表3 会話場面の非流暢性の種類の変化: 両児童

セッション	治療前	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
吃症状: A児	r4, r+p1	r6,　ij1	r5,p1,b1, st1	r7	r2,st1	ar2	r1	r6,b1,st1, p1	r10,b1	なし	r3	r10,p2	r4,st1, ic1	なし	r3	r11	r3	r6

	18	19	20	21	22
	r1	r5	r2	r33,p1,ij1, st1	r43,st6, p3

セッション	治療前	1	2	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
吃症状: B児	r27,ij5, p+r1,pa1	r5,st1,p1	st1	r103,st1, ij1,p1	r68,p2	r73,st2, ij3,ic1,p1	r16,st1, b1	r13	r24	r65,st1	r24	r37	r21,p1	r82	r24,st1	r58	r59,p4	r30,p2

注: r(繰り返し)、p(引き延ばし)、b(阻止)、p+r(引き延ばしからの繰り返し)、st(強勢)、ij(挿入)、ic(中止)、pa(間)

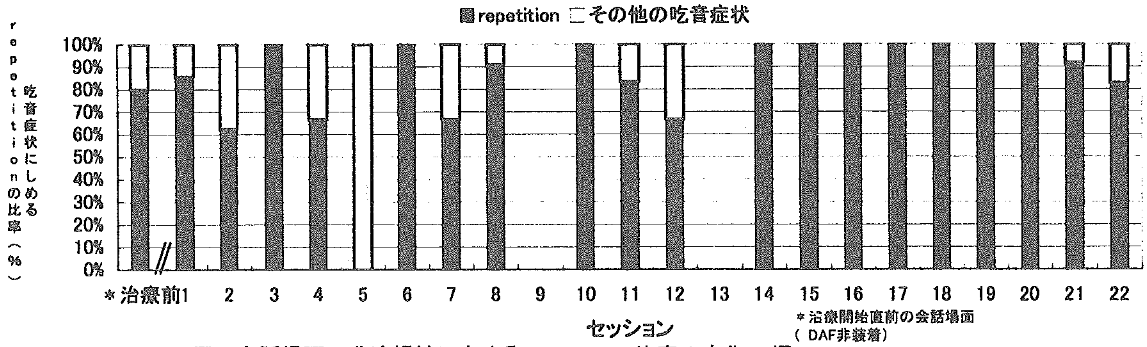

図3 会話場面の非流暢性に占めるrepetitionの比率の変化: A児

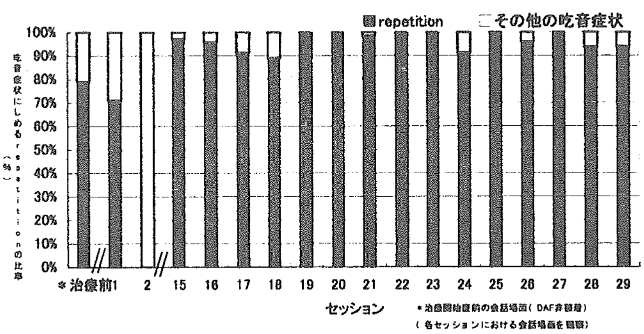

図4 会話場面の非流暢性に占めるrepetitionの比率の変化: B児

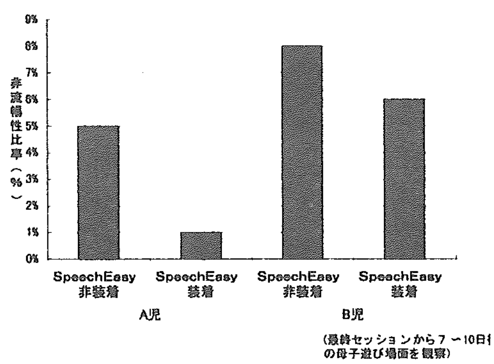

図5 SpeechEasy装着の有無による非流暢性生起の変化: 両児童

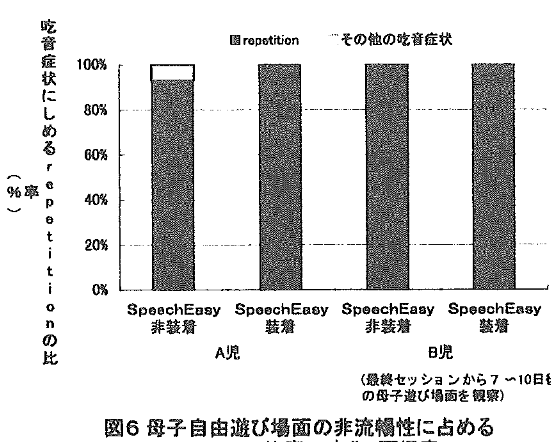

図6 母子自由遊び場面の非流暢性に占める
repetitionの比率の変化: 両児童

Ⅱ．研究成果の刊行に関する一覧表

研究成果の刊行に関する一覧表

書籍

著者氏名	論文タイトル名	書籍全体の編集者名	書籍名	出版社名	出版地	ページ	出版年
Gondo, K., Wakaba, Y., Inoue, S., Iizawa, M., Fujino, H.	Preliminary analysis of interaction characteristics between chronic stuttering Japanese children and their mothers	A. Packman, A. Meltzer, H. F. M. Peters	Theory, Research and Therapy in Fluency Disorders	Nijmegen University Press	Nijmegen	243-249	2004
Mori, K., Sato, Y., Ozawa, E., Imaizumi, S	Cerebral Lateralization of Speech Processing in Adult and Child Stutterers	A. Packman, A. Meltzer, H. F. M. Peters	Theory, Research and Therapy in Fluency Disorders	Nijmegen Univercity Press	Nijmegen	323-330	2004
Wakaba, Y., Iizawa, M., Gondo, K., Inoue, S., Fujino, H.	Preliminary study on effects of temperament of early development of stuttering in children	A. Packman, A. Meltzer, H. F. M. Peters	Theory, Research and Therapy in Fluency Disorders	Nijmegen University Press	Nijmegen	439-441	2004

