC in the second year of elementary school class.

2.5. Survey 2: Comparison among development-age-matched children with ADHD and ASD or TDC

To examine the time-course of development of the ability to understand emotions expressed by the voice in ADHD children, the correct answer rates in the emotion expressed by the voice judging tasks were compared with those of development-age-matched TDC and ASD children.

Table 2
Data according to the developmental age in ASD children and TDC.

Developmental age group	ASD			TDC		
	Age in months, mean (SD)	IQ mean (SD)	Gender (M/F)	Age in months, mean	IQ mean	Gender (M/F)
Early kindergarten group	73.56 (11.76)	71.11 (10.88)	8/1	52.00	≥75	10/10
Middle kindergarten group	79.40 (12.03)	81.75 (10.74)	16/4	64.14	≥75	9/12
Elder kindergarten group	97.76 (22.51)	80.95 (17.60)	18/3	74.88	≥75	13/12
First year of elementary school group	106.81 (18.74)	83.86 (14.23)	18/3	88.14	≥75	12/9
Second year of elementary school group	118.56 (17.24)	85.50 (12.52)	9/7	100.00	≥75	15/17
Third year of elementary school group	124.29 (16.65)	91.53 (13.18)	11/6	–	–	–
Fourth year of elementary school group	127.75 (13.65)	96.00 (10.64)	7/1	–	–	–
Fifth year of elementary school group	129.43 (11.16)	104.86 (9.84)	6/1	–	–	–
Sixth year of elementary school group	137.67 (8.24)	113.99 (8.63)	4/2	–	–	

ASD, autism spectrum disorder; TDC, typically developing children.

Table 3
Data according to the developmental age group in ADHD children, TDC and ASD children.

Developmental age group	ADHD			TDC			ASD		
	Age in months, mean (SD)	IQ mean (SD)	Gender (M/F)	Age in months, mean	IQ mean	Gender (M/F)	Age inmonths, mean(SD)	IQ mean (SD)	Gender (M/F)
Pre-school age group (early, middle or elder kindergarten group)	90.48 (22.64)	77.32 (17.71)	20/5	64.53	≥75	32/34	86.06 (19.78)	79.50 (14.37)	42/8
Early years of elementary school group (first or second year ofelementary school group)	113.59 (17.93)	84.29 (14.22)	11/6	95.30	≥75	27/26	111.89 (18.81)	84.57 (13.36)	27/10
Later years of elementary school group (third to sixth years of elementary school group)	128.44 (16.34)	94.22 (13.11)	8/1	–	–	–	128.08 (14.37)	98.32 (13.70)	28/10

ADHD, attention deficit hyperactivity disorder; TDC, typically developing children; ASD, autism spectrum disorder.

This survey was carried out in 51 children who were diagnosed as having ADHD in Japan, whose native language was Japanese (39 boys and 12 girls). These children were divided into three groups corresponding to their developmental ages: pre-school age group (25 children with their developmental age corresponding to the early, middle or elder kindergarten class), early years of elementary school group (17 children with their developmental age corresponding to the first or second year of elementary school class), and later years of elementary school group (9 children with their developmental age corresponding to the third to fifth years of elementary school class). Children diagnosed as having ADHD alone or ADHD+ another disease (other than ASD) were counted as ADHD children. That is, in the present study, children having any other disease accompanying ADHD were counted as ADHD children, as long as they did not have the characteristics of ASD.

For comparison, the TDC were divided into two groups, like in Survey 1, i.e., pre-school age (66 children in the early, middle or elder kindergarten class) and early years of elementary school (53 children in the first or second year of elementary school class). The ASD children were divided into three developmental age groups corresponding to the school years of the TDC, like in Survey 1, i.e., the preschool age group (50 children of developmental ages corresponding to the early, middle or elder kindergarten class) and the early years of elementary school group (37 children of developmental ages corresponding to the first or second year of elementary school class) and later years of elementary school group (38 children of developmental ages corresponding to the third to fifth years of elementary school class). We obtained informed consent from the children/guardians. Table 3 shows the age group distribution and IQ profile of the ADHD children, TDC and ASD children.

The correct answer rates in the literal meaning judging tasks and emotion judging tasks of [acceptance], [rejection], [bluffing], and [fooling] were compared among the ADHD children, TDC and ASD children at each developmental age (pre-school age, early years of elementary school and later years of elementary school groups) using the Kruskal–Wallis test. As the post hoc test, multiple comparisons were also compared. The Mann–Whitney *U* test was used for the comparison between each group.

