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Common Versus Unique Findings on Processing-Based Task Performance in Korean Speaking Children With Cochlear Implants

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Hypothesis: To better understand individual variability by examining overall neurocognitive underlying features in children with cochlear implants (CIs), and to investigate whether previous findings hold constant in Asian-language users.
Background: Studies have tried to explain the individual variability in children with CIs. However, performance on experience-dependent tasks does not seem to be sensitive enough to explain the underlying reason why children have language difficulties even after the surgical procedure. Thus, this current research has focused on underlying neurocognitive functions to better explain the reason for the wide variability in this population.
Methods: Using a separate univariate analysis paradigm, performance on processing-based tasks was compared between children with CIs and children with normal hearing. A total of 34 children ranging from 10 to 12 years old participated in the study. There were two different categories of processing-based tasks tapping processing capacity and processing speed. This study used nonword repetition (NWR), competing language processing task (CLPT), and counting span (CS) for examining processing capacity, while rapid naming (RAN) in color, shape, and color shape were used to investigate processing speed.
Results: Children with NH outperformed children with CIs on all processing-capacity tasks, except CS. Children with CIs performed similarly to children with NH on processing speed tasks.
Conclusions: We found children with CIs still experienced difficulties with processing capacity. Due to cross-linguistic features, we also discovered some interesting findings that differed from previous studies. Lastly, we found processing speed was fairly intact in children with CIs, which is a new finding. **Key Words:** Children with CI—Neurocognitive function—Processing capacity—Processing speed—Working memory.

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Individual variability has been the key word in research on early deprivation of auditory input followed by cochlear implants (CIs). Studies have suggested that conventional devices, demographics, and audiological measures cannot fully explain speech and language outcomes in children with CIs (1). Past research has focused on ''language knowledge,'' such as vocabulary size on standardized assessment tools, which are heavily based on children's life experiences (2). However, performance on experience-dependent tasks, such as standardized measurements, does not seem to be sensitive enough to explain the underlying reason why children have language difficulties even after the surgical procedure.

Thus, the current research focused on underlying neurocognitive functions to better explain the reason for the wide variability in this population (3). Increasing theoretical importance on underlying cognitive constructs has led our attention to assessment tools, which emphasize the cognitive-linguistic underpinnings of so-called processing-based tasks. Processing-based tasks deemphasize the role of previous knowledge or experience by using linguistic or nonlinguistic units. They are either equally familiar to participants (e.g., high-frequency vocabulary) or equally unfamiliar to participants (e.g., nonsense words that do not exist in the test language) (4). The idea is to level the playing field and minimize the role that previous language experience may have on performance (2).

When individuals process information, three components are critical factors: energy, space, and time (5). Energy and space are often considered a part of working memory, while time is often discussed in terms of processing speed. Many studies have investigated working memory in children with CIs (6–8). These studies support the hypothesis that language and information processing abilities are tightly linked and can even be good predictors of language outcomes later in life (3). Among the many processing-based tasks, digit span (DS) and nonword repetition tasks (NWR) have been widely studied in children with CIs, as they are sensitive in

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identifying children at high risk for poor performance (6,7,9).

Recent research findings suggest that children with CIs lack in working memory span, yet these findings are solely based on specific tasks, such as NWR or DS. For example, Pisoni et al. (3) examined DS and verbal rehearsal speed in children with CIs. The study found these children still performed lower than normal hearing children, even 10 years after implantation. Other studies have concluded that even though children with CIs have made rapid and remarkable progress in their abilities to learn spoken language, they still fell one standard deviation (SD) behind their age-matched peers with normal hearing (NH) on processing-based tasks (1,10). As seen above, while many studies have investigated working memory in children with CIs, there are a limited number of studies examining both working memory and processing speed within the same participants.

Thus, in this study, we examine how children with CIs perform on a range of processing-based measures. These measures are widely used in literature identifying language impairment and making comparisons to children with NH. Additionally, both working memory and processing-speed tasks are used to measure children with CIs' information processing abilities. These measurements are compared with those of children with NH. As mentioned above, processing limitations can be considered from the perspectives of memory and time per se, and both these limitations are not identical; rather, they are separable (11). Thus, to accurately identify the reason for individual variability in children with CIs, it is important to test both working memory and processing speed on a range of processing-based tasks.

For this study, we focused on processing abilities in children with CIs. The processing-based working memory tasks are NWR, competing language processing task (CLPT), and counting span (CS). The processing-speed tasks are rapid naming (RAN) in color, shape, and colorshape.

