Cohort Studies on Language Acquisition, Brain Development and Language Education

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1. ackground and Objectives

A foreign language is very difficult to master completely, despite its ever-increasing importance in the era of globalization. For the last few decades, there has been continuously a heated-discussion on early foreign language education in Japan on the government as well as among the society. Unfortunately, however, no reliable evidence has been found. We aimed at investigating native language (L1) and foreign language (FL) acquisition mechanisms in relation to brain development and functional plasticity of the brain, particularly focusing on pre-school and school-aged children, and hoped to provide scientific bases for educational policy-making and classroom practice.

2. Cohort studies of foreign language learning in elementary school children using ERP and fNIRS

2.1 How we established a brain-imaging cohort project at elementary schools in Japan

Foreign-language (FL) education in childhood is of outstanding social interest. Recent technology can visualize how education triggers brain events underlying FL learning. Previous neuroimaging studies usually test 20 or so participants but making an educational decision based on such a small sample may be risky. It is, therefore, crucial to collect as many data as possible to get a good grasp of the situations as well as to construct firm scientific bases. For this purpose, we conducted experiments on event-related potentials (ERP) and functional near-infrared spectroscopy (fNIRS) at the children's own schools, using our original neuroimaging vehicle. We invited hundreds of children for experiments in an attempt to bring neuroimaging to the level of social research. The large number of data also serves to reveal subtle effects of FL education in the presence of large individual variations.

2.2 The consolidation of word processing during pre-adolescence: A 3-year longitudinal ERP study

For rapid use of language, linguistic knowledge such as words must not only be newly acquired, but also be consolidated through repetitive use. We used ERP technique, which has high temporal resolution, to study the developmental changes in the speed of single-word processing. ERP data were acquired from Japanese primary school children in a longitudinal design. In the experiment, the children watched a picture and listened to a subsequent word (high-frequency Japanese word), which in some cases mismatched the preceding picture in meaning. We analyzed the timing of the onset of the mismatch response and assessed whether this timing became earlier after two years in the same individuals. One group of children (N = 40) who had initially been around 7 years of age demonstrated a shortening of the response onset by about 70 milliseconds two years later (when they were around 9). Another group of children (N = 40) who had initially been around 9 did not show such changes two year later (when they were around 11). The responses of both groups of children at age 9 or older were already equivalent to those of university students. These results support the view that the consolidation of the cortical mechanism of single-word processing is in progress at least until around age 9. Factors such as the maturation of the brain, daily repetitive use of language, and sharpening of phonological awareness by the acquisition of reading, might interact to result in such neuro-cognitive development (Ojima, et al., submitted a).

2.3 Neural correlates of foreign-language learning in childhood: A 3-year longitudinal ERP study

A foreign language (a language not spoken in one's community) is difficult to master completely. Early introduction of FL education during childhood is becoming a standard in many countries. However, the neural process of child FL learning still remains largely unknown. We longitudinally followed 322 school-age children with diverse FL proficiency for three consecutive years, and acquired children's ERP responses to FL words that were semantically congruous or incongruous with the preceding picture context. As FL proficiency increased, various ERP components previously reported in mother-tongue (L1) acquisition (such as a broad negativity, an N400, and a late positive component) appeared sequentially, critically in an identical order to L1 acquisition. This finding was supported not only by cross-sectional analyses of children at different proficiency levels but also by longitudinal analyses of the same children over time. Our data are consistent with the hypothesis that FL learning in childhood reproduces identical developmental stages in an identical order to L1 acquisition, suggesting that the nature of the child's brain itself may determine the normal course of FL learning. Future research should test the generalizability of the results in other aspects of language such as syntax (Ojima et al., to appear).

Furthermore, we analyzed 814 ERP data sets obtained repeatedly from 350 children of 6 to 11 years of age. In particular, we assessed the effects of age of first exposure (AOFE) to the FL, period of exposure (POE), hours of exposure (HOE), and the common logarithm (log10) of HOE, on children's ERP responses to FL words in semantic contexts. Regression analyses showed that ERPs were most closely related to the log10 of HOE, among the factors studied. HOE itself and POE had weaker effects, whereas AOFE had no statistically significant effects. These neuroimaging data illuminate how the hidden process of FL learning in the child's brain is affected by daily FL activities in real life (Ojima, et al., submitted b).

2.4 Sound to language: Different cortical processing for first and second languages in elementary school children as revealed by large-scale study using fNIRS

Recent neuroimaging studies have traced the neural development of language acquisition during childhood. Previous studies, though small in size, have successfully uncovered temporal dynamics of language/speech processing with age, but cortical functions of the normally developing brain remain largely unknown due to technological limitations. Thus, using fNIRS, we have conducted a large-scale study of elementary school children performing word repetition tasks in their native language (L1) and a second language (L2). While no difference in brain activation was seen irrespective of language, word-frequency, or hemisphere in early auditory cortices, significant differences were observed between languages (L1 vs. L2), hemispheres (left vs. right), and word-frequencies (low vs. high) in the posterior language areas and in Broca's area. These results suggest that small differences in "acoustic processing" initially derived from low-level non-domainspecific processing are enhanced at subsequent stages of “language processing” and exhibit higher-level functional specializations. Our results exemplify the strong involvement of a bilateral-language-network in children’s brains at the early stages of language acquisition/learning. Left-hemispheric segmental and right-hemispheric supra-segmental information processing are presumed to be executed in parallel, and children might depend more on supra-segmental processing while acquiring unfamiliar words (Sugiura, et al., submitted).