Children with ADHD/ASD in the pre-school age group and early years of elementary school group were compared with the TDC of the corresponding developmental ages. However, since the ability to understand by the TDC showed a ceiling effect in the early years of elementary school class, investigation of the TDC was limited to the age corresponding to the second year of elementary school class, and ADHD and ASD children in the later years of elementary school group were compared with TDC in the second year of elementary school class.

The study protocol was approved by the research ethics committee of Hiroshima University Graduate School of Biomedical & Health Sciences and Faculty of Health and Welfare, Prefectural University of Hiroshima.

3. Results

3.1. Comparison between development-age-matched ASD children and TDC(Table 4)

The correct answer rate in the [fooling] task did not differ between the ASD children in the early kindergarten age group and TDC of the corresponding developmental age, but was significantly lower in the ASD children in the middle kindergarten group and higher age groups and TDC of corresponding developmental ages ($p < 0.0001$). The correct answer rate in the [fooling] task in the TDC was already 90% or higher in the first year of elementary school class, while in the ASD children, it was only 6% in the middle kindergarten group, 18% in the elder age kindergarten group, 33% in the first year of elementary school group, and on the order of 50% even in the third to sixth years of ele-

Table 4
Comparison of the correct answer rates in the literal meaning judging tasks and the 4 emotions expressed by voices judging tasks between the TDC, ASD and ADHD children at each developmental age group (SD).

		early kindergarten class n=20	middle kindergarten class n=21	elder kindergarten class n=25	first year of elementary school class n=21	second year of elementary school class n=32	second year of elementary school class n=32
	ASD	early kindergarten group n=9	middle kindergarten group n=20	elder kindergarten group n=21	first year of elementary school group n=21	second year of elementary school group n=16	Later years of elementary school group (third to sixth years of elementary school group) n=38
	ADHD		Pre-school age group (early, middle or elder kindergarten group) n=25		Early years of elementary school group (first or second year of elementary school group) n=17		Later years of elementary school group (third to fifth years of elementary school group) n=9
Literal meaning	TDC	77.1(30.8)	98.4(3.1)	91.7(13.2)	95.6(6.3)	95.1(11.8)	95.1(11.8)
	ASD	94.4(8.3)	92.9(11.6)	96.8(7.7)	94.4(8.1)	96.4(5.2)	95.4(8.4)
	ADHD		96.3(5.9)		97.6(3.9)		97.2(4.2)
Acceptance	TDC	79.2(34.1)	100(0.0) **	99.3(3.3)	100(0.0)	100(0.0)	100(0.0)
	ASD	96.3(11.1)	85.8(24.3) **	93.7(22.0)	98.4(7.3)	100(0.0)	99.6(2.7)
	ADHD		99.3(3.3)		100(0.0)		100(0.0)
Rejection	TDC	64.2(40.6)	83.3(25.8)	87.3(19.4)	96.0(7.3)	94.3(11.7)	94.3(11.7)
	ASD	83.3(33.3)	84.2(31.3)	92.9(13.5)	93.7(11.2)	90.6(18.2)	92.5(16.8)
	ADHD		79.3(30.5)		88.2(16.4)		98.2(5.6)
Bluffing	TDC	51.7(35.4)	88.9(17.7) *	93.3(9.6)	98.4(7.3) *	99.0(4.1)	99.0(4.1)
	ASD	57.4(42.6)	62.5(41.5) *	67.5(42.0)	84.9(30.7) *	96.9(6.7)	95.2(16.4)
	ADHD		68.7(33.1)		90.2(25.0)		100(0.0)
Fooling	TDC	7.5(13.8)	43.7(33.1) **	66.7(32.6) **	92.1(16.4) **	99.0(5.9) ** **	99.0(5.9) **
	ASD	9.3(22.2)	6.7(14.7) **	18.3(32.0) **	33.3(44.4) **	34.4(33.0) **	57.0(42.0)
	ADHD		26.7(37.6)		66.7(31.7)		92.6(8.8) *

** p<0.01 * p<0.05

ASD, autism spectrum disorder; TDC, typically developing children; ADHD, attention deficit hyperactivity disorder.

mentary school group, not reaching the adult level even at this age.