The first research question concerned finding whether children with CIs perform similarly to children with NH on a range of processing-based tasks. It is expected that since tasks are all processing-based tasks, children with NH may outperform on all tasks. However, from a theoretical standpoint, processing speed and working memory are different systems. Thus, children with CIs may perform differently depending on the task type, as compared with children with NH.

The second research question concerned examining whether findings were in line with previous literature. For example, NWR and DS are known to be accurate identifiers and have clinical usefulness in the assessment of children with CIs (12). However, most of these studies were conducted using English-speaking children, and results could vary in Asian-speaking children with CIs. Variation is possible because NWR and DS are influenced by socioeconomic status, age, and culture (13,14). For example, a study found that NWR in Mandarin was not sensitive to identify language impairment in children, which was different from findings in English-speaking children (15). Thus, we may find different results from previous studies due to the test and participants' language being Korean.

MATERIALS AND METHOD

Children with CIs met the following criteria: 1) having received cochlear implants before the age of 4; 2) having used CIs for a minimum of 1 year; 3) having a nonverbal intelligence quotient (IQ) was 85 or greater, as measured by the Korean Kaufman Assessment Battery for Children (16); 4) not having any additional disorder. Parents provided information about their children's age of implantation (AOI) and duration of implantation (DOI). Table 1 shows the demographic information for participant children with CIs.

Children with NH were age-matched with the children with CIs (±5 mo) and were typically developing. Children with NH met the following criteria: 1) having passed a hearing screening test (pure tone presented at 20 dB at 1, 2, 4 kHz); 2) having a nonverbal IQ of 85 or greater, 3) not having any history of hearing loss, speech impairment, or cognitive or motor disorder.

This study tested a total of 34 children: 17 children with CIs (mean age = 133 mo, SD = 11 mo, AOI = 59.1 DOI = 98.1) and 17 children with NH (mean age = 136 mo, SD = 16 mo). Their ages ranged from 10 to 12 years old. The mean nonverbal IQ for the children with CIs was 111.2 (SD = 11.6), and the mean for the children with NH was 115.8 (SD = 11.1). There were no significant differences between the two groups in terms of age and nonverbal IQ.

TABLE 1. *Demographic characteristics of children with cochlear implants*

Patient No.	Age (in mo)	Age of CI Implantation (in mo)	Duration of Implantation (in mo)	Communication Mode
1	138	40	98	Oral
2	134	33	101	Oral
3	124	22	102	Oral
4	125	22	103	Total
5	128	40	88	Total
6	134	37	97	Oral
7	113	30	83	Oral
8	143	66	77	Total
9	130	16	114	Oral
10	157	48	109	Oral
11	136	22	114	Oral
12	144	60	84	Total
13	114	36	78	Oral
14	118	18	100	Oral
15	149	48	101	Oral
16	152	60	92	Oral
17	176	48	128	Oral

Total = accepting sign language with dominant use of oral language. CI indicates cochlear implant.

STIMULUS

Nonword Repetition (NWR)

The NWR task used in a previous study was used for this study (17,18). A native Korean speaker recorded the 20 nonwords onto a minidisk. Each child was tested individually in a quiet room. The task was administered via free-field speakers. The child was told that he or she would hear some ''made-up words'' and was asked to listen carefully and repeat them exactly as they were heard. The two practice items were presented before the test began. A trial was repeated once if the child's response was incorrect. No feedback was given on test items, but encouragement was given as required. Each experimental item was presented only once. The nonwords were presented in order of increasing difficulty (all 2-syllable nonwords, followed by 3-syllable nonwords, etc.). All responses were recorded verbatim and an audio was recorded for later transcription. The dependent variable for NWR was the accuracy at the phoneme level.

Competing Language Processing Task (CLPT)

Children were instructed to recall the sentence-final word in a series of sentences after judging the true validity of each sentence. The task had six conditions, with two groups of sentences at each condition. The number of sentences in a group ranged from 1-to-6 across conditions, for a total of 42 test sentences. Thus, there was one sentence in condition 1, two sentences in condition 2, and so forth. Each sentence was three words long and contained vocabulary designed for all children to understand.

For example, at the second level, children would hear ''Pumpkins are purple.'' They would then be instructed to answer ''yes'' or ''no'' regarding the truth of the sentence. Children would then hear ''Buses have wheels,'' and again make a yes/no judgment. Children would then be asked to recall the two last word of each sentence (purple, wheels). The yes/no judgments were used to ensure that the task required online processing, as well as recall. This task was developed as the Korean version to an English version used in a previous study (19,20). For the Korean version, sentences followed a strict word order of ''subject + object + verb.'' Thus, the last word to recall was a verb instead of an adjective/noun, as in the English version. The responses to CLPT were scored as percentage correct for comprehension (yes/no answers) and recall (word recall). The order of word recall did not have to match the sequence of sentence presentation.

