masks self-monitoring of own speech (Cherry & Sayers, 1956) also suggests the crucial role of the auditory system in stuttering.

The abnormal functional lateralization of language processing that has been so far demonstrated in the adult auditory brain, however, might be a result rather than a cause of stuttering, due to the possibility of compensatory plasticity during development with long-standing stuttering. The present results suggests either (1) that the abnormality is causal to stuttering, or (2) that stuttering persisting for only several years is enough to reset or even reverse the functional lateralization of the auditory area that should have been already established at the age of one year (Sato et al., 2003).

This long-standing issue can only be resolved by investigating younger stutterers than those studied here. Towards this end, we have chosen a novel functional brain mapping technique using multichannel NIRS, and a task that does not require active participation on the subjects. With this paradigm, the development of functional lateralization of speech processing in the auditory area can be monitored in infants (Sato et al. 2003). Behavioral tests requiring intensive attention, like dichotic listening tests, may not be possible with young children at the age of the highest risk of suffering from stuttering. Tasks requiring listening only without reading or writing allow the study of illiterate and preliterate children (Ahmad et al., 2003). Even speech tasks, as employed in previous adult studies (Fox et al., 1996; Salmelin et al., 1998), may not be reliably performed by younger stutterers.

Conventional neuroimaging techniques either do not have enough resolution (eg., evoked potentials), are not safe enough (PET and single photon emittion computerized tomography, SPECT), or are too restrictive (PET, SPECT, functional MRI) to be used for young stutterers. NIRS allows noninvasive measurement of human brain functions under a variety of conditions with little restraint of the subject (Kennan et al., 2002; Zaramella et al., 2001), and has a reasonable resolution due to the limited spread of near infrared light in the tissue (Yamashita et al., 1996), unlike evoked potentials.

As the NIRS method is best suited among the available brain mapping techniques for studying the lateralization of cortical auditory functions in children and infants, it may be useful for elucidating neural correlates of stuttering, and even evaluating and diagnosing stuttering in infants in the future.

5. Conclusion

NIRS and MEG were used to investigate the cerebral dominance of the auditory language processing in adult and child stutterers. Analysis-synthesized Japanese word stimuli with phoneme (/itta/ and /itte/) and pitch (/itta/ and /itta?/) contrasts were used. With NIRS measurement, we calculated the laterality index (LI) from the peaks of the left and right total Hb responses to each contrast in the auditory area. The results showed that there were no significant differences in LI between phoneme and pitch contrast responses in stutterers. Within-subject analysis showed no subject with a significant leftward shift of the LI in phoneme condition relative to pitch condition, although there were a few with a reversed laterality in comparison to the normal control. Similar trends were observed in the MEG study. These results confirm that stuttering is closely correlated to the abnormality of the cerebral dominance for processing heard speech, even in school-age children. The NIRS method used in this study has a potential clinical application as an objective test of stuttering because it enables evaluation of individual cerebral laterality. It also may help elucidating how the cerebral lateralization is related to stuttering.

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PRELIMINARY STUDY ON EFFECTS OF TEMPERAMENT CHARACTERISTICS ON EARLY DEVELOPMENT OF STUTTERING CHILDREN

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SUMMARY

Temperament is considered to be an important factor influencing the onset and development of stuttering in children. Wakaba estimates that one-third of children who stutter can be characterized as a *difficult child*, a higher proportion than among normally fluent children. This study examines two groups of subjects, five in an "Easy Child" group and five in a "Difficult Child" group. Four data collection strategies were used to assess the developmental history and behavior characteristics of the children and their relationships with their parents. Temperament was found to be a contributory factor in the development of stuttering symptoms associated with tension in the "Difficult Child" group. More subjects need to be studied before these results can be generalized.

1. Introduction

According to previous research (Andrews, 1985), stuttering is a condition that tends to emerge in infancy, with onset occurring before the age of 6 in 75% of cases. While significant advances have been made in finding important factors in the onset and development of stuttering in preschool age stutters, little research has been done on the mechanisms of the various factors influencing the early process of emergence and development of stuttering.

Thomas and Chess (1977) identified three types of children, the "Easy Child," the "Difficult Child" and the "Slow-to-Warm-Up Child," from longitudinal observations of children using nine categories of temperament: activity level, rhythm city, approach or withdrawal, adaptability, threshold of responsiveness, intensity of reaction, quality of mood, distractibility, and attention span and persistence. Carey and McDerritt. (1978) developed the 'Infant Temperament Questionnaire' (ITQ), which has been adopted in many countries. In Japan, Soeda et al. made a standardized 'Infant Temperament Questionnaire' (Japanese version) using data from 737 normal children 3 years of age (Soeda et al. 1967)

An 'Easy Child' has a generally good mood, mild reactions to external stimuli and regular physiological rhythms. Such children have the ability to adapt to changes in their environment. A 'Difficult Child' has irregular physiological rhythms and difficulty adapting to changes in his or her environment. Recently, children's temperament has come to be considered an important factor in determining problem behavior (Okubo & Sato, 1984). Wakaba reported that 'Difficult Child' accounted for 33.1% of stuttering children in whom onset of stuttering was in their third year, which is a higher percentage than among the general population of children in Japan (Wakaba 1997).

We began systematic research on the onset and development of stuttering in Japan in 2002. This report is a preliminary analysis of the influence of temperament on onset and development of childhood stuttering.

2. Method

Subjects

Two groups of subjects, five 'Easy Child' and five 'Difficult Child', were selected from 17 stuttering children whose ages ranged from 2 years and 11 months to 6 years and 1 month (mean = 3 years and 8 months), based on the results of the Behavioral Style Questionnaire (Japanese Version): JBSQ. Another seven subjects were assessed as 'Intermediate-Low Child'. They were compared in several aspects. The onset of stuttering was in the third year in all subjects (see Table 1).

Table 1. *Subjects*

Difficult Child group				Easy Child group			
Case		Onset	First ex	Case		Onset	First ex
A	*M*	2:3	3:2	O	*F*	2:2	3:10
B	*M*	2:3	3:2	P	*F*	2:4	3:1
C	*M*	2:3	3:2	Q	*F*	3:7	3:9
D	*M*	2:7	3:10	R	*M*	2:5	3:1
E	*M*	2:7	3:4	S	*M*	2:6	3:1

Data collection strategies

A) *Information on stuttering symptoms: Status at the time of initial examination.* The subjects were observed by 2 trained observers for 30 minutes as they played with their mothers. The observers rated (1) the severity and (2) the type of the stuttering symptoms. 'The Scale for Rating Severity of Stuttering' (Johnson et al.,. 1963) was used to rate the severity of the stuttering. *Evaluation of period from onset of stuttering until initial examination.* (1) Judgment of tendency to increasing severity: Subjects in whom associated behavior and blocking were seen in the first year after the onset of stuttering were judged to have a tendency for increasing severity. (2) Appearance of physical tension: A judgment was made as to whether the child was tense in part or all of his or her body. (3) A judgment was made as to whether any associated behavior had appeared. (4) A judgment was made as to whether any emotional response had appeared.

B) *Data related to personality or behavior characteristics:* At the initial examination, the mother completed (1) the 'TS Personality Test for Preschooler and School Age Children', and (2) a questionnaire on emotional problems (developed by Wakaba, this questionnaire covers 6 types of behaviors: eating behaviors, behaviors of digestion and excretion, sleeping behaviors, sensitiveness, neurotic habits, other specific behaviors.)

C) *Data related to history of growth and development:* At the initial examination, the mother completed questionnaires on the child's history of stuttering and history of growth and development. The mother was also interviewed with regard to these histories.

D) Information on parent-child relationship: At the initial examination, the mother or father completed the 'Japanese Standardized Parent/Child Relations Test'. Each of 10 items was scored, with 1 point for "stable," 3 points for "borderline," and 5 points for "risk." A total score was then calculated.

Statistical analysis

To compare the 2 groups, a Mann-Whitney test was conducted for the results of the age at onset of stuttering and the results of the 'Japanese Standardized Parent/Child Relations Test'.

3. Results

The scores of nine categories of temperament in two groups is shown in Figure1 and Figure 2. The results of two groups are shown in Table 2. From the indicators of physical and language development, it is seen that the subjects in both groups showed normal development.