研究成果の刊行に関する一覧表

雑誌

発表者氏名	論文タイトル名	発表誌名	巻号	ページ	出版年
井上剛伸，佐々木一弘，森浩一，酒井奈緒美，上村智子，塚田敦史，二瓶美里	福祉用具の満足度評価スケールの開発 －QUEST 簡易版－	リハビリテーション工学カンファレンス講演論文集		10-11	2005
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Minagawa-kawai,Y.,Mori,K.,Sato,Y.,Koizumi,T.	Differential cortical responses in second language learners to different vowel contrasts	Neuroreport	15(5)	899-903	2004
皆川泰代,森浩一	言語認知研究における NIRS 機能検査	臨床精神医学	33(6)	741-747	2004
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酒井奈緒美，森浩一，小澤恵美，餅田亜希子	耳掛け型メトロノームを用いた吃音訓練 －成人吃音者を対象に－	音声言語医学	47(1)	16-24	2006
発表者氏名	論文タイトル名	発表誌名	巻号	ページ	出版年
佐藤裕，森浩一，福島康弘	吃音者の発声におけるピッチ制御の聴覚フィードバック特性,	国立リハ研紀要	25	7-13	2004
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原由紀	幼児から学齢期の吃音臨床	言語聴覚研究	2(2)	98-104	2005
原由紀	幼児の吃音	音声言語医学	46(3)	190-195	2005

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A PRELIMINARY ANALYSIS OF INTERACTION CHARACTERISTICS BETWEEN CHRONIC STUTTERING JAPANESE CHILDREN AND THEIR MOTHERS

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SUMMARY

The purpose of this study was to compare interaction characteristics between a group of 9-year-old Japanese stuttering children (N=3) and their mothers during free play to those of a control group of nonstuttering children (N=3) and their mothers. A 10-minute play session for each pair was analyzed in terms of a number of utterances, number of topic initiations, MLU, a number of interruptions and conversational functions. Subjects in the stuttering group showed fewer interruptions during the conversation than the subjects in the non-stuttering group. Conversational functions varied among subjects; however, 2 mothers of the stuttering group showed a tendency to control their children's behaviors.

1. Introduction

Parents often report their distress and feelings of helplessness when faced with their child's dysfluency during a clinical assessment (Rustin et al. 1996). Such negative feelings might affect parent-child interaction style in the course of the development of stuttering. Clinically, it is very common for clinicians to suggest to parents of a stuttering child that they have their child's linguistic and/or para-linguistic behaviors corrected through the therapeutic process (Kelly, 1995). Linguistic behaviors include length and complexity of utterances, and para-linguistic behaviors include speech rate, turn-taking and the like. Egolf et al. (1972) reported that decreasing the number of negative behaviors parents have toward stuttering children, such as linguistic aggression, silence and interruptions, resulted in fewer dysfluent utterances by the children. Stephenson-Opsal and Ratner (1988) pointed out a relation between the mothers' slower speech rate and the reduction of dysfluent utterances by stuttering children. As clinical studies have indicated, parent-child interaction seems to play an important role in the process of onset, development, and recovery of stuttering. A number of studies comparing parents of stutterers and parents of non-stutterers have been conducted in terms of linguistic/paralinguistic characteristics of interaction (Kelly & Conture, 1992; Meyers & Freeman 1985), although, the results vary among the studies and no consensus has been reached.

In Japan, it is recognized by clinicians that in order to improve fluency a non-stigmatizing interaction style, as indicated in the studies of English-speaking families, is crucial (Wakaba 1999). Unfortunately, few attempts have been made to investigate characteristics of interaction between Japanese stuttering children and their parents (Wakaba, 1999). Therefore, it is necessary to shed light on the research topic by using Japanese subjects. The final goal of this research project is to identify the interaction characteristics of stuttering children and their parents that might contribute to the onset, development, and recovery of stuttering. As a first step toward this goal, we carried out a preliminary study on this topic with the participation of a group comprising 3 stuttering children and their mothers, and also a control group comprising 3 non-stuttering children and their parents. The following interaction characteristics were analyzed: (1) quantitative adjustment of utterances, (2) assertiveness in a conversation, (3) characteristics of turn-taking, and (4) communicative functions.

2. Method

Subjects

Subjects for the study were 3 children (KK, SD, AS) who chronically stutter and their mothers. The ages of the children were 9;0, 8;3, and 8;8. All mothers were the children's biological mothers and their ages were 38, 33, and 35, respectively. Based on ITPA scores (PLQ obtained by ITPA Japanese version were 8;6, 8;11, and 7;2 respectively) and also the fact that parents did not express concerns about their children's language competencies beyond the stuttering, the children were assumed as having normally-developing language skills. The ages of onset of stuttering were 3;0, 5;7, and around 3 years old, respectively. The levels of stuttering at the onset of the 3 children were very severe according to their mothers. However, the current severity levels of stuttering were 2, 3, and 2 on the Iowa Scale of Severity of Stuttering (Johnson, et al. 1963). The control group consisted of 3 non-stuttering children (CK, HS, SK) and their mothers. The ages of the children were 8;4, 8;10, and 8;6. All mothers were the children's biological mothers and their ages were 35, 43, and 32. Based on ITPA scores (PLQ were 8;4, 8;10, and 8;6 respectively), the control group children were also evaluated as having normally-developing language skills. All of the children were first-born males and lived with both parents. The children also came from a socio-economical middle class background.

Data collection

Each child and mother was asked to sit at the table face-to-face in a university playroom. They were also asked to play with clay for about 20 minutes. They were given no special instructions except "Do what you normally would do." The sessions were recorded by DAT and VHS.

Data analysis

Prior to the current study, a 10-minute videotaped segment was transcribed and analyzed according to certain categories, which will be mentioned below, by 2 trained researchers (the first and the third author of the current paper) to verify the analysis' reliability. Agreement of coding by the two was above acceptable levels of reliability (above 90%). For the current study, the researchers then further transcribed and coded the verbal behaviors of the subjects. The first 10-minute segment of each videotape was transcribed for verbal behaviors produced by the subjects. Unintelligible utterances were eliminated from the data.

To examine the characteristics of quantitative adjustment of utterances, the number of utterances and MLU (by words and by moras) for each subject were measured. Assertiveness in a conversation was examined by counting the number of topic initiation that each participant (either a child or a mother) made during the 10-minute interaction. Mean number of turns per topic was also obtained for each participant. The number of interruptions was also counted to see turn-taking characteristics. Finally, all verbal behaviors were coded according to categories such as direction, question, request for clarification, praise, and negative statement. The variables are defined below.