Counting Span

Children were tested individually, in a quiet room, and by a trained experimenter. To complete the task, children sat in front of the computer, beside the experimenter, and viewed a series of white screens. Each screen contained three-to-seven target dots, colored green, and twice as many distracter dots, colored yellow. The dots were oval-shaped and approximately 2 cm high × 1.25 cm wide. To limit subvocal rehearsal, children were instructed to count the number of green dots on the screen aloud in Korean, pointing to each dot as it was counted. They were also told that at the end of a set of screens, they would be asked to recall aloud in Korean the number of green dots they counted on each screen in the group. The end of the set was signaled by a screen with an image of a stoplight on it. Children were told they could recall the numbers in any order.

Children first completed two practice sets; each practice set contained two screens of dots. During the practice sets, the experimenter assisted children as necessary to ensure that they understood the task. Once the practice sets were completed, children were told they would begin the experimental task and the experimenter would no longer be able to help them.

The 15 experimental sets consisted of three sets at each of the five levels, presented in increasing order of difficulty. Each level contained one-to-five screens to be recalled. Every child completed all levels, regardless of his or her performance. During the task, the experimenter advanced to the next screen of dots as quickly as possible to discourage a child from silently rehearsing previous screens. The examiner recorded both the number of dots a child counted on each screen and the numbers recalled at the end of the group, in the order that they were recalled. Unlike Case et al.'s (21) administration, children were not timed in any portion of this task, as the variable of interest was not counting efficiency.

Rapid Naming

Children were to name all items from left-to-right, and were asked to label its shape (circle, triangle, square, or star), color (yellow, red, green, or blue), and then shape plus color (e.g., red circle). A total of 36 items were outlined into six stimuli in each row. All test procedures were executed after the practice session. Their error rates and response times were measured.

Procedure

Trained research assistants tested the children with NH and CIs at the Child Language Laboratory in Ewha Women's University. Both groups of children were tested in two phases: screening and experimental. The assistants administered the children with NH a nonverbal IQ test and a brief, pure-tone hearing test for screening. This screening process ensured that children were within the normal range. Nonverbal IQ had to be at least 85 for both groups. All children went through screening tests before undertaking the experimental tasks.

RESULTS

A separate univariate analysis was used to compare the two groups on processing capacity via three experimental tasks. Children with CIs performed significantly poorer ($M = 47.18$, SD = 10.22) than children with NH ($M = 72.94$, SD = 47.18) on NWR (F [1, 32] = 54.55, $p < 0.05$). Additionally, children with NH outperformed on CLPT accuracy (F [1, 32] = 16.23, $p < 0.05$), where the mean accuracy of children with CIs was 31.92 (SD = 20.3) and the mean accuracy of children with NH was 54.76 (SD = 12.07). Children with NH also outperformed on comprehension (F [1, 32] = 22.39, $p < 0.05$), where the mean accuracy of children with NH was 95.64 (SD = 3.85), and that of children with CIs was 78.69 (SD = 14.23). However, both groups performed similarly on CS (F [1, 32] = 0.008, $p > 0.05$), where children with NH scored 74.86 (SD = 11.4) and children with CI scored 75.26 (SD = 13.8). See Figure 1 for the data results. Figure 1 indicates the results (accurate scores/total number of items × 100) for NWR, CLPT, and CS.

For the analysis of processing speed, RAN in three conditions was analyzed by a multivariate analysis. The analysis found no significant difference between groups on all three tasks (see Fig. 2). Children with CIs showed a mean response time (RT in ms) of 26.1 (SD = 7.67). Children with NH showed RT of 23.0 (SD = 3.08) on RAN color (F [1, 23] = 2.48, $p > 0.05$). Additionally, the mean RT of children with CIs on RAN shape was 26.32 (SD = 10.85) and 22.82 (SD = 5.18), while in children with NH, it was (F [1, 23] = 1.43, $p > 0.05$). Finally, for RAN color and shape, children with CIs (M = 70.96, SD = 18.9) performed similarly to children with NH (M = 61.96, SD = 8.78) (F [1, 23] = 3.18, $p > 0.05$). Table 2 shows the descriptive statistics on all experimental tasks between the two groups.