In the 'Difficult Child' group, the mean age at onset of stuttering was 2 years and 6 months (range: 2;3 – 2;7), and the mean age at initial examination was 3 years and 4 months (range: 3;2 – 3;10). Four of these children (80%) showed a tendency for increasing severity of stuttering. The severity of stuttering at the initial examination ranged from 2 to 5, with a mean of 3,4. The type of stuttering symptoms were diverse, with 3-12 types exhibited. Associated behavior had appeared in all 5 children in this group (in 2 of whom it had disappeared at the time of initial examination). Physical tension was seen in all 5 children. Two of the children became frustrated when they could not say something, and exhibited an emotional response, such as saying "I can't say it!". All five children experienced fluctuations in worsening and abating symptoms. Emotional problem behaviors included a tendency to sensitivity, such as being uneasy with new people or places, perspiration, coughing, colds, and eczema. From the personality test the 5 children were judged to have a tendency to maladjustment (nervousness, emotional instability, low level of sociality, familial maladjustment, regression, low self-control). A problem in the parent-child relationship was seen in 3 of the children.

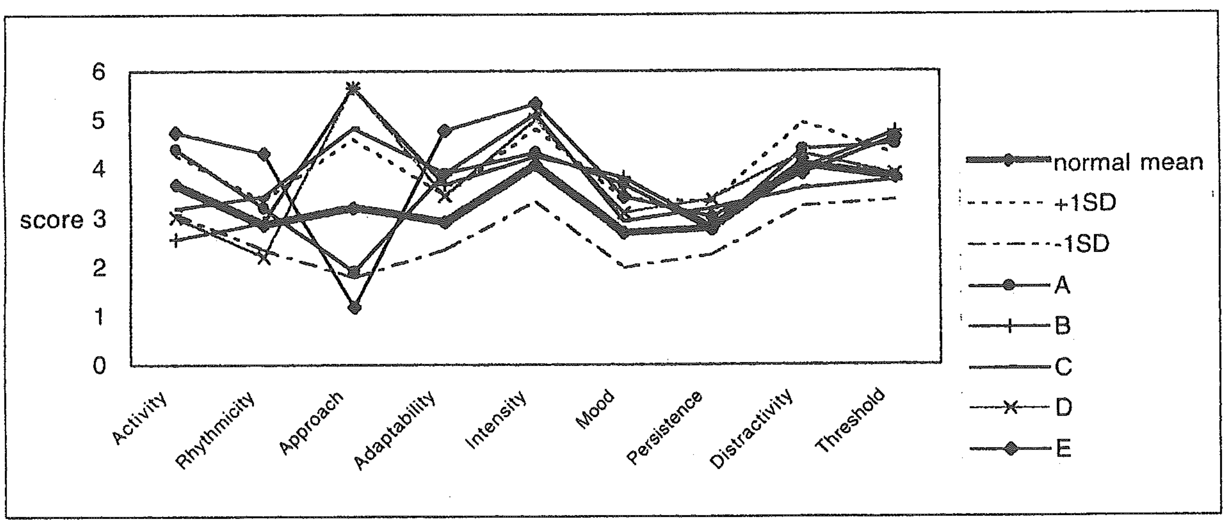

Figure1. *Score of JBSQ/Difficult Child group*

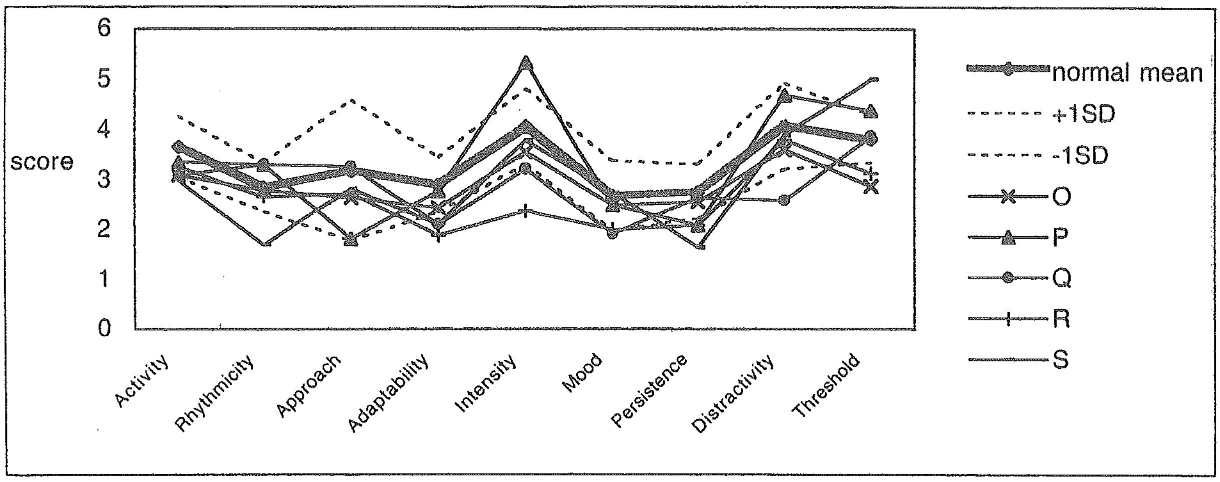

Figure 2. *Score of JBSQ/Easy Child group*

Table 2. *Comparing the two groups*

		Difficult Child Group	**Easy Child Group**
Age at onset of stuttering		2;3~2;7 (M=2;6)	2;2~2;7 (M=2;7)
Age at initial examination		3;2~3;10 (M=3;4)	3;1~3;10 (M=3;4)
Time since onset of stuttering		9 m~1 y 3 m (M=10 m)	2 m~1 y 8 m (M=9 m)
Development of stuttering	Changes in severity	Increasing severity (80%)*	Increasing severity (40%)*
	Physical tension	+ (60%)*	+ (20%)*
	Associated symptoms	+ (100%)*	+ (60%)*
At initial examination	Emotional response	+ (40%)	+ (0%)
	Stuttering severity assessment	2~5	2~5
	Type of stuttering symptoms	Various symptoms (3~12 types)	Few symptoms (2~5 types)
Emotional problem behaviors (since birth)		Sensitivity (100%)* Nervous habit (60%)*	Sensitivity (80%)* Nervous habit (80%)*
Personality test (at initial examination)		maladjustment tendency (100%)*	maladjustment tendency (40%)*
Score on mother-child relationship test (at initial examination)		20.0**	16.6**
Score on father-child relationship test (at initial examination)		16.0**	15.0**

*Percentage of children in the group (%)

**Score is given according to level of maladjustment

In the 'Easy Child' group, the mean age at onset of stuttering was 2 years and 7 months (range: 2;2 – 3;7), and the mean age at initial examination was 3 years and 4 months (range: 3;1 – 3;10). A change toward increasing severity was seen in two of the children (40%). The severity of stuttering at the time of initial examination ranged from 2 to 5, with a mean of 3.2. Two to five types of stuttering symptom were observed, which was less than in the Difficult Child group.

Associated behavior was seen in three children, but not in the other two. Physical tension was seen in 1 child. No emotional responses were observed. Two children experienced fluctuations in the severity of stuttering symptoms. Emotional problem behaviors included a variety of nervous habits, such as finger sucking, sucking on clothes, nail biting, masturbation, drooling, and hair loss. In the personality test, two children showed a tendency to maladjustment (aggressiveness, impulsiveness, instability, and sulking when admonished), whereas three showed adaptive tendencies. Problems in the parent-child relationship were found in three cases.

There were no statistically significant differences in the age at onset of stuttering or parent-child relationship test results between two groups.

4. Discussion

The two groups were compared with regard to the development of stuttering, using the four indicators of time from onset of stuttering until initial examination, changes in severity physical tension when stuttering, appearance of associated symptoms, and appearance of emotional responses. These four kinds of indicators were more prevalent in the 'Difficult Child' group than in the 'Easy Child' group. In the 'Difficult Child' group, stuttering became more severe in the year following onset, and physical tension appeared frequently. Associated symptoms are thought to be physical movements performed to release physical tension when a child is about to make an utterance in situations that produced physical tension in the child. As seen in the results of the questionnaire on temperament, children in the 'Difficult Child' group tended to respond sensitively to stimuli from their surroundings, and it is supposed that tendencies for such behavioral patterns would make a child susceptible to physical tension.

No difference was seen between the groups in the assessed severity of stuttering at the time of the initial examination. The 'Difficult Child' group was observed to have a clearly greater number of types of stuttering symptoms than the 'Easy Child' group. In the therapeutic process, observations of fluctuations in stuttering symptoms revealed a decrease in the number of types of stuttering symptoms as the severity of the stuttering abated. It is thought that in young children the number of types of symptoms as well as the frequency of symptoms reflect the severity of stuttering.

