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Language treatment effects on communicative abilities and working memory in Korean-speaking agrammatic Broca's aphasia caused by moyamoya disease: Phase II evidence from a case study

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ABSTRACT

The present study reports on the language treatment outcomes from sentence- and story-level linguistic facilitation and its generalization effect on communicative abilities, working memory, and sentence processing in the case of an adult with Moyamoya Disease (MMD). After treatment, the patient's overall performance, including the Aphasia Quotient, and sentence processing ability as measured by language testing, were improved. Furthermore, the treatment effects were generalizable to working memory abilities. Our case study conveys clinically meaningful implications since it is the first report on the effects of language treatment on linguistic and cognitive domains for an individual with MMD-induced agrammatic Broca's aphasia

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Moyamoya disease; aphasia; agrammatism; language treatment; generalization effect

Introduction

Moyamoya Disease (MMD) is a cerebrovascular disorder induced by occlusion of the vessels around the circle of Willis, leading to collateral damage on the extensive small vessels that resemble a "puff of smoke," a cloudy appearance in angiography (Moore et al., 1997; Perna & McGee, 2017). MMD has been diagnosed primarily in East Asian countries, including Korea and Japan, predominantly in females (Ahn et al., 2014; Perna & McGee, 2017). The Annual MMD incidence in the United States from 2008 to 2015 was 0.293 per 100,000 (Ghaffari-Rafi et al., 2020), whereas that of Korea was 1.7 to 2.3 per 100,000 from 2007 to 2011 (Ahn et al., 2014). Considering that the incidence of MMD in Korea is tremendously high compared to the U.S, researchers need to pay more attention to MMD-related linguistic and cognitive symptoms and their treatment for Korean-speaking individuals with MMD.

Reported research on MMD-related cognitive and language impairment has mostly concerned pediatric cases in Japan. There have only been a couple of case reports on cognitive deficits in adults with MMD. The results from the pre-surgical neuropsychological testing for adults with MMD suggest that they exhibited impairment in executive functioning with a relatively unimpaired memory function (Karzmark et al., 2008). However, there is minimal evidence of rehabilitation that facilitates linguistic function for adult MMD cases. A couple of case reports suggest that multidisciplinary treatment programs including physical, occupational, and speech-language therapies have contributed to physical and cognitive recovery (Perna & McGee, 2017). But most studies about rehabilitation have focused on cognitive domains with relatively less attention to and little evidence concerning linguistic domains.

Given that MMD induces a stroke, linguistic deficits may emerge as one of the chief complaints following an MMD-induced stroke. However, these linguistic symptoms have received relatively less attention as compared to other cognitive domains. In the current study, we present the case of a Korean-speaking individual with MMD who demonstrated linguistic deficits that primarily featured agrammatic symptoms. We will report novel findings concerning Korean agrammatic symptoms from an MMD case. Furthermore, for this patient, we developed a linguistic treatment program including two linguistic levels, namely, 1) a sentence-level treatment protocol and 2) a discourse-level treatment protocol. The sentence-level protocols focused on facilitating communication abilities by reducing agrammatic symptoms based on the improvement of their sentence comprehension and completion. The purpose of the discourse-level protocol is to enhance their working memory (WM) and to maximize mnemonic strategies aimed at the comprehension the target-story script based on keywords and semantic categories within the story.

Studies on linguistic deficits and the effects of have mainly focused on patients with a left-hemisphere brain injury (Dickey, 2021; Elman & Bernstein-Ellis, 1999; Poeck et al., 1989). Among the various methods for assessing patients' language abilities, the representative language test is the Western Aphasia Battery-Revised (WAB-R), which has had important international research outcomes by measuring aphasia (Kertesz, 2020; Wallace et al., 2014). The Aphasia Quotient (AQ) calculated from the WAB-R is the summary of the verbal assessment including spontaneous speech, auditory comprehension, repetition, naming, and word finding. The results of WAB-R and AQ are comprehensive-outcome measurements that are frequently used to assess language abilities in aphasia patients (Brady

et al., 2016). We also used the AQ as a dependent variable to detect changes in linguistic abilities before and after treatment.