Turns: A string of one or more utterances belonging to a single speaker separated from other utterances by the other speaker or separated from other utterances by him/herself by more than 500 msec.

Topic initiation: How many times each participant (either mother or child) starts a new topic.

Conversational functions

Direction: An utterance that directly controls the conversational partner's behavior. For example, "Look at me," "Stop it."

Question: An utterance that requests new information. Both yes/no questions and wh-questions are included in this category. This category also includes requests for clarification: i.e., a speaker asks the conversational partner to clarify his/her utterance.

Praise: An utterance that gives a positive feedback to the conversational partner in an exaggerated manner such as "Good job!," "You are neat!," and "How could you do it!"

Negative statement: An utterance that gives a negative feedback to the conversational partner such as "Can't you make it better?" or "You are clumsy with clay."

3. Results and Discussion

The number of utterances during the 10-minute interaction for each subject is shown in Figure 1. All the mothers of stuttering children tended to produce relatively more utterances than their children did, while the mothers of non-stuttering children varied.

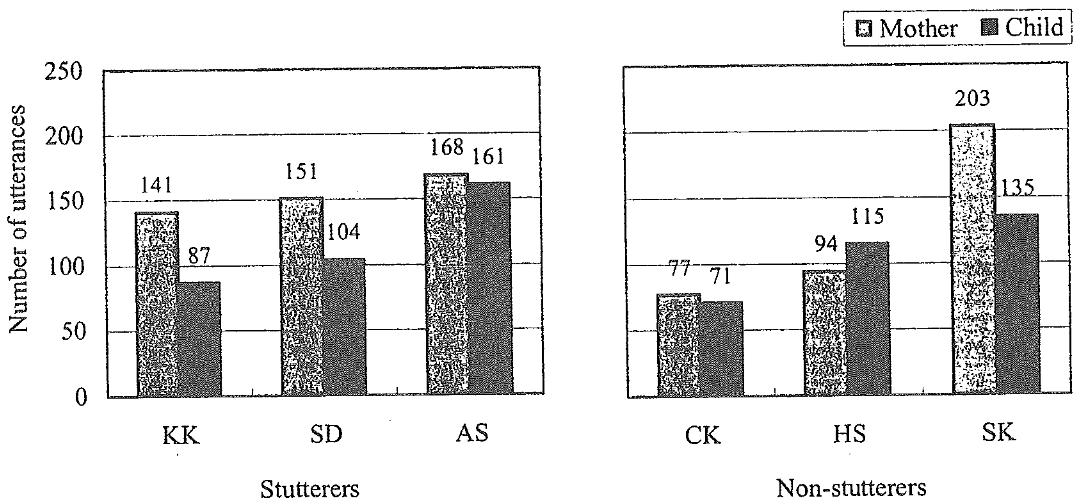

Figure 1. *Number of utterances for each participant*

Figure 2(a) shows the results of MLU by content words and Figure 2(b) show the results of MLU by moras. The results demonstrated that 2 mothers (KK, SD) of stuttering children tended to produce longer utterances than their children did, while all of the mothers of non-stuttering children produced MLUs that were similar to their children's.

In the current study, assertiveness in a conversation was examined by the number of topic initiations that a child and mother made (Figure 3), and also by mean number of turns per topic (Table 1). All the mothers, except AS (stuttering group), showed a tendency to introduce new topics more often into the conversation than their children. Mean number of turns per topic varied from 5.8 to 11.9 and no notable differences were found between groups.

The most interesting result of the current study was the number of interruptions, shown in Figure 4. Although statistic analysis cannot be done because of the limited number of subjects, the non-stuttering children and their mothers produced more interruptions than the stuttering children and their mothers did. One possible explanation is that the stuttering children have been in speech therapy in the past and the mothers were advised not to interrupt while their children were speaking.