In the area of emotional problem behaviors of these children since birth, behaviors showing sensitivity were found to be more common in the 'Difficult Child' than in the 'Easy Child' group, whereas nervous habits were more common in the 'Easy Child' group. The differences between the two groups cannot be understood descriptively with the present data, so further investigations with a greater number of subjects are needed. The results of the personality test showed a greater tendency for maladjustment in the 'Difficult Child' group. This agrees with a finding in an earlier study on temperament (Thomas et al., 1980), in which it was pointed out that 'Difficult Child' do not have good compatibility with their environment. Maladjustment to the environment is thought to produce tension in children while at the same time strongly affecting psychological stability, and may thus be considered a factor in increasing severity of stuttering.

Temperament characteristics seemed to contribute to the formation of stuttering symptoms associated with tension in difficult children. In the future a greater number of subjects should be examined to generalize these results.

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福祉用具の満足度評価スケールの開発　－QUEST簡易版－

Development of User Evaluation Scale of Satisfaction with Assistive Technology.
- QUEST in Japanese -

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キーワード：心理評価，標準化，利用効果，測定手法

1　はじめに

福祉用具は障害者の生活を支える重要な役割をもち、補装具・日常生活用具の給付制度や介護保険による貸与・給付制度により、その利用は広がりを見せている。それと同時に、給付や貸与した用具の利用効果に関する評価はますます重要な課題になってきた。

福祉用具は利用者の生活に密着した道具であり、利用者の立場に立った福祉用具の選択・適合および開発が必要である。そのためにも、福祉用具の心理的評価は欠かせない。さらに利用者の心理状況の変化が、日常生活における自立度の向上や介護負担の軽減に結びつく場合が少なくない。しかし、それらを説明するための標準化された測定法は確立されていないのが現状である。

本研究では、利用者が使用している福祉用具に対してどの程度満足しているかを、客観的に評価するスケールを開発することを目的としている。そのために、欧米で広く使用されている福祉用具満足度評価スケール（QUEST）に着目し、その日本語版を作成するとともに、信頼性および妥当性の検証を行った。

2　QUEST Ver.2 日本語版の作成

QUESTはDemersらが開発した評価スケールである[1),2)]。当初開発されたスケール27項目からなるものであったが、その後項目の検討を行い、現在12項目からなる簡易版（第2版）が広く利用されている。この第2版は英語版の他、フランス語、オランダ語、デンマーク語などに翻訳されている。今回は、このQUEST 第2版の日本語訳を作成した。QUEST 2.0（日本語版）は福祉用具の利用者を対象にした評価スケールであり、ユーザーが福祉用具の特徴や、その関連サービスにどれほど満足しているかを評価する。質問の構成は以下のとおりである。

1）質問1

福祉用具に関する8項目（大きさ，重さ，部品の取り付け方法や調節方法，安全性，丈夫さ（耐久性），簡単に使えるかどうか，使い心地の良さ，有効性）と、関連するサービスに関する4項目（手に入れるまでの手続きや期間，修理サービス，専門家の指導・助言，継続的なアフターサービス）を「1.まったく満足していない」「2.あまり満足していない」「3.やや満足している」「4.満足している」「5.とても満足している」の5段階で評価する。

2）質問2

質問1の12項目の中から、福祉用具利用者が満足度を評価する上で最も重要だと考える項目を3つ選択し、チェックを付す。

3）質問3

福祉用具と関連するサービスに対する全体的な満足度を「1.まったく満足していない」「2.あまり満足していない」「3.やや満足している」「4.満足している」「5.とても満足している」の5段階で評価する。

質問3は、スケールの得点に関する妥当性を評価するために、今回の研究用に設置した質問である。

3　信頼性・妥当性の検証

本研究では、車いす、義足、入浴・排泄用具の利用者に対して調査を行い、信頼性と妥当性の検証を行った。また、吃音軽減用具の導入前後で本スケールによる評価を行い、妥当性の検証とした。各用具における被検者の属性は表１の通りである。

表１　被検者の属性

用具	被検者数（男・女）	年齢	備考
車いす	30(27·3)	33.8±8.5	手動25,電動5
義足	15(12·3)	51.8±13.5	股義足2,大腿6,下腿7
入浴・排泄用具	23(12·11)	73.3±8.1	ポータブルトイレ12,尿器・便器4,入浴用いす4,浴槽内いす2,浴槽リフト1
吃音軽減用具	4(1·3)	31.0±13.6	メトロ2,DAF 2

車いす、義足、入浴・排泄用具の使用者を対象とした、再テスト信頼性および内部一貫性の検証結果を表２に示す。再テスト法では、７日間を基準とし６日～14日の範囲で同じ検査を２回行い、その相関（ピアーソン）係数を算出した。内部一貫性については、クロンバックのα係数を使用した。

表２　信頼性の結果

		車いす	義足	入浴・排泄用具
再テスト	総合得点	0.87	0.96	0.93
	用具得点	0.86	0.80	0.87
	サービス得点	0.86	0.97	0.92
内部一貫性	総合得点	0.92	0.75	-
	用具得点	0.88	0.85	-
	サービス得点	0.84	0.59	-

以上の結果から、総合得点および福祉用具とサービスの各サブスケール得点については、高い信頼性が得られることが確認できた。また、車いすと義足の使用者の結果から、内部一貫性による信頼性も確認できた。これより、それぞれの得点に関しては、信頼性の高いスケールであるといえる。

車いすについて、質問１の総合得点、用具得点、サービス得点と質問３の得点の相関をとったところ、総合得点で0.91、用具得点で0.61、サービス得点で0.74という値を得た。総合得点では、特に高い値であり、本スケールの妥当性を示す結果といえる。

成人吃音者４名に対して、吃音軽減用具として耳掛け型メトロノーム（２名）、耳掛け型DAF/FAF（２名）を４ヶ月から８ヶ月使用した後、その効果を測定するとともに、QUEST による満足度の評価を行った。電話場面における発話の評価の結果、３名については非流暢性頻度の低下がみられ、装置の有効性が示された。QUEST の評価結果では、装置の有効性が示された３名の福祉用具サブスケールの得点は4.25、4.13、4.13 であり、有効性の示されなかった１名の福祉用具サブスケールの得点は 3.50 であった。これより、効果の得られた被験者では福祉用具サブスケール得点が高い傾向が得られ、本スケールの妥当性を支持する結果が得られた。

4　まとめ

福祉用具の満足度を評価するスケールとして、QUEST 第２版の日本語版を作成した。本スケールは福祉用具サブスケール（8項目）、サービスサブスケール（4 項目）の合計１２項目からなる。車いす、義足、入浴・排泄用具の利用者に対して行った調査結果から、高い信頼性が得られることが示された。また、車いすおよび吃音軽減用具の利用者に対する調査結果から、本スケールの妥当性が示された。

今後、項目ごとの検討を行うとともに、被検者数を増やし、多面的な検証を行う予定である。

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Reliability and Validity of the Japanese version of QUEST 2.0

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In this article, test-retest reliability and validity of the Japanese version of the Quebec User Evaluation of Satisfaction with assistive Technology 2.0 (J-QUEST) was evaluated. J-QUEST consists of a questionnaire. The respondent rates his or her satisfaction with respect to 12 aspects (dimensions, weight, adjustment, safety, durability, ease of use, comfort, effectiveness, service delivery, repair & servicing, professional services, and follow-up) on a five-point scale. J-QUEST yields three scores: device subscale score (the average score for eight items related to a device), service subscale score (the average score for four items related to a service) and a total score (the average score for all twelve items). Twenty-three users (73.3±8.1years, 12 males & 11 females) of aids for personal care participated. A face–to-face interview was conducted. The second test was performed from seven to fourteen days after the first test. To examine the validity of J-QUEST, we asked about overall level of user-satisfaction with his or her assistive technology on a five-point scale. Reliability proved to be good ($\kappa_w \geqq 0.61$) for seven item scores. On the other five item scores moderate reliability ($\kappa_w \geqq 0.41$) was observed. Regarding three J-QUEST scores, excellent reliability (Pearson's $r \geqq 0.70$) was obtained. There was a good correlation between total score and overall level of user-satisfaction (first trial r=0.65, second trial r=0.69). The results of this study demonstrated that J-QUEST was a highly reliable and valid instrument to assess user-satisfaction with his or her assistive technology.