Another important factor in confirming changes in language abilities is WM (Adams et al., 1989; Caspari et al., 1998; Sung et al., 2009). A WM deficit is one of the main symptoms of aphasia patients due to brain damage (Friedmann & Gvion, 2003; Murray, 2004). WM is a cognitive mechanism for temporarily maintaining, processing, and computing linguistic information when individuals process language, based on their short-term memory (STM) (Baddeley & Hitch, 1974). We defined WM and STM as terms pertaining to WM, based on the assumption that WM contains an STM buffer, which is a subset of WM (Engle et al., 1999). As a methodology of measuring WM abilities, it consists of a dual task (e.g., sentence reading span task) that requires two simultaneous types of information processing (Daneman & Carpenter, 1980), and a single task (e.g., digit span task, word span task) that recalls information or recalls it after operational processing.

WM related to the sentence processing, sentence comprehension, and holding the information and computing syntactic structures among many linguistic domains (Baldo et al., 2012; Caplan & Waters, 1995; Kohn et al., 1990; Tompkins et al., 1994). Many studies reported the effectiveness and generalization effects of language intervention in aphasia patients with a WM deficit (Eom & Sung, 2016; Kalinyak-Fliszar et al., 2011; Salis, 2012). Kohn and colleagues reported that a sentence treatment based on semantic units and functional words can increase speech fluency, sentence production. Furthermore, the treatment effects generalize spontaneous speech and WM for patients with chronic conduction aphasia. Eom and Sung (2016) compared the effect and generalization of sentence-level of WM treatment for Korean agrammatic patients with chronic stage aphasia in a single left-hemisphere stroke. They reported that the performance of all participants in the treated and untreated sentence repetition task increased significantly, and positive generalization effects were found in sentence comprehension, WM, and general language tasks. From previous studies, it can be confirmed that WM is closely related to sentence processing abilities. In this study, we tried to verify the effectiveness of the treatment by measuring the WM before and after treatment.

In previous studies, agrammatic symptoms of patients with aphasia patients have been reported (Friedmann & Grodzinsky, 1997; Lee et al., 2015). Korean aphasia patients who have agrammatism exhibited a grammar deficit such as function words error, content words omission, word order error and a case marker processing deficit (Bae, 2005; Park et al., 2006). Korean has a case-marking system that is placed at the post-position of a noun to denote the sentence structural function. Unlike English-speaking aphasia patients, it is important for Korean-speaking aphasia patients to examine their case marker assignment abilities to check for agrammatism (Eom et al., 2016). Since our case report patient exhibited agrammatism, we evaluated her case marker abilities before and after treatment.

The current case report will describe the treatment's pre-efficacy in facilitating sentence- and story-level linguistic abilities and its generalization effects in a case of agrammatic Broca's aphasia associated with MMD. In detail, the patient's

overall linguistic abilities, indexed by the score from the PK-WAB-R, WM, sentence comprehension and her case marker assignment ability, were compared pre- and post-treatment.