However, the correct answer rates in the [literal meaning judging] tasks and the emotion judging tasks of [acceptance], [rejection] and [bluffing] did not differ significantly between the ASD children at any developmental age from the early kindergarten group to the third to sixth years of elementary school group and the TDC of the corresponding development ages, except for the correct answer rates in the [acceptance] and [bluffing] tasks between the ASD children in the middle kindergarten group and TDC of corresponding age and in the [bluffing] task between the ASD children of the first year of elementary school group and TDC of corresponding age; the correct answer rates in the [acceptance] and [rejection] tasks were 80% or higher in the ASD children of the early kindergarten to higher age groups, and the correct answer rate in the [bluffing] task was 80% or higher in the ASD children of the first year of elementary school or higher age groups. In the analysis of the standard deviation (SD) among the ASD children and TDC, the SD was on the order of 10 or less for each voice task in the TDC from the first year of elementary school onwards, while the SD among the ASD children of the corresponding developmental age groups was on the order of 10 for [acceptance] and [rejection], and on the order of 30–40 for [bluffing] and [fooling]. Thus, the SD for both [bluffing] and [fooling] was large in ASD children of the first year of elementary school group, and only the SD for the [fooling] task still remained large in ASD children of the second and third to sixth years of elementary school groups.

3.2. Comparison between development-age-matched ADHD children and TDC and between development-age-matched ADHD children and ASD children (Table 4)

The correct answer rate in the [fooling] task was significantly lower in the ADHD children of the early years of elementary school group than in the TDC of corresponding developmental ages ($p < 0.0001$), but did not differ between the ADHD children of the preschool group or later years of elementary school groups and the TDC of corresponding developmental ages. The correct answer rate in the [fooling] task was significantly lower in the ASD children than in the ADHD children in both the early years of elementary school ($p < 0.01$) and the later years of elementary school groups ($p < 0.05$).

On the other hand, the correct answer rates in the [literal meaning judging] tasks and the emotion judging tasks of [acceptance], [rejection] and [bluffing] did not differ significantly between the ADHD children and

TDC and between the ADHD children and ASD children at any developmental age. In the analysis of the SD among the ADHD children, TDC and ASD children, the SD in the TDC of the early years of elementary school was on the order of 10 or less for each of the voice tasks, while the SD for [fooling] was on the order of 30–40 in the ADHD children and ASD children of the early years of elementary school groups. However, there was no difference in the mean correct answer rate or SD between the ADHD children in the later years of elementary school group and the TDC in the second year of elementary school class. On the other hand, in the ASD children of the later years of elementary school group, there was difference in the mean correct answer rate or SD of the [fooling] task in the ADHD of the later years of the elementary school group and TDC of the second year of elementary school class.

4. Discussion

4.1. Differences in the developmental age between ASD children and TDC at which they develop the ability to understand the emotions expressed by the voice of the speaker

In this study, the correct answer rates in the emotion expressed by the voice judgment tasks were compared between TDC and developmental-age-matched ASD children and the influence of the disorder characteristics other than that of intellectual development in the ASD children was investigated.

In the analysis carried out in TDC and development-age-matched ADC children, the correct answer rate in the [fooling] task was significantly lower in the ASD children than in the TDC at every age after the age corresponding to middle kindergarten class. Also, analysis of the SD revealed that inter-individual differences in results in the voice tasks of [bluffing] and [fooling] were small among TDC in the first year of elementary school class, while marked inter-individual differences in the SD for the [bluffing] and [fooling] tasks were observed among the ASD children of corresponding developmental age. Among the ASD children of the second year of elementary school or higher age groups, inter-individual differences in the SD within the same developmental age were noted only for the [fooling] task. These results indicate that the ability to understand the emotion of fooling expressed by prosody of voice varies among individual ASD children even from the later years of elementary school group, and the mean correct answer rate reflects the difficulty of the ASD children to understand this emotion expressed by prosody of voice. However, no significant differences in the correct answer rates in the [acceptance], [rejection] and [bluffing] tasks were observed between the ASD children and TDC at any developmental age, except for the rates in the [acceptance] and [bluffing] tasks between the ASD children of the middle kindergarten group and TDC of the corresponding age, and in the [bluffing] task between the ASD children of the first year of elementary school group and TDC of the corresponding age group. The correct answer rates in the [acceptance] and [rejection] tasks were also high (80% or more) in the ASD children of the early kindergarten group. In regard to the judgment of emotions expressed by the voice, it is known that TDC tend to judge the speaker's emotions from the literal meanings of the spoken phrases from age 4 to the early years of elementary school, but that they tend to consider the prosody of the voice as well from ages corresponding to the later years of elementary school [8,9]. Thus, it would appear that the understanding of the emotions of [acceptance] and [rejection] in preschool age children is based more closely on the literal meanings of the phrases than on the prosody of voice. For this reason, it seems that even in children with ASD from the preschool age group to the earlier years of elementary school group, spoken phrases with their literal meanings consistent with the emotions expressed by the voice are easier to understand.