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福祉用具の心理的効果測定法の利用
—QUEST第2版とPIADS—

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Key words: 福祉用具, 評価, QOL

【はじめに】福祉用具には日常生活活動における介助量軽減だけでなく，ｸﾗｲｴﾝﾄの主体性回復に寄与する心理的効果が期待されている．前者の効果測定には標準化された評価(Functional Independence Measure等)が用いられるが，後者の測定は叙述的な事例報告に留まっている．主体性を促す福祉用具ｻｰﾋﾞｽの発展には，福祉用具や関連ｻｰﾋﾞｽによる心理的影響を測定する量的評価の開発が必要である．国際的にはQUEST第2版(Quebec User Evaluation of Satisfaction with assistive Technology：福祉用具と関連ｻｰﾋﾞｽの12種類の特徴への満足度を1点：まったく満足していない～5点：非常に満足しているで評定．用具ｽｺｱとｻｰﾋﾞｽｽｺｱと総ｽｺｱを算出．ｽｺｱは順に，8項目，4項目，全12項目の得点の平均値) やPIADS(Psychosocial Impact of Assistive Devices Scale：福祉用具使用による利用者の心理的効果を26項目で測定．使用によって各項目の心理的特性が減少したと感じる場合には-3～-1点，不変の場合には0点，増加したと感じる場合には1～3点で評定．効力感と積極的適応性と自尊感の各ｻﾌﾞｽｹｰﾙの得点を算出．各ｽｹｰﾙは26項目中順に，12項目，6項目，8項目の得点の平均値)が利用され，評価の信頼性と妥当性も検証されている．しかし，日本ではまだ使用されていない．そこで，福祉用具導入によって主体的に活動するようになった事例への心理的効果を2種類の評価で調べて，各評価法の利用法を検討した．【方法】頚髄脂肪腫によって四肢麻痺を発症したMさん（女性．導入時19歳)のﾎﾟｰﾀﾌﾞﾙｽﾌﾟﾘﾝｸﾞﾊﾞﾗﾝｻｰ(PSB)導入による心理的効果をQUEST第2版とPIADSを用いて調べた(導入5年後に実施)．Mさんは，PSBを用いて食事と電動車いすの操作が一部可能になった．PSBを利用する作業の選択や操作方法の学習を通して，Mさんは作業療法場面以外の生活でも自らのしたい作業を選択し，構造化し，遂行するように変化していった．自らの考えを積極的に表現するようになり，他者との交流や活動への参加が増えた．将来に向けて英語の勉強を始めるきっかけにもなった．【結果・考察】QUEST第2版の結果は，用具ｽｺｱ：3.25，ｻｰﾋﾞｽｽｺｱ：3.00，総ｽｺｱ：3.20．2点(あまり満足していない)以下の項目とｺﾒﾝﾄ：(重さ)調整する人には重いと思う，(部品の取り付け方法や調整方法)調整しにくい，(手に入れるまでの手続きや期間)遅すぎたであった．PIADSの結果は，効力感ｻﾌﾞｽｹｰﾙ：2.58，積極的適応性ｻﾌﾞｽｹｰﾙ：2.83，自尊感ｻﾌﾞｽｹｰﾙ：2.25であった．2種類の評価はMさんが全体としては福祉用具や関連ｻｰﾋﾞｽに満足しており，用具利用によって効力感や積極的適応性や自尊感情が向上したことを示していた．しかしQUEST第2版の下位項目をみると，PSBの調整の困難さや導入の遅れについては満足していないことが明らかになった．2種類の評価において福祉用具ｻｰﾋﾞｽの心理的影響の量的測定や問題点の抽出に有効である可能性が示された．

Different Brain Strategies Underlie the Categorical Perception of Foreign and Native Phonemes

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Abstract

■ The present study using near-infrared spectroscopy examined the neuronal correlates of Japanese long/short vowel contrast discrimination and its relationship with behavioral performance by comparing native Japanese (L1) subjects and Korean subjects learning Japanese as a second language (L2). Phoneme-specific responses were predominantly observed in the left auditory area only in the L1 subjects, although the behavioral scores of the L2 subjects indicated categorical perception (CP) that was indistinguishable from that of the L1 subjects. These inconsistent relationships were more evident in the correlation coefficients between the brain recording and behavior. However, slower reaction times and nonspecific brain responses in the L2 listeners suggest differences in their cortical processes from those of the L1 subjects. These findings suggest that the CP of L2 phonemes as determined by behavioral scores alone does not always predict a language-specific neural processing as employed by the L1 listeners. ■

INTRODUCTION

Languages differ in the constitution of their phoneme inventories and in the distinctiveness of those phonemes. Such phonemic repertories are acquired through the linguistic experience of the first language (L1) that modifies the innate perceptual ability to optimally adapt to the phonological system in L1 (Jusczyk, 1997; Strange, 1995; Kuhl, Williams, Lacerda, Stevens, & Lindblom, 1992; Aslin & Pisoni, 1980). Cross-linguistic behavioral experiments such as identification and discrimination tests have shown that, as a consequence of the linguistic experience, an adult's perception of the L1 phonemic contrast is both categorical and efficient, whereas that of certain contrasts in nonnative languages (L2) turns out to be inaccurate and difficult (e.g., English /r/ and /l/ by Japanese listeners; Yamada & Tohkura, 1992; Miyawaki et al., 1975). Furthermore, brain imaging studies have demonstrated neurophysiological evidence for language-specific phoneme perception (Rivera-Gaxiola, Csibra, Johnson, & Karmiloff-Smith, 2000; Sharma & Dorman, 2000; Simos et al., 1998; Dehaene-Lambertz, 1997; Näätänen et al., 1997). Some of these studies using magneto-encephalography (MEG) and near-infrared spectroscopy (NIRS) showed that the large responses that are derived from phonemic differences and not acoustic physical ones in L1 are observed in the left auditory area (Minagawa-Kawai, Mori, Furuya, Hayashi, & Sato, 2002; Rivera-Gaxiola et al., 2000; Dehaene-Lambertz, 1997; Näätänen et al., 1997).

Phonemic contrast of English /r/ and /l/ is frequently referred to as an example of difficult phonemes for Japanese adults to distinguish. There have been extensive behavioral studies that examined possible factors influencing the identification of /r/–/l/, such as positions of the phonemes within a word, age of learning L2, duration of learning experience, and methods of training (Takagi, 2002; Bradlow & Pisoni, 1997; Lively, Logan, & Posoni, 1993; Yamada & Tohkura, 1992; Logan, Lively, & Pisoni, 1991). Training with only a restricted word or synthetic /r/–/l/ continuum in limited word positions did not result in learners' perceptual improvement because the acquired ability of identification/discrimination, if any, did not generalize to the perception of phonemes in various word or speaker contexts (Lively et al., 1993; Logan et al., 1991; Strange & Dittomann, 1984). Instead, it was found that the more effective stimuli for inducing generalization were naturally spoken tokens of /r/–/l/ occurring in various word positions pronounced by multiple talkers (Lively et al., 1993; Yamada & Tohkura, 1992). However, most of the training studies failed to demonstrate learners' perceptual improvement to the level of natives even after the intensive training (Takagi, 2002).

Neurophysiological studies on the training processes revealed neural plasticity associated with L2 phoneme learning by way of short but intensive training sessions (Callan et al., 2003; McClelland, Fiez, & McCandliss, 2002; Menning, Imaizumi, Zwitserlood, & Pantev, 2002; Tremblay & Kraus, 2002; Imaizumi, Itoh, Tamekawa,

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Deguchi, & Mori, 1998). Because what most of those studies revealed, however, were neurophysiology based on the training of a phonemic contrast in a certain limited word and speaker context, it could have been that the neural changes found in these training studies might be different from those acquired in natural linguistic context. One way to reveal neurophysiologic correlates to the naturally acquired novel L2 phonemes is to examine bilinguals (or high-proficiency L2 learners). Several imaging studies explored neuronal basis of bilingualism (Chee, Soon, Lee, & Pallier, 2004; Dehaene et al., 1997; Kim, Relkin, Lee, & Hirsch, 1997; Perani, Dehaene, et al., 1996). Brain activity during listening stories in L1 and L2 was different between low-proficiency and high-proficiency bilinguals but not between early- and late-acquired bilinguals (Perani, Paulesu, et al., 1998; Perani, Dehaene, et al., 1996), suggesting that the age of learning alone does not influence the neuronal activity related to listening to L2. Although their studies were not specific about the abilities of L2 phoneme identification, their results do not relate well to the difficulties of distinguishing L2 phonemes for adults without pre-adolescent L2 exposure (Takagi, 2002) in contrast to the ease for children (Kuhl, Tsao, & Liu, 2003; Cheour, Shestakova, Alku, Ceponiene, & Näätänen, 2002). In fact, neuroimaging studies on phonemic processing in L2 learners (or late bilinguals) have been limited (Chee et al., 2004), and more analytical work is lacking on the correlation of the neurophysiological evidence with the behavioral results of the L1 and L2 phonemic contrast. Until now, such correlations have been assumed rather than fully elucidated (cf. Winkler et al., 1999). Does the similar behavioral performance on L2 phonemes by L2 listeners to those by L1 listeners in fact denote the use of a neuronal circuit similar to that for L1 listeners? The present study directly addresses this question by examining the neural substrates for processing the Japanese phonemic contrast as L1 and L2 and its relationship with the behavioral performance.