DISCUSSION

This study examined how children with CIs perform on a range of processing-based tasks that emphasize processing capacity and processing speed, as compared with children with NH. The results showed that children with CIs still performed poorly on processing capacity tasks, which was measured by NWR and CLPT, compared with children with NH. These findings are similar to previous literature that found children with CIs still lag behind on verbal short-term memory, as measured by DS task and NWR (1,3,7,10). However, there has not been a study in which the CLPT task was used for this population. It has been found that when children have language impairment (e.g., children with specific language impairment) they perform as well as typically-developing children on CLPT comprehension, but poorly on CLPT accuracy. Recall that CLPT comprehension requires listening to a sentence and then decide whether the sentence makes sense. Thus, to do well on this task, children were to understand the sentence well enough while holding the last word of each sentence. Previous findings confirmed that children with language impairment only had difficulty with capacity, in terms of holding the last words of sentences in their memory with no difficulties on processing information on CLPT (i.e., listen to the sentence, make a decision on the veracity of the sentence, and say ‘‘yes’’ or ‘‘no’’ to the question). However, our findings showed that children with CIs have difficulty both with processing information, as well as holding the information in their memory.

Different from English-based literature, children with CIs performed similarly to children with NH on CS. Recall that the NWR and CS can be influenced by other factors, and thus Korean-speaking children may show different results compared with English-speaking children due to the phonotactic complexity of the language (15) and the weight of information that the numbers carry

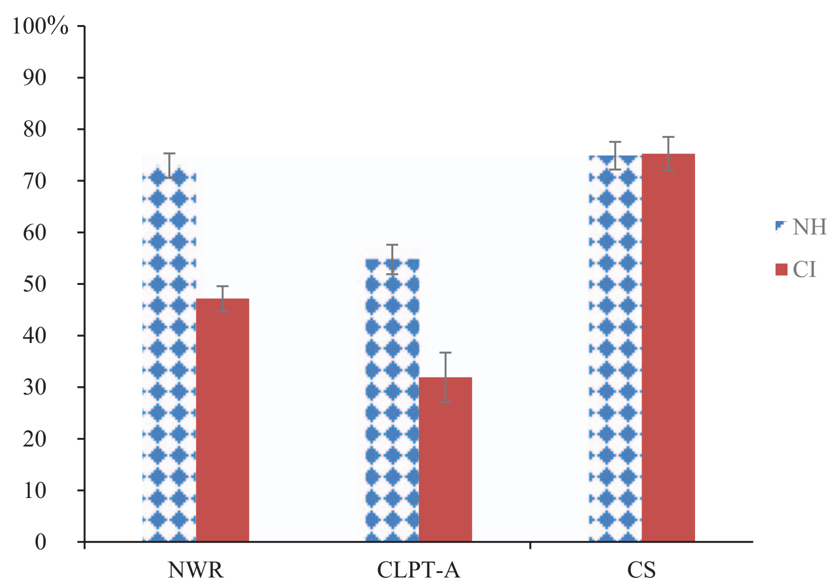

FIG. 1. Processing capacity performance by group. Children with NH outperformed compared with children with CI on NWR (F [1, 32] = 54.55, $p < 0.05$) and on CLPT accuracy (F [1, 32] = 16.23, $p < 0.05$). However, children with CI performed similarly to children with NH on CS (F [1, 32] = 0.008, $p > 0.05$). Y-bar indicates percent accuracy. CI indicates cochlear implant; CLPT, competing language processing task; CS, counting span; NH, normal hearing; NWR, nonword repetition.

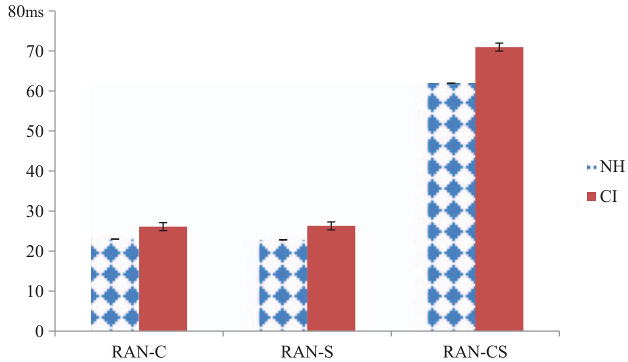

FIG. 2. Processing speed performance by group. There were no significant differences between groups on all three tasks: color (F [1, 23] = 2.48, $p > 0.05$); shape (F [1, 23] = 1.43, $p > 0.05$); color and shape (F [1, 23] = 3.18, $p > 0.05$). Y-bar indicates ms.