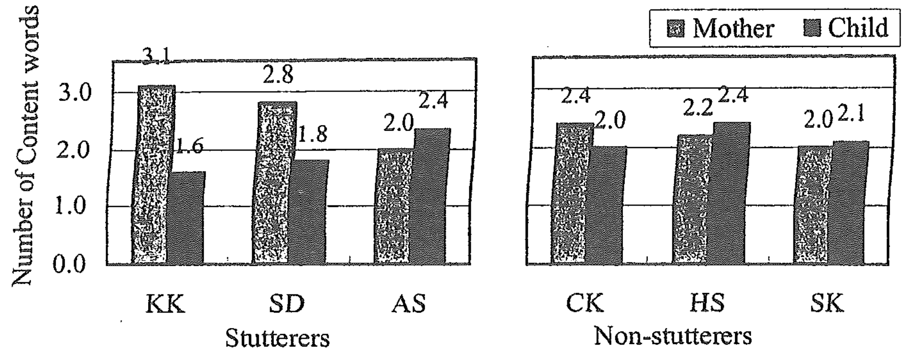

Figure 2a. *Mean length of utterances (content words) for each particippant*

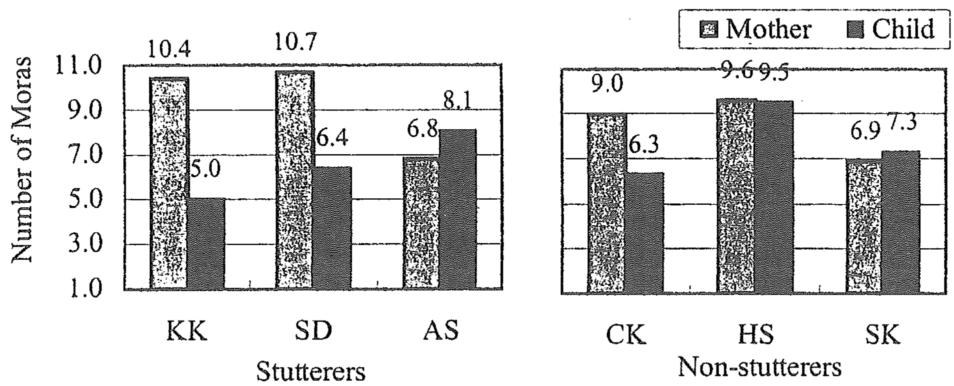

Figure 2b. *Mean length of utterances (moras) for each particippant*

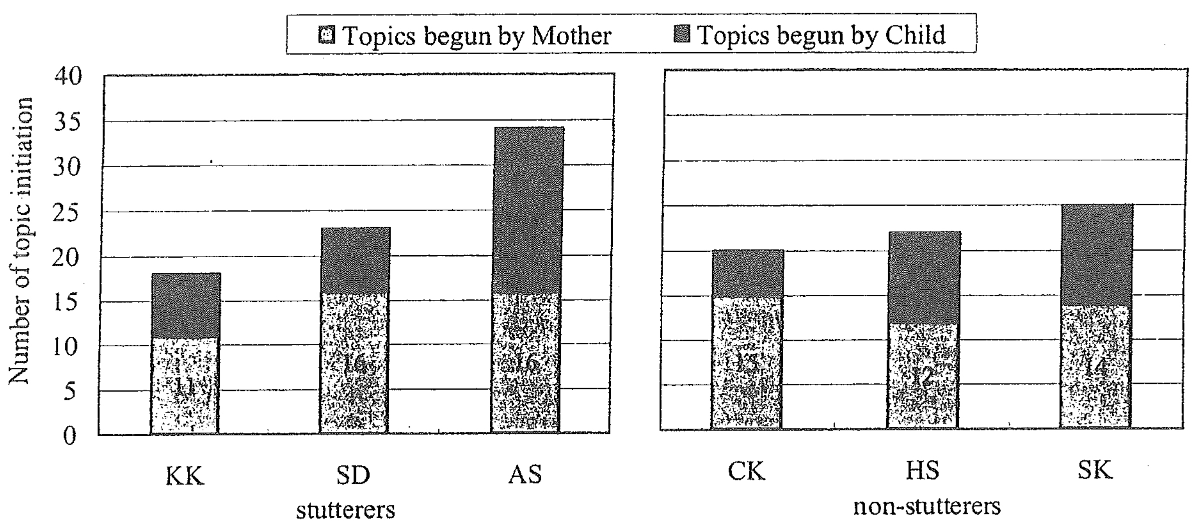

Figure 3. *Number of topic initiations for each participan*

		Topics begun by	N	Mean	(SD)	Total Mean	Total (SD)
stutterers	KK	Mother	11	9.1	(9.84)	10.9	(11.29)
		Child	7	9.7	(8.5)		
	SD	Mother	15	12.7	(12.73)	11.4	(11.04)
		Child	7	8.7	(6.02)		
	AS	Mother	16	9.1	(7.71)	8.4	(6.97)
		Child	18	7.7	(6.39)		
non-stutterers	CK	Mother	15	5.5	(4.55)	5.8	(4.18)
		Child	5	6.6	(3.05)		
	HS	Mother	12	7.3	(5.28)	8.1	(5.70)
		Child	10	9.0	(6.32)		
	SK	Mother	14	16.3	(12.63)	11.9	(10.79)
		Child	11	6.4	(3.32)		

Table 1. *Mean and standard deviation of the number of turn per topic for each particippant*

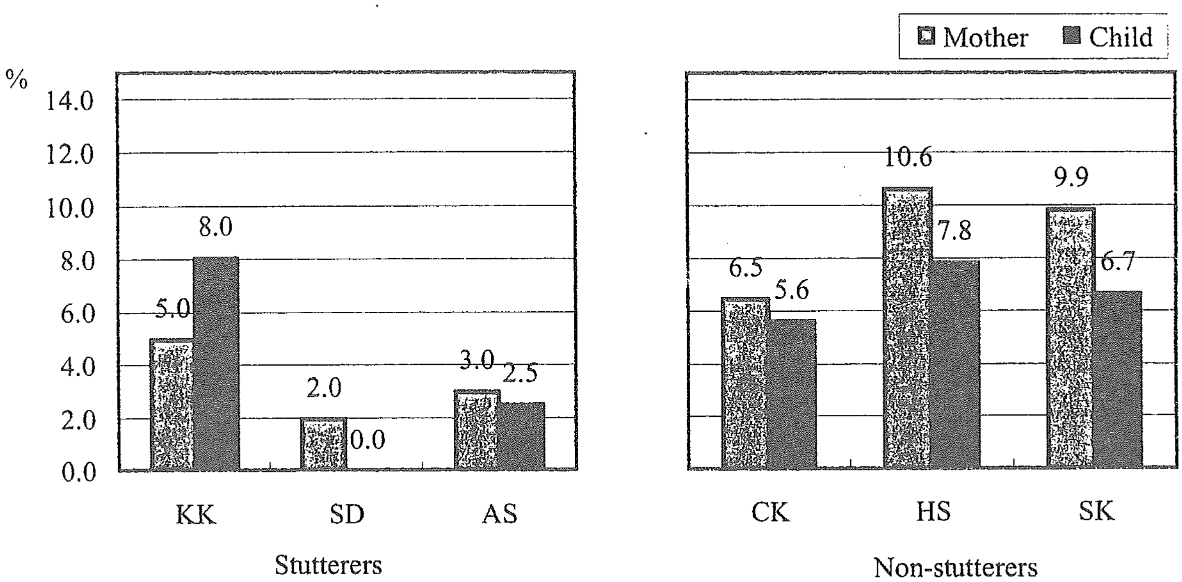

Figure 4. *Number of Interruptions for each particippant*

Conversational functions of the subjects' utterances are shown in Figure 5. Conversational functions selected for the current study, such as directions, questions, praises, and negative statements have been recognized as the functions that possibly put the stuttering children's fluency under pressure. Total frequency of occurrence of the 4 functions were 54.6% (KK), 33.1% (SD), 30.4% (AS) for the mothers of stuttering children and 24.7% (CK), 18.1% (HS), and 31.0% (SK) for the mothers of non-stuttering children. Conversational functions of the subjects' utterances are shown in Figure 5. The mother of KK showed very directive and negative interaction style toward KK. The mother of SD, on the other hand, used directions only 5 times (3.3% of total utterances) and more praise was used compared to other subjects. Her interaction style seems to be non-directive and positive. However, an excessive use of praise might be a sign of manipulation of children's behaviors. Therefore, it can be said that both the mother of KK and the mother of SD had a tendency to control their children's behaviors, although the manners in which they did this were quite different.