In regard to discrepant voice tasks (voice tasks where the literal meaning is not consistent with the emotion transmitted), there were differences in the correct answer rates among the TDC between the previous and present studies. This point is discussed here. In the previous study of elementary school children [5,6], the correct answer rate among the male TDC in the early years of elementary school was on the order of 50% for discrepant voice tasks (banter and sarcasm). In the present study, on the other hand, the correct answer rate among the TDC in the first year of elementary school class for discrepant voice tasks ([bluffing] and [fooling]) was on the order of 90% [10]. The voice task for [banter] used in the previous study was adopted as an approximately equivalent task to [fooling] in the present study, although the details of this tasks differed between previous and present studies (the phrase "No" often used during conversation among children to express the emotion of fooling was used in the present study, while in the previous study, the phrase, "You're wrong" often used by adults to address children for the purpose of banter, was used). Thus, the difference in the understanding between the phrase for banter often uttered by adults while addressing children and the phrase for fooling uttered by children to address other children seems to have had some influence on the observed difference in the correct answer rate between the present and previous studies. This may be explained as follows. Adults tend to use phrases that they think are easier for children to understand by judging the state of the child under a given circumstance [22], and the phrases for [fooling] and [banter], which transmit an intention differing from the literal meaning are considered to be difficult to

understand for children. Such phrases may be unfamiliar to children, since they are not often used under ordinary circumstances by adults while addressing children. In this sense, the voice tasks adopted in the present study were probably easier for the children to understand. This difference probably explains the difference in the correct answer rates between the present and previous studies.

When voice tasks designed for easy understanding by TDC of a very young age were applied to ASD children, the correct answer rate for discrepant voices, such as [bluffing] and [fooling], differed significantly between the TDC and the ASD children. Among children of ages corresponding to the middle kindergarten class and first year of elementary school, the correct answer rate for [bluffing] was significantly lower in the ASD children than that than in the TDC. If this result were combined with the data on the SD shown above, we may infer that ASD children can catch up with the TDC in terms of their understanding ability when they reach developmental ages corresponding to the second year of elementary school class or higher age. This is probably because [bluffing] is a self-regulation voice task produced by suppression/restriction of one's emotions, and because the ability of self-assertion among Japanese TDC is reported to develop by age 3–4 and to stop after age 4.5 (instead, self- regulation ability develops after 4.5 years of age) [23], resulting in the development of [bluffing] at an age of the middle kindergarten class (4 years) among the TDC. In regard to the ability for understanding [bluffing], the results indicate that ASD children, who tend to interpret voice tasks literally, were slower in recognizing it than the TDC, but caught up with the TDC when they reached developmental ages corresponding to the second year of elementary school class.

In terms of understanding of [fooling], a task in which the meaning of the phrase is inconsistent with the emotion expressed, there was a difference between the ASD children and TDC at all ages after the age corresponding to middle kindergarten class. The correct answer rate for [fooling] was significantly lower in the ASD children of developmental ages corresponding to the third to sixth year of elementary school (on the order of 50%) than in the TDC in the second year of elementary school class. The ASD children did not catch up with the TDC in terms of understanding of [fooling], even when they reached the age of children in later years of elementary school. Such a difference between the ASD children and TDC seems to be attributable to the characteristic of the disorders in ASD children, who tend to understand phrases literally. A major symptom seen in ASD children is disturbed communication [11] and ASD children have been reported to have problem in recognition of the speaker's prosody which is needed for communication [13–17]. For this reason, It is found difficult that ASD children understand the prosody of the voice lacking consistency between literal meaning and emotion expressed by the voice such a [fooling], possibly explaining why the correct answer rate was low in this study. [Fooling] is considered as a valid means of personal communication, contributing to the creation of an enjoyable atmosphere and conveyance of intimacy with the interlocutor [24]. [Fooling] is also considered as a sophisticated communication skill, by which people can convey unspoken messages in an indirect way, and cosensitivity is necessary to understand it. Adachi, et al. [25] stated that it is difficult for ASD children to gain a semantic comprehension of sarcasm, where also, the literal meaning of the spoken phrase is discrepant from the intended emotion. It is thought that the difficulty of the situational understanding of sarcasm in Adachi's study and of [fooling] in this study explains the consensual failure of the speaker and listener to share feelings.

In the present study, the ability to understand [fooling] was shown to develop later than the ability to understand the other 3 emotions expressed by the voice examined. So, evaluation by determining the correct answer rate in the [fooling] understanding task is expected as a useful means for objective evaluation of ASD children having difficulties in interpersonal communication, different from other existing means of evaluation, such as behavioral observation and questionnaire.