Japanese is referred to as a "mora-timed language" in which the duration of each mora (a subsyllabic unit) is kept roughly constant; thus, the duration of geminate vowels and consonants is psychologically perceived for about twice as long as that of single ones. Because these types of long/short phonemes (e.g., kado [corner] and kadoo [flower arrangement]) that occur in any syllable position can be distinguished solely by their durational difference, many learners of Japanese whose native language does not possess a similar contrast find it very difficult to distinguish this contrast (Minagawa-Kawai, Maekawa, & Kiritani, 2002; Toda, 1994). Cerebral representations of this type of opposition for L1 listeners were reported in Japanese (Minagawa-Kawai, Mori, Furuya, et al., 2002) and in Thai (Gandour et al., 2002). The present study measured hemodynamic responses to this Japanese long/short vowel contrast in fluent L2 speakers (Koreans) without specific phonetic training and L1 speakers with NIRS using a contrastive paradigm (Furuya & Mori, 2003). To assess whether the Korean (L2) and also Japanese (L1) subjects exhibit similar neural responses specific to the phonemic difference in Japanese language, three contrastive conditions were prepared, comprising AB (a short vowel pair of Stimulus A and Stimulus B), BC (a short and long vowel pair of Stimulus B and Stimulus C), and CD (a long vowel pair of Stimulus C and Stimulus D). Although each stimulus pair differs equally in length, only the BC condition has a phonologically distinctive difference in Japanese linguistic system, and thus, the L1 group is expected to show large neural response to the B and C contrast. In contrast, the comparisons of AB and CD are control conditions where no language-specific responses would be observed. Finally, the relationship between the hemodynamic and behavioral results was then analyzed in each group.

RESULTS

Behavioral Results

The stimulus word used in both the behavioral and NIRS experiments was the pseudoword "mama" whose final vowel ranges from /mama/ (short vowel) to /mama:/ (long vowel). The subjects in the identification test of long/short vowels judged if the final vowel of the stimulus is a long or short phoneme. The results of the test showed that the averaged values of the phoneme boundary (PB) was 192 msec (SD = 7.5, n = 8) for the Korean group and 198 msec (SD = 6.9, n = 8) for the Japanese group (Figure 1). The PB for both groups was located between the Stimuli B and C, where the

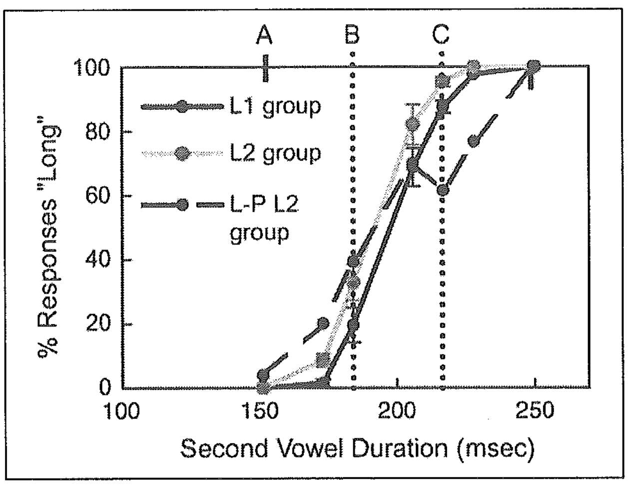

Figure 1. Identification rates of /mama/–/mama:/ continuum. Averaged responses of the L1 group (solid line), the L2 group (gray line), and the low-proficiency (L-P) L2 learners from the previous data (dotted line) are indicated. Durations of the second vowel of the Stimuli A through D are indicated in the graph. The phoneme boundary lies between Stimuli B and C. Error bars indicate one standard error of the mean.

slopes of the identification curve were the steepest. There was no significant difference in either the PB or the slope value between the Japanese and the Korean subjects (PB: $p = .072, t = 1.64$; slope: $p = .152, t = 1.11$). In the discrimination test, the two stimuli whose final vowel differed by 11 msec in length were presented sequentially in each trial. The subjects were asked to judge which of the two words had a longer final vowel. Discrimination functions (Figure 2) in both groups had the highest discrimination ratio in the across-category trial (BC) and poorer within-category discrimination (AB and CD).

The results of the behavioral identification and discrimination tests indicate that the L2 learners had acquired categorical percepts of Japanese long/short vowels that were indistinguishable from those of the L1 subjects. This result is also evident when the present subjects were compared with the low-proficiency learners (data analyzed from Minagwa-Kawai, 2000) who had never been exposed to Japanese before 16 years old (average learning period; 1.7 years, $SD = 1.2$) nor had ever stayed for more than 1 week in a Japanese-speaking environment. Their identification curve does not show as steep a change in the BC segment (Figure 1). There is a significant difference in the slope of the present high-proficiency L2 learners ($p = .008, t = 2.36$).

NIRS Results

Automatic change-detection responses were recorded in the L1 and L2 subjects by presenting them with baseline stimuli and deviant stimuli under three conditions, namely, Sessions AB, BC, and CD. All these conditions presented the baseline and deviant stimuli differing by the same length; however, only the stimulus pair under the BC condition had a phonemic length difference

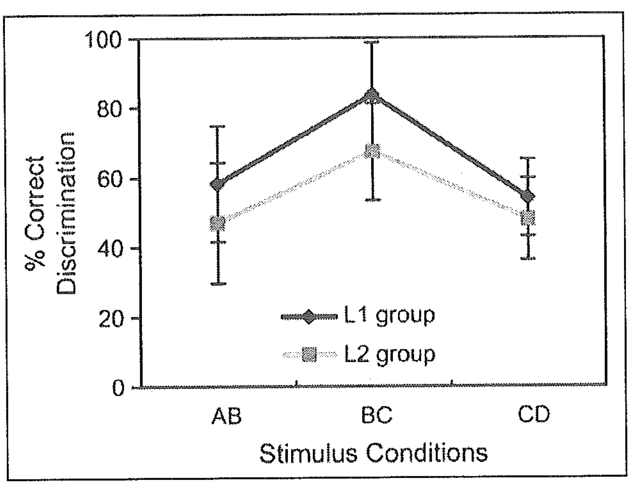

Figure 2. Average discrimination rate of /mama/–/mama:/ continuum. Both the L1 group (solid line) and the L2 group (gray line) show higher discrimination rates in the stimulus pair near the phoneme boundary.