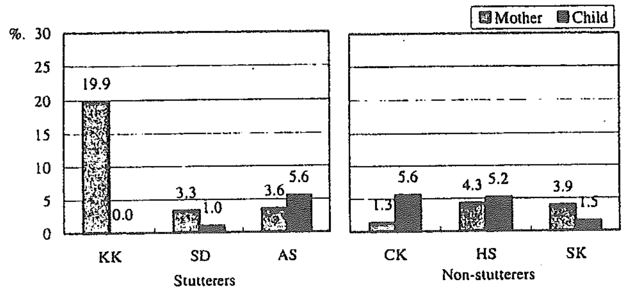

Figure 5a. *Number of Directions*

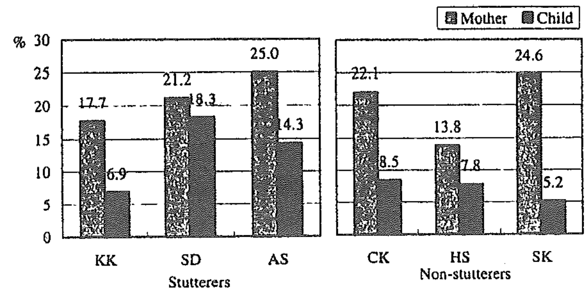

Figure 5b. *Number of Questions*

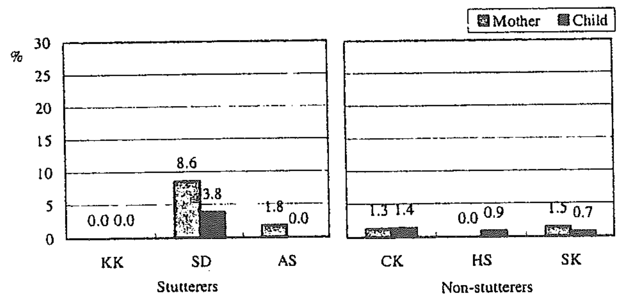

Figure 5c. *Number of Praises*

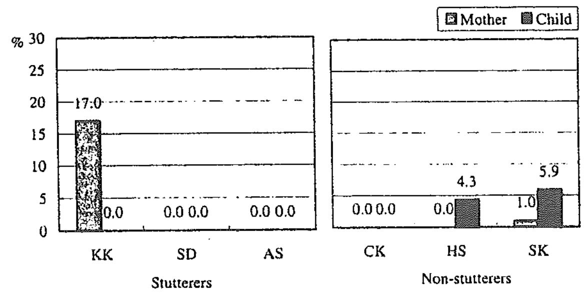

Figure 5d. *Number of Negative statement*

The overall results indicated that two mothers of stuttering children did not quantitatively adjust their utterances to their children's. These mothers also showed a tendency to be directive to the children, while the mother of AS in the stuttering group demonstrated a well-adjusted communication style with her child.

Because of the limited number of the subjects reported here, we have to be careful not to generalize the results. However, this study gives us a future direction for research in terms of characteristics of interaction between chronic stuttering Japanese children and their parents.

This study was conducted as a part of a 2-year interdisciplinary research project supported by Japanese government: Grant-in-Aid for Scientific Research, Category B (1) No 14390015 (Title: Study on onset, development, spontaneous recovery, and fundamental therapeutic information of stuttering by interdisciplinary research method). The final goal of the project is to find clues to identify the types of stuttering soon after onset so that clinicians can give a better diagnosis and prospect of treatment. Data collection and analyses are in progress on 40 three-year-old children who recently began to stutter and 20 nine-year-old children who chronically stutter, with the same number of non-stuttering children for the control groups. Thus, the research question obtained by the study here will continue to be investigated with a larger number of subjects in conjunction with other environmental and biological factors.

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CEREBRAL LATERAIZATION OF SPEECH PROCESSING IN ADULT AND CHILD STUTTERERS: NEAR INFRARED SPECTROSCOPY AND MEG STUDY

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SUMMARY

Cerebral lateralization of speech processing in stutterers were assessed with noninvasive brain imaging techniques, magnetoencephalography and multichannel near infrared spectroscopy (NIRS), with which neuromagnetic and hemodynamic responses, respectively, were recorded to analysis-synthesized prosodic and phonemic minimal contrast word trains. Adult stutterers did not show normal leftward dominance for the phonemic contrast with either method. Children underwent only NIRS sessions, with results similar to those of adults, which indicates that the cerebral dominance in processing heard speech is in disarray even in school-age stutterers. The NIRS method may be useful in screening young stutterers and in elucidating neural correlates of stuttering.

1. Introduction

Although the cause(s) of stuttering is not known, failed establishment of cerebral dominance for speech processing has been demonstrated in adult stutterers with various brain mapping techniques including positron emission tomography (PET) (Braun et al., 1997; Fox et al., 1996; Wu et al., 1995) and magnetoencephalography (MEG) (Salmelin et al., 1998). Braun et al. (1997) reported that rCBF patterns in stuttering subjects differed markedly during the formulation and expression of language, failing to demonstrate the left hemispheric lateralization that is typically observed in normal controls. In another PET study (Wu et al., 1995), stutterers showed significant decreases in regional glucose metabolism in Broca's area, Wernicke's area and frontal pole in a reading aloud (stuttering) condition compared to a non stuttering condition. Fox et al. (1996) characterized developmental stutterering not only with extensive hyperactivity of cerebral and cerebellar motor system, but also with right dominance in the cerebral motor system. They deduced that the surprising levels of deactivation in the temporal lobe correspond to the stutterers' lack of normal monitoring of their speech (Ingham, 2001). Salmelin and colleagues indicated that the functional organization of the stutterers' auditory cortex was fundamentally different from that of normal subjects. In fluent speakers, the left auditory cortex is more sensitive to the side of stimulation (right versus left ear), whereas the right auditory cortex is more sensitive in stutterers. They concluded that the interhemispheric balance is more unstable in stutterers and this might lead to disturbances in the control of speech (Salmelin et al., 1998).