in the tested language (14). In English, digits can be labeled or named as ''one, two, three, four, and five.'' These words contain not only name of numbers (e.g., if the child sees the symbols ''1, 2, 3,'' they say them as ''one, two, three''), but they also convey the meaning of the amount of an object. We call this ''counting'' (e.g., one book versus two books). Thus, ''one'' or ''two'' has same format for naming the digits and for counting. In contrast, in Korean, if the child sees ''1, 2, 3,'' they will say them as ''*il*, *eei*, *sam*,'' which does not contain the meaning of the amount of something. Rather, it just labels the digits. If the child has to convey the meaning of the amount of an object like with ''one book,'' then the child would say ''*hana*,'' and ''two books'' would be ''*dool*.'' Thus, Korean has different methods for naming the digits and counting the digits. In our study, we used the digit span with the naming format, which does not contain the counting meaning of ''il, eei, sam.'' Using this format may have made the working memory load of the task slightly different than the English version. Thus, this may be the reason why it was easy for children with CIs to process that information, leading to no difference between the two groups. Thus, it is important to know that tasks measuring working memory can be sensitive in one language, but not in another language. The data results nevertheless showed that their performance was not at the ceiling level. For future study, it would be worth testing the two Korean versions of the digit span to provide evidence of whether there are notable differences with working memory load.

Interestingly, we found no group difference between children with CIs and children with NH on processing time measured by RAN. Recall that Leonard et al. (11) found that information processing time and memory can have separable factors. This study's results confirmed those previous findings; i.e., the relationship among different types of processing can contribute differently when understanding individual variabilities.

This study examined children with one visit. This was limiting, as documenting children's overall performance at several different time points can elaborate on whether underlying processing skills change in the target population. For instance, when children with CIs were compared with children with NH over 1 year, Yim (22) found that even though children with CIs performed poorly on year 1, they caught up by year 2 on working-memory task. Thus, with enough time of exposure, there may be room for children to grow on a certain area of underlying processing. Additionally, a future study with a larger number of children for comparing groups with CIs whose language skills are good versus poor is warranted. A comparison of these groups may allow us to more directly answer whether the language skills are explained by a variance in processing measurements.

Based on the study results, we can infer when professionals provide support for children with CIs, supporting capacity rather than speed is what is best for efficient processing of information. This study used the two tasks of NWR and CLPT. We found that listening to either a linguistic or nonlinguistic sound and repeating those sounds may be a good exercise to work on for this population. Additionally, children with CIs showed difficulties with not only processing capacity, but also with processing information on CLPT. These results may be due to the inefficient allocation of the resource for processing and storing information at the same time. However, participants were good at processing speed, yet poor on memory. Based on these results, participants must have used too much energy on storing information while processing the sentence. Thus, emphasizing the memory space will free up the energy for storage and eventually balance their resources. This notion is critical for this population because children daily listen to

TABLE 2. *Descriptive statistics on experimental tasks by group*

	NWR (%)	CLPT-C (%)	CLPT-A (%)	CS (%)	RAN-C (ms)	RAN-S (ms)	RAN-CS (ms)
NH	72.94 (10.11)	95.64 (3.85)	54.76 (12.07)	74.86 (11.4)	23.0 (3.08)	22.82 (5.18)	61.94 (8.78)
CI	47.18 (10.22)	78.69 (14.23)	31.92 (20.3)	75.26 (13.8)	26.16 (7.67)	26.32 (10.85)	70.96 (18.90)

CLPT-A indicates accuracy score on competing language processing task, accurate number of words recalled/total number of items × 100; CLPT-C, comprehension score on competing language processing task, accurate score/total number of items × 100; CS, counting span, accurate number of items recalled/total number of items × 100; NWR, nonword repetition, accurate number of phoneme produced/total number of consonants × 100; RAN-C, rapid automated naming–color; RAN-CS, rapid automated naming–colorshape; RAN-S, rapid automated naming–shape.

Standard deviations are indicated in parentheses.

abundant incoming sentences, and must process those sentences while holding important information.

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I, Dongsun Yim, have a full responsibility for this submitted paper and have data access. This research adhered to basic ethical considerations for the protection of human participants in research which was approved by the Ewha Womans University Institutional Review Board. This manuscript contains no copyrighted materials and has not been previously published nor is currently under review elsewhere. I contributed to the study for testing subjects, analyzing data, and read the latest version of the manuscript.

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