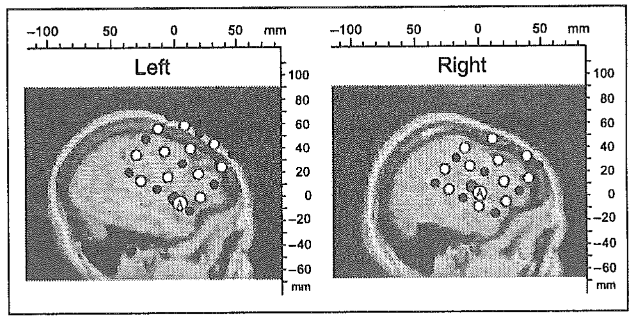

Figure 3. Locations of the NIRS probes and recording channels. NIRS probe positions (small white circles) and the centers of the measurement channels (white circles) are superimposed onto the parasagittal MR brain images. The lateral posterior borders of the Heschl's gyri are labeled "A." The channels with the maximal responses are shown with gray circles. Positive is towards the anterior and towards the vertex in the scales.

of the long/short vowels (across-category condition). Among the 12 recording sites on either side, the largest hemodynamic changes to the target block containing the deviant stimuli were most frequently observed in the auditory area (Figure 3), whereas the temporal and amplitude patterns of the recorded responses in the posterior frontal and inferior parietal areas (Figure 3) were smaller for all the subjects and varied considerably in both groups. The auditory channel on each side that presented maximal peak responses in the total hemoglobin (Hb) was chosen for statistical analysis. The averaged coordinates for the channels chosen were $y = -11.0$ ($SE = 2.9$) and $z = 11.5$ (2.2) on the left side and $y = -9.7$ (1.9) and $z = 8.9$ (5.6) mm on the right side for the Japanese group (only y and z coordinates are measured on parasagittal projection because the precise recording depths or x are not exactly known). Those for the Korean group were $y = -14.0$ ($SE = 1.6$) and $z = 9.9$ (2.7) on the left side and $y = -12.0$ (1.7) and $z = 11.7$ (2.4) mm on the right side with no statistical difference from those of the L1 group ($p > .3$). These areas are more superior and posterior to the lateral border between Heschl's gyrus

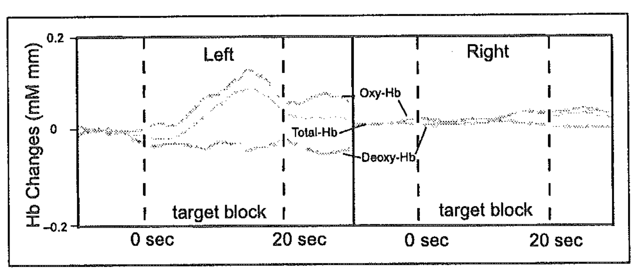

Figure 4. Time course of NIRS response in an L1 subject. The average total Hb changes in response to the phonemic contrast (BC) recorded at the left and right channels. A marked increase in Hb was observed 20 sec after the deviant stimulus was presented in the target block (vertical dotted line) in the left auditory channel.

and planum temporale (PT) in the superior temporal gyrus (STG), corresponding to BA 22 (part of Wernicke's area). The hemodynamic responses in those channels were observed to peak at 5–14 sec after the target stimulus onset (Figure 4). There was no significant difference in the peak latency for the L1 and L2 groups (L1: 9.7 sec, $SD = 3.1$; L2: 9.9 sec, $SD = 2.3$; $p = .45$, $t = 0.139$). Figure 5 shows the averaged peak responses of the total Hb to the target stimuli under the three conditions. For the Japanese subjects (L1), the across-category BC condition induced prominent responses compared with those in the within-category conditions, however, no such difference was observed for the Korean subjects (L2). A three-way analysis of variance, conducted with Conditions (AB, BC, and CD), Groups (L1 and L2), and Sides (left and right) as factors, revealed a significant Condition × Language interaction [$F(2,84) = 7.28$, $p = .0012$]. A post hoc test (Fisher's PLSD) indicated that this interaction was due to the BC condition in the Japanese group. That is, the hemodynamic change in the BC condition was significantly larger than that in the other conditions for the L1 group (BC vs. AB: $p = .0014$; BC vs. CD: $p = .0044$), whereas no significant differences were found among the three conditions for the L2 group. It should be noted that the lack of significant brain responses for the L2 listeners was not due to a measurement failure or artifacts, because the same L2 listeners showed significant brain responses to the Japanese (L2) phonemic contrast /a–e/, which is also a distinctive contrast in their native language (Minagawa-Kawai, Mori, Sato, & Koizumi, 2004).

The lateralization observed for this BC condition in the L1 group showed a significantly larger response in the left hemisphere than in the right ($t = 2.65$, $p = .016$). The laterality index calculated from the formula $(L - R)/(L + R)$, where L and R represent the peak total Hb changes in the left and right auditory channels, respectively, was 0.31 for the BC condition in the L1 group. The same indices for the AB and CD conditions were −0.33 and 0.04, and those for the AB, BC, and CD conditions in the L2 group were 0.03, 0.17, and −0.27, respectively. The only index that significantly differed from zero was that for the BC condition in the L1 group ($p = .01$, zero test).

The correlation between the behavioral test and the NIRS measurements was analyzed (Figure 6). The segmental slopes of the identification function reflect the sensitivity to the durational judgment. The representative data of one Japanese subject (Figure 6A and C) shows that the slope values of identification correlated to the peak hemodynamic changes under the three conditions of AB, BC, and CD ($r = .88$, $p < .05$). Conversely, the data of a Korean subject show no such correlation ($r = -.73$, $p > .05$) (Figure 6B and D), although this subject showed a typical categorical perception (CP) for the Japanese long/short vowel contrast, judging from the identification function. A similar tendency is also observed in the correlation between the discrimination ratios and the peak hemodynamic changes (Figure 6C and D). Correlation coefficients between the slope values in the identification functions and the hemodynamic changes, calculated from all the pooled data, were .51 ($p < .001$) for the L1 group and −.28 ($p > .05$) for the L2 group. The values for the discrimination scores were 0.57 ($p < .001$) for the L1 group and 0.07 ($p > .05$) for the L2 group.

DISCUSSION

Comparison of the hemodynamic responses to the long/short Japanese vowel contrast between L1 subjects and high-proficiency L2 listeners revealed differential patterns of activation. The L1 subjects showed larger responses in the left auditory area only for the across-category condition, even though each condition contained two stimuli differing by the same length. This suggests that the linguistic cerebral representation of the Japanese durational contrast is encoded in the left auditory area, which presumably corresponds to Wernicke's area (Figure 3). In contrast, the L2 group does not have such specific neural representations as the L1 group, because this group exhibits neither

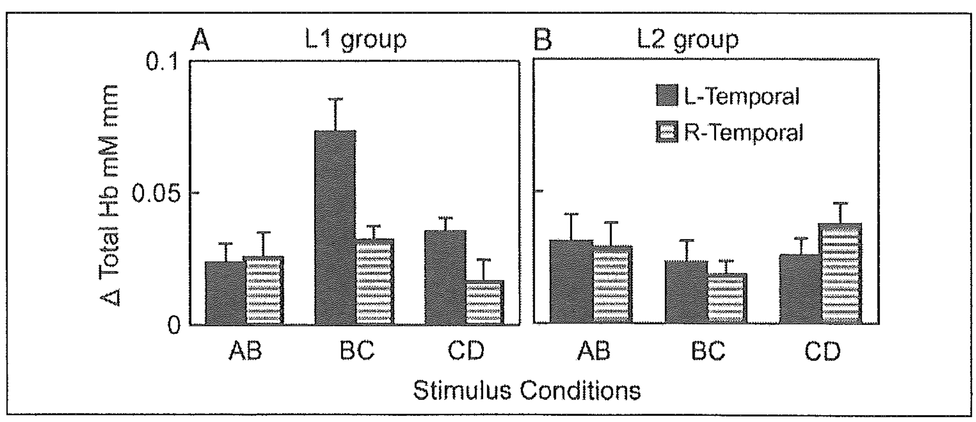

Figure 5. Averaged peak responses to durational contrasts. The total Hb changes for the L1 (A) and L2 (B) groups are indicated according to the three stimulus conditions (AB, BC, and CD). The responses in the left hemisphere (L, filled bars) and the right hemisphere (R, striped bars) are shown separately. Error bars indicate one standard error of the mean.