While these MEG and PET studies generally suggest that stuttering and nonstuttering speakers differ in the lateralization of various cortical processes, the crucial question for elucidating the possible causal relationship between stuttering and brain lateralization is how the development of speech dominance in children is affected by stuttering, or vice versa. Because conventional functional brain mapping techniques are not well-suited for children, due to safety concerns and/or requirement for rigorous restraint, few studies if any have been conducted in stuttering children.

The aim of this study is to investigate the functional laterality in adult and child stutterers during auditory language processing. The present study employed multichannel near infrared spectroscopy (NIRS), which is optical, non-invasive monitoring system of cerebral hemodynamics that can be easily used with children and infants for assessing cerebral lateralization for speech. In order to validate the NIRS method, MEG was also used for adult stutters with the same set of stimuli.

2. Methods

2.1 MEG experiment

Subjects and procedures: Three adult stutterers (3 male, age range 22-32 years) and ten fluent speakers (Imaizumi et al., 1998) participated in the MEG experiment. Written informed consent was obtained from each subject in accordance with the Declaration of Human Rights, Helsinki, 1975. All subjects were right-handed, native speakers of Japanese. With a 122-channel whole head SQUID magnetometer (Neuromag Ltd., Finland), the elicited magnetic fields (MFs) were measured.

Stimuli: Three different forms of the Japanese verb /iku/ (meaning "to go") were produced with a synthesis by analysis system (ASL, Kay Elementrics Corp., USA) based on a speech signal recorded by a male adult (Imaizumi et al, 1998). By changing the vocal pitch contour and the formant frequencies, (A) past declarative /itta/ ("went"), (B) interrogative /itta?/ ("went?"), and (C) imperative /itte/ ("Go away"), were synthesized. Only the final syllable was changed among the three words. Particular combinations of two of the three words formed phoneme (/itta/ and /itte/) or pitch (/itta/ and /itta?/) contrasts. An oddball-like paradigm was adopted. One of the three words was presented as the high-frequency standard stimuli and the others as deviant rare stimuli at the frequency of one per 6 standard presentations. The inter-stimulus interval was randomly varied from 0.9 to 1.0 s. The stimuli were presented 800 times per each session in a randomized order, through a pair of tube earphones (EAR-TONE 3A) at the comfortable sound level.

Five sessions were performed: three ignore and two attention conditions. The three ignore sessions were carried out with the three different standards /itta/, /itta?/ and /itte/, under the instruction to ignore the speech stimuli. Under the attention conditions, /itta/ was presented as the standard and the subjects were instructed to count the number of times either /itta?/ or /itte/ was heard. The order of the sessions was counterbalanced across subjects.

Data analysis: The difference MFs or mismatch magnetic fields (MMFs), corresponding to the mismatch negativity (MMN) in evoked potentials, were calculated by subtracting the MFs that were elicited when a word was the standard from those when the same word was a deviant (Imaizumi et al., 1998). Application of a single-current dipole model to the MMFs estimated the location, latency, and moment (Q) of their equivalent current dipoles (ECDs). The model employed was considered to adequately represent the measured MFs if the goodness-of-fit (g) between the data and the model was > 0.7. The ECD latency was determined as the time corresponding to the peak value of Q between 150 and 200 ms after the onset of the final syllables.

The effects of the group (stutterers, fluent speakers), the contrast condition (prosody, phoneme, both) and side (left, right) on the ECD moments were analyzed by a three-way analysis of variance (ANOVA).

2.2 NIRS experiment

Subjects and procedures: Ten stuttering adults (10 male, age range 18-44 years) and five school-age stuttering children (3 male, 2 female, age range 6-12 years) who stutter participated in the NIRS experiment. All subjects were right-handed as assessed by Edinburgh Handedness Inventory (Oldfield, 1971) and native speakers of Japanese. Subjects were recruited in Hospital of National Rehabilitation Center for Persons with Disabilities (NRCD), Japan, and a self-help group for stuttering. Written informed consent was obtained before the experiment. The research was approved by the ethical committee of NRCD.

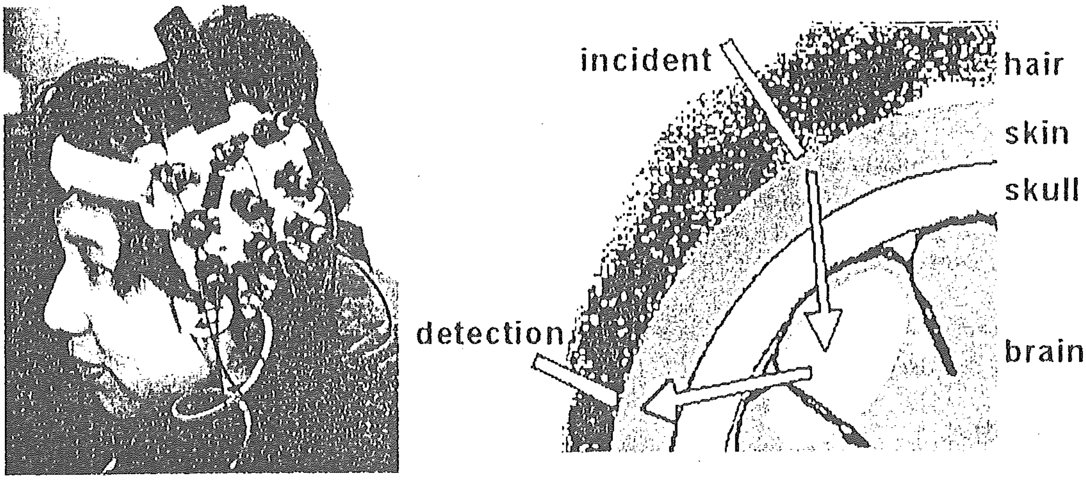

Figure 1. *NIRS measurement system [Left panel] Optical probes were placed on the scalp with thermoplastic shells. All probes were connected to the data acquisition system with flexible optical fibers. [Right panel] Near infrared light arrives at the brain tissue through the skin and skull, and returns to the detection probe by scattering.*