Materials and methods

Participant information

The woman in her 50s with a French-language B.S. degree participated in this study, which was approved by the Institutional Review Board of Ewha Womans University (No. 116-1). Before her strokes, she was a housewife, generally healthy with an active lifestyle. Korean was her native language. She had a history of diabetes mellitus, hypertension, and dyslipidemia without psychiatric disease. From 2007 to 2017, she experienced three strokes, the first in her life. The initial stroke occurred in March 2007 with left thalamic infarction, and the Magnetic Resonance Imaging (MRI) resulted in an MMD diagnosis. At that time, she had only right-side hemiplegia without speech and language problems. The second stroke was in 2013, and in April of 2017, she suffered from the most recent stroke, which resulted in aphasia, dysarthria, and cognitive limitations. In August of 2017, she was referred by the department of neurology to our speech-language clinic with speech and language problems. The patient's chief complaints about their linguistic capacity were, "I don't have any problems with conversation in daily life, but the words that I have to say don't come to mind in conscious communication. And, it's difficult to produce long sentences." The MRI results revealed that the patient's left frontal operculum was chronically changed due to ischemic atrophy or secondary change related to the arachnoid cyst. The left parietal ischemic lesion is quite wide and involved both superior and inferior parietal lobule of the supra-marginal and angular gyrus. Her Magnetic Resonance Angiography (MRA) results showed occlusion of the both distal Internal Carotid Arteries (ICA), complete lack of both Anterior Cerebral Artery (ACA) and Middle Cerebral Arteries (MCAs), the disappearance of Posterior Cerebral Artery (PCA). Compatible with MMD with Suzuki stage V. In addition, normal MRA showing both distal ICA, MCA, and ACA. The MRI and MRA results are provided in Figure 1.

Standardized language and speech evaluations

She was diagnosed as having a moderate to severe degree of Broca's aphasia. The AQ was 58.5 on the Paradise Korean-Western Aphasia Battery-Revised (PK-WAB-R; Kim & Na, 2012) by speech-language pathologists (SLPs) in the initial assessment session. She was classified as questionable with regard to cognitive impairment, with a Clinical Dementia Rating (Hughes et al., 1982) score of 0.5, and moderate cognitive decline, with a Global Deterioration Scale (Reisberg et al., 1988) of 4. The Seoul Neuropsychological Screening Battery (SNSB; Kang & Na, 2012) results indicated that she had vascular cognitive impairment without dementia. We additionally administered the Digit Span Test (DST) from the SNSB word span tasks (Sung, 2011).

She reported having problems with her speech such as a slow overall speech rate and inaccurate articulation. We also

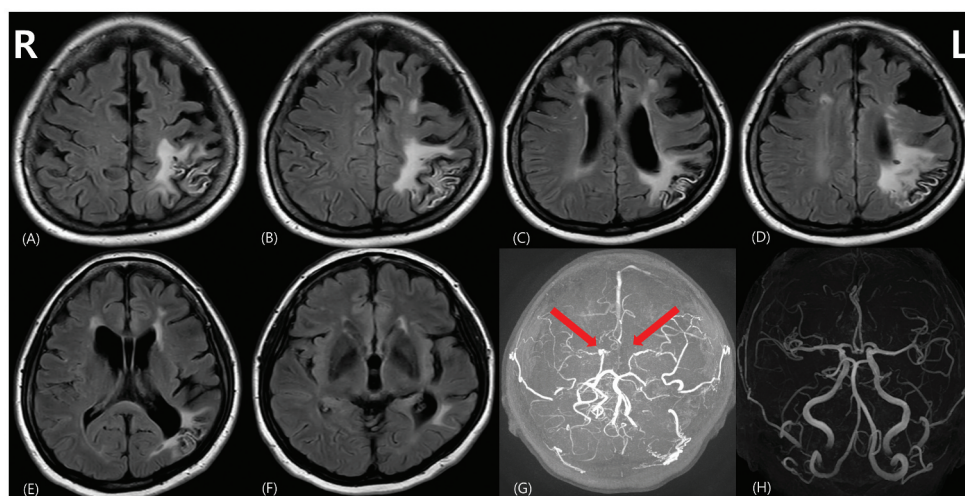


Figure 1. The left frontal operculum shows chronic change due to ischemic atrophy or secondary change related to arachnoid cyst. The left parietal ischemic lesion is quite wide, involving both the superior and inferior parietal lobules of supramarginal and angular gyrus (A–E). The left superior temporal gyrus is spared (F). The patient’s MRA shows the occlusion of both distal ICAs, and complete lack of both the ACA and MCAs (red arrow), as well as the disappearance of PCA. This is compatible with Moyamoya disease with Suzuki stage V (G). A normal MRA showing both distal ICA, MCA, ACA (H).