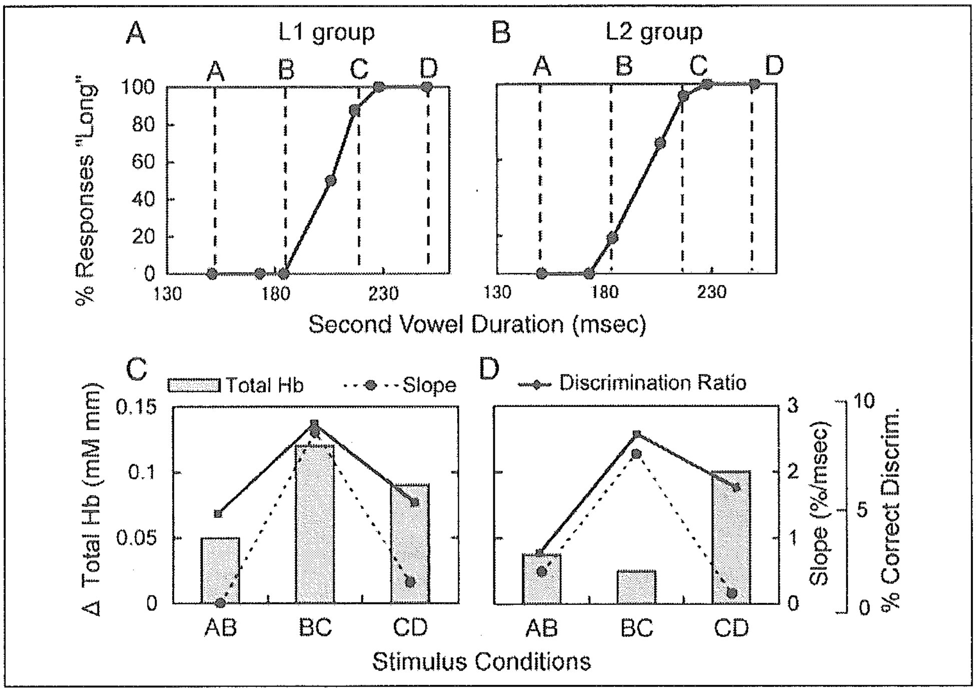

Figure 6. Correlation of behavioral tests and brain responses. Individual data of the L1 (A,C) and L2 (B,D) subjects are shown. Identification rate of /mama/–/mama:/ continuum and durations of the second vowel in the Stimuli A–D (dotted line) are indicated (A,B). The slopes of identification function between two stimuli for each condition and discrimination ratios (right axis) were plotted onto the total Hb responses in the left auditory area (left axis) (C,D).

category-specific nor left-dominant responses, but only small, nondifferential responses. The behavioral results of the identification and discrimination tests indicated that the L2 learners had acquired categorical percepts of Japanese long/short vowels that are indistinguishable from those of the L1 subjects. However, the correlation coefficients between the brain recording and behavior revealed inconsistency between the L1 and L2 groups. The identification slopes for the L1 group were well correlated with the peak amplitude of hemodynamic changes, whereas those for the L2 group were not. A reason for this discrepancy may lie in the response time for the behavioral test. Because the averaged latency to identify phonemic types was longer for the L2 group (586 msec) than for the L1 Japanese group (482 msec), it is likely that the L1 listeners could identify long/short vowels more promptly (p = .039, t = 2.11) with the use of linguistic neural representations encoded in the left auditory area. This was indicated by the cortical hemodynamic response exclusive to the across-category stimuli. The L2 listeners' longer latency suggests that their cortical processes for it were different and less efficient than that of the L1 subjects, due to the apparent lack of native-like phoneme representations in the Wernicke's area. These results indicate that the behavioral scores of the L2 listeners, indistinguishable from those of the L1 listeners, did not predict language-specific cerebral processing, which is recruited by the L1 listeners.

Although the hemodynamic responses to the contrastive stimuli were observed similarly as previous studies with fMRI and PET (Schall, Johnston, Todd, Ward, & Michie, 2003; Tervaniemi, Medvedev, et al., 2000), they could result from any difference in the stimuli, such as duration and intensity in ERP and MEG studies (Todd & Michie, 2000; Tervaniemi, Lehtokoski, et al., 1999). The similar levels of responses in all conditions, except under the BC in L1 subjects in the left, are most likely due to the physical durational contrast of the same amount (33 msec) across conditions, as well as its concomitant changes in the average level. On the other hand, the timing differences of the stimulus onsets and offsets, rather than duration, should not have contributed to the results because hemodynamic measurements cannot resolve timings of less than 1 sec (Watanabe, Yamashita, Maki, Ito, & Koizumi, 1996). The increased left responses only under the BC condition as observed in the L1 subjects are attributable to experience- or language-dependent neural memory traces for phonemes of the native language (Näätänen et al., 1997), because the largest responses were evoked specifically by the contrast which had a phonemic difference and only in the L1 group. The larger and more leftward responses in the L2 subjects to one of their native phonemic contrasts (Minagawa-Kawai, Mori, Sato, et al., 2004) are consistent with this view, and together highlight the lack of phoneme-specific brain responses to the L2 contrast in this group. The peak activations found in our study were slightly superior and posterior to the lateral boundary between Heschl's gyrus and the PT in the STG, from which Jacquemot, Pallier, LeBihan, Dehaene, and Dupoux (2003) also observed strong activations associated with the processing of phonological grammar. The present results would also support the view that the PT relates to the language- or experience-dependent phonological processing, in addition to the general acoustic processing (Jacquemot et al., 2003; Scott & Johnsrude, 2003).

Listening to stories in L1 is shown to consistently activate the left temporal lobe (Perani, Paulesu, et al., 1998; Dehaene et al., 1997; Perani, Dehaene, et al., 1996; Bottini et al., 1994). A cross-language study using PET (Perani, Paulesu, et al., 1998) showed that high-proficiency bilinguals did not differ in their cortical activation between L1 and L2 listening, regardless of their age at the time of L2 acquisition. However, differences were reported in the cortical activities of the low-proficiency L2 learners while listening to L1 and L2 stories (Perani, Dehaene, et al., 1996; Dehaene et al., 1997). In those subjects, variable activations from complete right-lateralization to weak left-lateralization were demonstrated during L2 story listening (Dehaene et al., 1997). This inconsistent lateralization pattern may be similar to that observed in our study for the L2 learners in their responses to the across-category stimuli. However, because listening to a story involves phonological, semantic, and syntactic processing plus prosodic feature decoding, the observed variable brain activations (Perani, Paulesu, et al., 1998; Dehaene et al., 1997; Perani, Dehaene, et al., 1996; Bottini et al., 1994) could have resulted from the variance in any or all of those linguistic processing levels. Although the activation at the individual levels for L1 processing has already been studied with functional brain mapping (e.g., Friederici, Ruschemeyer, Hahne, & Fiebach, 2003; Bookheimer, 2002), similar analytical work has been sparse for the L2. The present work revealed the brain activation related to a specific level of linguistic perception (i.e., L2 phonemes), which turned out to be different from that for L1. This in turn explained, at least partially, the variable brain activity regarding L2 story listening and further showed a discrepancy between brain activation and behavior. These results suggest that the neuronal substrates for L2 processing could be even more complicated and interesting by considering respective linguistic levels than shown previously.

The identification and discrimination tests, known as the CP paradigm (Strange, 1995), have been employed by cross-language behavioral researches to empirically verify the perceptual discontinuities of CP by evaluating the slope of the identification function, the phonemic boundary, and the discrimination peak. The conceptual definition of CP was that discrimination of certain speech sounds would be limited by classification (identification); thus, two different stimuli could be discriminated solely to the extent that they are classified differently (Liberman, Harris, Hoffman, & Griffith, 1957). This translates to the discrimination rate profile of pairs of sounds differing by a constant physical amount that peaks around the phonemic boundary of CP, as was observed in the present behavioral results. Although it is now widely accepted that CP is not specific to human speech perception (Dooling, Okanoya, & Brown, 1989; Kuhl & Miller, 1975; Locke & Kellar, 1973), the identification and discrimination tests and some variations of these tests (Beddor & Gottfried, 1998) are still used as the basic methods for examining whether L2 learners acquire L2 phonemes. This is partly because CP is rarely observed in the perception of untrained L2 phonemes. However, the neuronal correlates of behavioral results given from these measures have not been thoroughly examined as yet. The present study revealed that the behavioral identification and discrimination scores that are identical to the natives do not always indicate an involvement of language-specific cerebral processes as employed by the native listeners.

In the current experiment, the CP of the L2 contrast was achieved even though L2 listeners recruited a neural circuit different from that of the L1 listeners. This is partly due to the artificial experimental situation wherein L2 listeners were required to identify phonemes in an isolated word. However, such a circuit, which requires longer latency, may not be efficient enough in processing L2 phonemes that are contained in continuous running speech in actual conversation. This may explain a fact well known to Japanese instructors, that is, distinguishing and producing Japanese long/short phonemic contrasts is challenging even for the high-proficiency learners (Minagawa-Kawai, Maekawa, et al., 2002; Toda, 1994; Han, 1992).

The current study revealed the differential relationships between the behavioral scores and cerebral representations of a Japanese vowel contrast for L1 listeners and proficient late L2 learners. The behavioral scores and the corresponding NIRS responses showed a clear correlation only in the L1 group. Along with the longer latency in identifying phonemes for the L2 group, a cerebral processing strategy that was probably different from that of the L1 group was proposed. The findings suggest that a language-specific neural processing as employed by the native listeners is only predictable when L2 listeners are assessed by neurophysiological measures in addition to the observations of the CP evaluated by the conventional behavioral tests.