Recordings of the changes in hemoglobin (Hb) concentrations in the bilateral temporal areas were made with a 24-channel NIRS system (ETG-100, Hitachi Medical Co., Japan), which uses continuous near infrared lasers at two wavelengths modulated at different frequencies and detected with lock-in amplifiers (Watanabe et al., 1996). The recording channels resided in the optical path in the brain between the nearest pairs of incident and detection probes which were separated by 3 cm on the scalp surface. Five incident and four detection probes arranged in a 3 x 3 square lattice were placed on each lateral side of the head, which made the total number of recording channels 12 on either side (Fig. 1). After the recording, the tip positions of optical probes were measured with a 3D digitizer (Polhemus, Vermont, USA). The coordinates of the centers of the nearest incident and detection probe pairs were calculated, which served as the lateral pointers to the actual centers of respective recording volumes in the brain. The centers of recording sites were identified by superimposing the above coordinates onto T1-weighted parasagittal MR brain images for each adult subject. The channels nearest to the lateral end of the border between the transverse temporal gyrus (TTG) and the planum temporale (PT) in a parasagittal projection were presumed to be in the auditory area (Furuya & Mori, 2003; Minagawa-Kawai et al., 2002). This procedure selected the recording channels whose centers were within the 1.5 cm radius of the TTG-PT border, and thus should contain the signals in the auditory cortex due to the spread of the laser in the brain tissue (Yamashita et al., 1996). Since it was difficult to acquire MR brain images of some child subjects without anesthesia, the positions of optical probes were recorded with either a 3D digitizer or a digital camera for identification of approximate recording areas.

*Stimuli:*Two sessions were performed using the same word stimuli as for MEG experiments in a block design paradigm. In the phoneme contrast session, the baseline block contained only /itta/ which was repeated approximately every second, whereas the test block consisted of /itta/ and /itte/ presented in a pseudo-random order with the equal probabilities at the same rate as in the baseline block. Both blocks lasted for 20 s respectively, and presented alternately at least five times. The pitch contrast session was the same as the phoneme contrast session except for the presentation of the /itta/ and /itta?/ combination in the test block. The order of two sessions was counterbalanced among subjects. Stimuli were presented at a comfortable level (60-70 dB SPL) via insert earphones (EAR-TONE 3A) to adults and a loudspeaker (i15, TANNOY) to children.

Data analysis: The Hb contrast data were sampled at 10 Hz and smoothed with a 5 s moving average. The concentration of total Hb during the test block was averaged after excluding the blocks with artifacts in each session. The maximal total Hb change was calculated against the 10 s pre-test baseline period in each channel. In order to assess cerebral lateralization, laterality index, LI=(L-R)/(L+R), was calculated from the peaks of the maximal total Hb responses in the left (L) and the right (R) auditory areas. LI could range from -1 to 1, with a positive value indicating left dominance. LIs were compared between the two conditions (Mann-Whitney U-test).

Within subject analysis was also performed. Without averaging over repeated blocks, the left and right peaks of Hb concentration changes were obtained for individual test blocks, for which LIs were calculated and pooled for comparison between the two contrast conditions within each subject (Mann-Whitney U-test).

3. Results

MEG

The average peak moment (Q) of the ECDs of MMFs of the stutterers was significantly smaller than that of the nonstutterers ($p < 0.01$, ANOVA) in the ignore conditions. The main effects for other factors and interactions were not significant in the ignore conditions.

Figure 2 shows the Q values of the ECDs under the attention conditions. Only the group effect was significant (stutterers < fluent speakers; $p < 0.01$, ANOVA). No significant differences in ECD locations and latencies were found between groups or conditions.

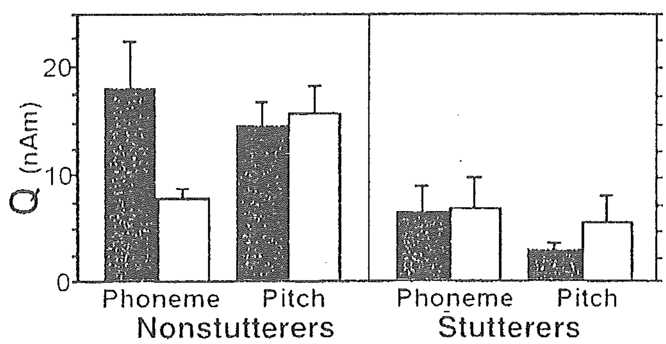

Figure 2. *Dipole moments for phoneme and pitch contrasts under the attention conditions. Filled bars: left, white bars: right dipole moments in the auditory area. Error bars: one standard error.*

NIRS

Figure 3 shows NIRS responses in an adult stutterer. The peak concentration change in total Hb was larger in the right auditory channel than in the left in response to the presentation of the phoneme contrast. The left-right preponderance in the response to the pitch contrast was opposite to that to the phoneme contrast. This left-right pattern of activation is reversed from the normal control (Furuya & Mori, 2003; Figure. 4 left).

Because the stutterers showed much wider variation in the relationship between the LIs to pitch and phoneme contrasts than the control, neither children or adult stutterers showed any significant difference in LI between the two contrast conditions as a group.(Figure 4).

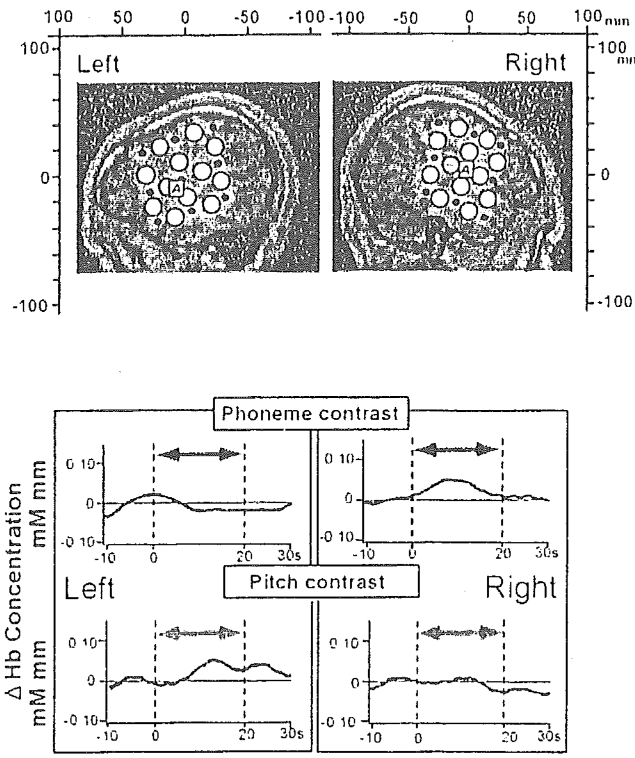

Figure 3. *Hb responses evoked by phoneme and pitch contrasts. [Upper Panel] The probe locations (black circles) and the center of the presumed measurement channels (white circles) are superimposed onto the left and right parasagittal MR images. Anterior is positive in the scales above the images, with 0 mm at the pre-auricular points. The lateral posterior borders of the Heschl gyrus are labeled "A". The channels with the maximal responses on respective sides are shown with gray circles. [Lower Panel] The averaged Hb concentration changes in response to the two contrasts (Phoneme: black arrows, upper graph; Pitch: light arrows, lower graph) recorded at the same left and right channels shown in the upper panel.*