4.2. Differences in the developmental age at which the ability to understand emotions expressed by prosody of the voice is acquired among TDC, ADHD children and ASD children

The correct answer rates in the tasks of [acceptance], [rejection] and [bluffing] in the ADHD children did not differ significantly from that in the TDC and ASD children at any developmental age, indicating that there was no difference among ADHD children and TDC and ASD children in the developmental age at which they acquired the ability to understand the 3 emotions expressed by the voice other than [fooling].

The correct answer rate for [fooling] did not differ significantly between the ADHD children and TDC, and between the ADHD children and ASD children in the preschool age groups (children of developmental ages corresponding to the early, middle and elder kindergarten classes). On the other hand, ADHD children of the early years of elementary school group (first and second year of elementary school groups) showed a significantly lower correct answer rate than the TDC and a significantly higher correct answer rate than the ASD children. At this developmental age, corresponding to the early years of elementary school, the TDC achieved a level of understanding that was almost equal to that in adults (90% or more of the adult level), while the ADHD children achieved a level of understanding that

was about 60% of the adult level, and the ASD children achieved a level of understanding that was about 30% of the adult level, indicating that development of the ability to understand the speaker's intention from the prosody of voice was the earliest in the TDC, relatively more delayed in the ADHD children as compared to the TDC, and most delayed in the ASD children. Downs [26] reported that ADHD children were unable to understand intentions of speakers around them expressed through prosody of the voice at age 8, which was endorsed by the findings of the present study. However, at ages corresponding to later years of elementary school (three to fifth years of elementary school groups), the ADHD children achieved a level of understanding of [fooling] comparable to that in adults (correct answer rate 90% or more of the adult level), while the children of this age with ASD was about 50% of that in adults, indicating that ADHD children acquired the ability to understand this emotion expressed by the voice earlier than the ASD children. Also in the analysis of SD, the inter-individual difference within the same developmental age became smaller for each voice task among the TDC in the early years of elementary school, while there were observed inter-individual differences in the SD for [fooling] among the ADHD children and ASD children of corresponding developmental age. However, at developmental ages corresponding to the later years of elementary school, there was no longer any difference in the mean or SD of the correct answer rate between the ADHD children and TDC. This result indicates that ADHD children eventually catch up with the TDC by the time they grow up to be in the late elementary school years, in terms of their ability to understand [fooling] expressed through prosody of the voice. This result, taken together with the finding that the ability of ASD children of the later years of elementary school group to understand [fooling] was lower than that ADHD children of corresponding developmental age and also lower than that of even younger TDC (from the early years of elementary school), clearly suggests that acquisition of the ability to understand prosody of the voice, especially that used to convey [fooling], is even more delayed in ASD children than in ADHD children.

These results, indicating delayed development of the ability to understand the emotion expressed by prosody of the voice of [fooling] in ASD children as compared to TDC and ADHD children, suggest the possibility that the ability of understanding [fooling] may serve as one of the characteristics of the social communication disorder in ASD children.

4.3. Future tasks

Even at the developmental age corresponding to the third to sixth year of elementary school, ASD children had not reached the adult level in terms of the ability of understanding the emotion of [fooling] expressed through prosody of the voice. ASD children are believed to show poor flexibility in understanding the different meanings of phrases, to be likely to have difficulties in understanding prosody of the voice in language, and to have problems in the understanding of homonyms [13]. With such findings borne in mind, it would be of interest to conduct a similar study in junior high school children and adults with ASD, so as to examine when ASD children might begin to understand discrepancies between the literal meanings of phrases and emotions expressed by prosody of the voice, and investigate whether ASD children might continue to have these difficulties in understanding even after they grow into adults.

When we compared the number of boys and girls in this study, the proportion of boys was higher in the ASD children and ADHD children than in the TDC. Beaucousin et al. [27] stated that men are more likely than women to rely on semantic cues when understanding emotional speech in the neural networks engaged. Thus, we thought that it is necessary to conduct same-sex comparisons among ASD children, TDC and ADHD children.

5. Conclusions

In our evaluation of the ability of understanding emotions expressed by the voice in speech containing discrepancy between the literal meaning of phrase and the emotion expressed by the voice, the correct answer rate in the [fooling] understanding task was low in ASD children, even after elimination of the influence of the intellectual developmental level. The results of comparison with ADHD children also suggested that the poor understanding level of [fooling] represented a characteristic of the disorder related to social communication in ASD children. Evaluation of the ability to understand the emotion expressed by the voice of [fooling] through prosody of the voice may serve as an objective tool for the evaluation of children with ASD that is applicable from early childhood.

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