METHODS

Subjects

Eight Korean subjects who had been learning Japanese (3 men and 5 women, 27–40 years, mean age: 32 years, *SD* = 4.3) and eight native speakers of standard Japanese (3 men and 5 women, 28–39 years, mean age: 31 years, *SD* = 4.3), who grew up in the Tokyo area, participated in the NIRS recording after giving their written informed consent. Some of the subjects were the same as those reported in the previous study (Minagawa-Kawai, Mori, Sato, et al., 2004; Minagawa-

Kawai, Mori, Furuya, et al., 2002). All the subjects had normal hearing and were right-handed according to the Edinburgh inventory (Oldfield, 1971). Although four more subjects participated in a pilot experiment with different stimuli, they were not included in the present subjects because cerebral activations could not be steadily measured from some channels.

The present Korean subjects were judged as high-proficiency, late-acquisition, second-language learners (bilinguals), according to the criteria employed by Perani, Paulesu, et al. (1998), Kim et al (1997), and Perani, Dehaene, et al. (1996) in terms of language exposure, education, and residence in an L2 environment. They started learning Japanese after 24.6 years (*SD* = 3.2) on average and were highly proficient in Japanese with an average learning period of 7.6 years (*SD* = 4.1). They had been living in Japan for more than 3 years (average: 5.4 years, *SD* = 2.5) during which time they used Japanese in their daily communication. Five of the subjects were graduate students of the University of Tokyo and the others were employees of Japanese companies at the time of the experiment.

Procedures

The changes in Hb concentration and its oxygenation level in the bilateral temporal areas and infero-posterior frontal and lower parietal lobes were measured with a 24-channel NIRS system (ETG-100, Hitachi Medical, Japan). The NIRS system emits continuous near-infrared lasers whose wavelengths are approximately 780 and 830 nm, modulated at different frequencies and detected with the sharp frequency filters of lock-in amplifiers (Watanabe et al., 1996). It can assess localized cortical responses with 24 channels closely arranged two-dimensionally and recorded simultaneously. The temporal resolution of the NIRS system is 1–2 sec (Watanabe et al., 1996) after a hemodynamic latency of approximately 2 sec (Malonek & Grinvald, 1996). The recording channels exist in the brain's optical path, between the nearest pairs of emission and detection probes, which were separated by 3 cm on the scalp surface. This separation enables us to measure hemodynamic changes in the brain 2.5–3 cm deep from the head surface, which corresponds to the gray matter on the outer surface of the brain (Fukui, Ajichi, & Okada, 2003). Five emission and four detection probes arranged in a 3 × 3 square lattice were fitted on each lateral side of the head. This resulted in a total of 12 recording channels on either side. After the optical measurement, the positions of the optical probes were recorded with a three-dimensional digitizer (Polhemus, Colchester, Vermont). The 3-D coordinates were superimposed onto T1-weighted MR brain images for each subject to identify the centers of recording sites (Figure 3). T1-weighted anatomical images were acquired in 80 contiguous axial slices with thickness of 2.0 mm using a 1.5-T scanner (Excelart, Toshiba Medical, Japan) (repetition time/echo time [TR/TE] 15/3.4 msec, flip angle [FA] 20°, matrix 256 × 192, field-of-view [FOV] 22 × 22 cm). The channels close to the lateral end of the border between the transverse temporal gyrus and the PT, as projected onto a parasagittal MRI, were presumed to be the "center" of the auditory area. This procedure selected the recording channels whose centers were within a 1.5-cm radius of the abovementioned border; thus, the channels should include the signals in the auditory cortex due to the spread of the laser in the brain tissue (Yamashita, Maki, & Koizumi, 1996). The averaged coordinates of the center of the auditory area as defined above were $x = -63.2$ (*SE* = 1.4), $y = -7.2$ (2.5), and $z = 5.0$ (1.5) mm in the left side and $x = 62.0$ (1.3), $y = -5.8$ (3.8), and $z = 3.9$ (1.6) mm in the right side (Figure 3), where positive y is to the anterior, and z is superior (coordinate system of Talairach and Tournoux). There were no statistical significant differences between the two groups.

Stimuli

Pseudoword stimuli consisting of two "ma" syllables were synthesized to obtain a low–high pitch pattern (a Japanese unaccented pattern) with a stable pitch contour and steady formant structure in the final vowel by a PARCOR (partial autocorrelation) analysis–resynthesis procedure (Markel & Gray, 1976) with Onsei-Rokubunken (Imagawa & Kiritani, 1989; Datel, Japan: www.datel.co.jp/onsei/). The original speech source for the analysis–synthesis was recorded by a female Japanese speaker. The long/short target vowel was set at the final position, where nonnative speakers find it most difficult to identify phonemic length (Minagawa-Kawai, Maekawa, et al., 2002). The first syllable was 110 msec and intervocalic /m/ was 90 msec. The acoustical parameters including pitch and duration were determined from the results of a word production experiment performed beforehand with seven native standard Japanese speakers. The averaged segment durations of /mama/ and /mama:/ words were as follows: the first syllable /ma/ = 113 msec, the second consonant /m/ = 92 msec, the final short vowel /a/ = 129 msec, and the final long vowel /a:/ = 313 msec. The duration of the final syllable is set to more than twice of that of the first syllable, because the word-final syllable are 1.5–2.5 times longer in duration than the nonfinal ones universally in any languages (Hoequist, 1983; Klatt, 1976), including Japanese (Minagawa-Kawai, Kagomiya, & Maekawa, 2003), particularly in an isolated word context. Four stimuli (A–D) differing in the final vowel duration in 33-msec steps were selected from the /mama/ to /mama:/ continuum. The durations of the final vowels were 151 msec (A), 184 msec (B), 217 msec (C), and 250 msec (D). Because a pilot behavioral experiment showed that the phonemic boundary of long and short vowels was located between Stimuli B and C, the across-category condition included the B and C stimuli, and the two within-category conditions included A and B, and C and D stimulus pairs. In Session AB (a within-category condition), Stimulus A was repeated for 20 sec as a baseline block. Then, Stimuli A and B were presented in a pseudorandom order with equal probabilities of another 20-sec period as a target block with an SOA of 1.25 sec. The baseline and target blocks were alternated and repeated at least five times. Similar procedures were carried out for Sessions BC (an across-category condition) and CD (a within-category condition). These three sessions and the two extra sessions for the other experiments were assigned to each subject in a random order. The subject seated in a chair was instructed to listen to the stimuli delivered through insert earphones (EarTone 3A) at a comfortable level (≈70 dB SPL).

Behavioral Test

The subjects participated in identification and discrimination tests of Japanese long/short vowel categories after the NIRS recording. The stimuli used in the identification test were the same pseudowords A–D as that in the NIRS recording and the three extra stimuli whose second vowels were 173, 206, and 228 msec in duration. The subjects were instructed to listen to these stimuli repeated 16 times each (Jamieson & Morosan, 1986; Fujisaki, Nakamura, & Imoto, 1985) in random order played back by a PC through a pair of headphones. They were asked to decide whether the second vowel was a long vowel or not. In the discrimination test, the two stimuli, whose final vowel duration differed by 11 msec, were presented sequentially in each trial (interstimulus interval = 500 msec), and the subjects were asked to judge which of the two words had a longer final vowel. The durations of the final vowels for the pseudoword pair used were 151 msec (A) versus 162 msec, 184 msec (B) versus 195 msec, 206 msec versus 217 msec (C), and 239 msec versus 250 msec (D). These were repeated 14 times in random order (Fujisaki et al., 1985; Jamieson, & Morosan, 1986), and the stimulus order within each pair was balanced to avoid a positional effect. The response time was measured in both tests. The PB between the long and short vowels was defined as the vowel length, where the fitted identification curve crossed 50% of the responses "long." The curve was fitted by the least square method.

Data Processing

The concentrations of oxygenated, deoxygenated, and total Hb were calculated from the absorbance changes of 780 and 830 nm laser beams sampled at 10 Hz. After discarding the blocks with artifacts, the Hb concentrations of the remaining blocks were averaged five or six times synchronously to the target blocks and smoothed with a 5-sec moving average. The response peaks of the averaged target blocks were measured against the 10-sec pre-stimulus period.

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