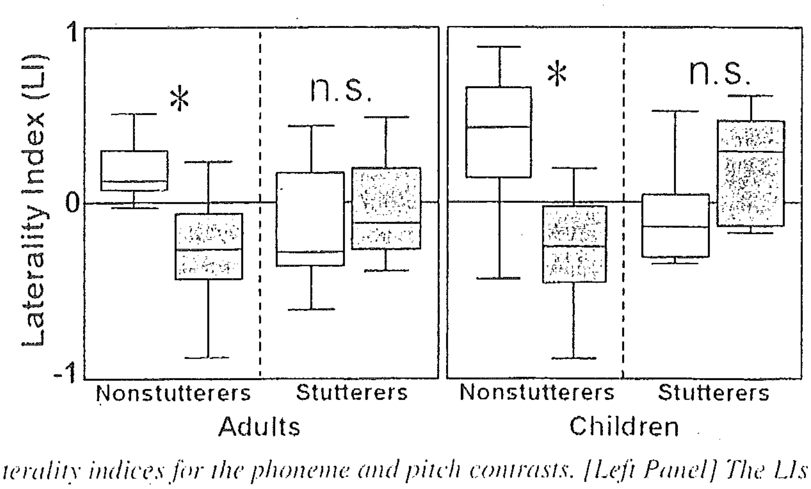

Figure 4. *Laterality indices for the phoneme and pitch contrasts. [Left Panel] The LIs for the phoneme (white boxes) and pitch (gray boxes) contrasts of adult nonstutters (Furuya & Mori, 2003) and stuterers. [Right Panel] School-age stutterers as a group did not show a significant difference between the two conditions. The nonstutter control group consisted of 3-5 years old children (Sato et al., 2003). Boxes: the quartiles. Bars in the boxes: the medians. Hinges: the ranges. *: a significant difference of LIs between the phoneme and pitch contrast (p < 0.01). N.S.: not significant (p > 0.05).*

Within-subject analysis revealed that none of the stutterers showed a significant difference between pitch and phoneme LIs, except two adults (the results of one of whom are presented in Fig.2) and one child showing rightward LI for the phoneme contrast. This is markedly different from the right-handed control where 85% of adults showed significantly more leftward LIs for phoneme than for pitch, with the remaining 15% showing no significant difference between the two contrast conditions (Furuya & Mori, 2003) (Figure 5).

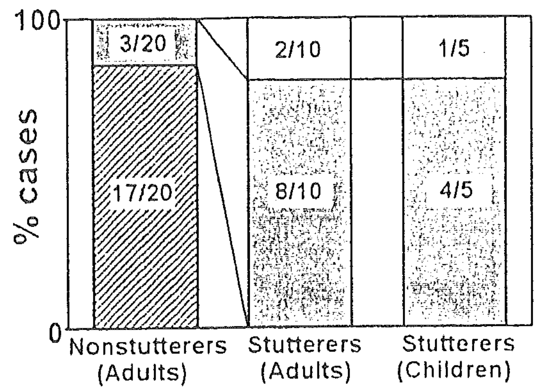

Figure 5. *Within-subject analysis for LIs between phoneme and pitch contrasts*

Cerebral dominance as percentage of subjects is plotted for each group with the number of subjects in each bar. Oblique hatched bars: a significantly more positive LI in the phoneme than in the pitch contrast session, indicating the left side dominance in the phoneme processing. Grey bars: no significant difference between the contrast condition. White bars: a significant negative shift of LI in the phoneme contrast condition relative to the pitch.

4. Discussion

We have demonstrated the differences between developmental stutterers and nonstutterers in cerebral lateralization in the auditory processing of prosodic and phonemic contrasts by using NIRS and MEG. Abnormal functional lateralization in speech processing has been already demonstrated with MEG (Salmelin et al., 1998), with which our MEG results are in line. Using the same stimuli as MEG, we investigated adult and school-age stutterers with NIRS, with the adult subjects showing similar results to those with MEG, but with a hint of a higher sensitivity of NIRS than MEG. Both adult and school-age children who stuttered showed abnormality in the lateralization of phoneme contrast processing, which is consistent to and extends the previous finding of different functional interhemispheric asymmetry of auditory language processing between adult stutterers and nonstutterers (Fox et al., 1996; Salmelin et al., 1998; Curry & Gregory, 1969). Because all the stutteres in our study demonstrated abnormality in functional lateralization of speech processing, the diagnostic sensitivity for stuttering of our method is 100%, while its specificity is 85% according to the results from the adult control (Fig. 3). Our results in children indicate that the abnormality in the auditory functional lateralization starts at least as early as the elementary school age.

The etiology of developmental stuttering is still unknown, although various abnormalities have been postulated as its causes; the laryngeal control (Conture, 1986), the motor systems controlling the speech organs (Fox et al., 1996), the Broca's area and speech planning (Wu et al., 1995), neural processing sequence among the motor and the Broca's areas (Salmelin et al., 2000). Although stuttering refers to a speech motor dysfunction, previous studies of functional lateralization in stutterers using various methods (Curry and Gregory, 1969; Hall and Jerger, 1978; Fox et al., 1996; Salmelin et al., 1998; this study) have found less-than-normal left-side dominance for linguistic processing and suggest the significant involvement of the auditory system in the disorder. The fact that fluency can be induced with delayed auditory feedback (DAF, Lee, 1950) or white noise that