2.5 Second-language learning and functional changes in brain activity ― A large-scale study of elementary school Children using fNIRS ―

Technical innovations for measuring brain activity enable us to demonstrate the neural basis of language learning. By means of fNIRS, we have conducted a large-scale study enrolled approximately 500 elementary school children to study how the brain changes functionally as a result of learning. Single word repetition tasks in their L1 (Japanese) and L2 (English) were employed. The similar pattern of cortical activation between L1 and L2 seen in the close pairs of languages was confirmed in the higher L2 proficiency group in our study which examined a pair of quite different languages both phonetically and linguistically. Children recruited bilateral language-network for the word processing and seem to depend more on the right-hemispheric supra-segmental processing on the process of acquiring unfamiliar words. Cortical activations associate with L2 proficiency were observed in the parietal and prefrontal regions, most notably in the left angular gyrus, at the early stage of formal classroom L2 learning. The present results suggest that the attained proficiency is one of the principle determinants of the cortical representation of L2 and that the left angular gyrus appears the site of language competence. Also, L1 and L2 showed distinct difference in functional changes with proficiency. Brain activation increased with L2 proficiency, while it decreased with L1 proficiency. The difference in proficiency-related functional changes in L2 and L1 is accountable by two different information-processing operations, “controlled search” and “automatic detection”. The sequence of appearance of proficiency-related functional changes in the brain regions is likely to follow the sequence of functional maturation or the cortical development. The function of parietal region might develop by experience and learning in early school-age, after the maturation of lower-level functions. In addition, we have not so far observed any adverse effects of learning L2 by children at early school age on their first language, instead, behavioral benefits were observed both in their L1 and their L2 performance (Sugiura, et al., to be submitted).

3. Native and non-native language processing in pre-school children: ERP and fNIRS studies

3.1 Effects of non-native language activities on the semantic processing of native language in preschool children: an ERP study

We investigated the effects of non-native language activities (English) on ERPs among first-, second-, and third-year preschool native speakers of Japanese while they listened to semantically congruent and incongruent Japanese sentences. The children were divided into high non-native language activity group and low non-native language activity group based on their exposure to non-native language activity. We compared the ERPs recorded from high- and low-groups each of first-, second-, and third-year preschoolers. N400 was observed in all first-, second-, and third-year preschoolers; furthermore, late positive components (LPC) were observed only the third-year preschoolers. Differences owing to the children’s exposure to non-native language activities were not observed in the first- year preschoolers but were observed in the second- and third-year preschoolers. In the second-year preschoolers, the latency of the N400 in the high-group was shorter than that of the low-group, whereas the duration of the N400 in the high-group was longer than that of the low-group. Furthermore, in the third-year preschoolers, the duration of the LPC in the high-group was longer than that of the low-group. These results showed that the time course of the semantic processing for native-language sentences varied depending on the preschooler's exposure to non-native language activity (Takahashi, et al., submitted).

In addition, we also conducted the experiments with children attending an early FL (English) immersion program for the duration of three years, beginning from the initial stages of the FL immersion program (5–7 years old). The experimental paradigm was the same as that of Takahashi, et al. (submitted). The results showed that for all the age groups the N400 was elicited and it was followed by a late negativity that distributed over the right hemisphere. The ERP responses exhibited a longer N400 latency than that of our previous results wherein children were less exposed to FL and showed a discontinuous progress in the time course and distribution of the ERPs for the duration of three years. Our results suggest that the semantic processing of L1 sentences in children enrolled in an early immersion program may progress in a different manner from those of monolingual children since their exposure to FL (Suzuki, et al., submitted).

3.2 Changes in brain activity for second language processing among preschoolers

We investigated the brain activity in 3–5 year-old preschoolers as they listened to connected speech stimuli in Japanese (first language), English (second language), and Chinese (rarely exposed, foreign language) using fNIRS. Unlike the younger preschoolers who had been exposed to English for almost one year, the brain activity in the left hemisphere of the older preschoolers who had been exposed to English for almost two years was higher for Japanese and English speech stimuli than for Chinese. This tendency was consistent with that observed in adults who had learned English for some years. These results indicate that the changes in brain activity for a second language occur in the early developmental stage among preschoolers, in accordance with individual proficiencies of second language processing (Hidaka, et al., submitted).

4. Second language instinct and instruction effects: Nature and nurture in second language acquisition

Adults seem to have greater difficulties than children in acquiring a second language (L2) because of the alleged "window of opportunity" around puberty. Post-puberty Japanese subjects learned a new English rule with simple sentences during one-month of instruction, and then they were tested on "uninstructed complex sentences" as well as "instructed simple sentences". The behavioral data show that they can acquire more knowledge than is instructed, suggesting the interweaving of nature (universal principles of grammar, UG) and nurture (instruction) in L2 acquisition. The comparison in the "uninstructed complex sentences" between post-instruction and pre-instruction using fMRI reveals significant activation in Broca's area. Thus, this study provides new insight into Broca's area, where nature and nurture cooperate to produce L2 learners'rich linguistic knowledge. It shows neural plasticity of adult L2 acquisition, arguing against the critical period at least in the domain of UG (Yusa, et al., submitted).