Table 1. Descriptive results from the initial assessment.

Test	K-MMSE	CDR	GDS	AQ	DST-Forward	DST-backward	WST-forward	WST-backward
Score	26/30	0.5	4	58.8/100	2/14	2/14	4/14	2/14

Note: K-MMSE = Korean Mini Mental State Examination (Kang, 2006); CDR = Clinical Dementia Rating (Hughes et al., 1982); GDS = Global Deterioration Scale (Reisberg et al., 1988); AQ = Aphasia Quotient; DST = Digit Span Test (Kang & Na, 2012); WST = Word span task (Sung, 2011)

conducted a non-standardized dysarthria protocol to determine whether she exhibited dysarthria and to what degree. The results showed that she was not classified as having any type of dysarthria. However, we identified the speech problems such as effortful, halting speech, telegraphic speech which is missing functional words, and difficulty initiating speech or conversation caused by a deficiency in finding words during spontaneous speech.

The speech problem she complained about seemed due to a word-finding deficit in sentences. The descriptive results of the initial standardized language test assessments are summarized in Table 1.

Evaluations of Korean agrammatical symptoms


Sentence processing tasks

To scrutinize linguistic symptoms, we administered deep language tests such as the sentence comprehension test (Sung et al., 2015) and the case marker assignment task (Sung, 2017). The sentence comprehension test is based on the sentence-picture paradigm, consisting of semantically reversible sentences. Sentence stimuli are auditory presented with two pictures that depict agents and themes using human pictograms: One is a target picture, and another is a syntactic foil. The sentence comprehension test contains three sentence types an active sentence with 2-place verb (Active-2), an active sentence with 3-place verb (Active-3), and a passive sentence

(Passive). Each sentence type includes both canonical and non-canonical word order, resulting in a total of six different syntactic structures. We manipulated the canonicity by changing the word order within the sentences. A canonical word order in Korean has the following structure: “Subject (S) + Object (O) + Verb (V)”, whereas a non-canonical word order is considered to be OSV. Korean has a case-marking system, which is placed at the postposition of a noun to denote the structural function of the sentence. In active sentences with a canonical word order, a noun with a nominative case marker (*ka*) placed in the subject position as an agent comes first and a noun with an accusative case marker (*lul*) placed in the object position as a theme follows. In active sentences with a non-canonical word order, the order of the noun phrase is changed in the subject position and object position. For passive sentences, the first noun phrase with a nominative case marker (*ka*) in the subject position as a theme comes first and the second noun phrase with an oblique case marker (*eykey*) as an agent follows. Furthermore, the verb with passive morphemes is placed at the end of the passive sentence. As with active sentence types, by changing the positions of a theme and an agent, a passive sentence with non-canonical word order is produced. Each syntactical structure consists of six items, leading to a total of 36 items. An example of the sentence comprehension test is illustrated in Table 2.

The difficulty in case marking assignment is known to be one of the agrammatical symptoms for Korean-speaking individuals with aphasia (Kang, 2006). The conditions of sentence type are the same as those of the sentence comprehension test. In the case marker assignment task, nouns and verbs are presented along with a target picture, and participants are asked to select the correct case markers corresponding to the picture among the nominative (*ka*), accusative (*lul*), locative (*ey*), and dative (*eykey*) case markers. Participants must select the relevant case markers and fill in the blank from the case-marker word cards presented below the blank. To give examples of Active-2 sentences in

Table 2. An example of sentence comprehension test.

Sentence type	Sentence example	Picture example
Active_ Canonical sentence	The Black Chases the Yellow. (In English) Kemcengi-ka_NOM Nolangi-lul_ACC Ccoch-ta_Active verb.	
Active_ Non- canonical sentence	The Black Chases the Yellow. (In English) Nolangi-lul_ACC Kemcengi-ka_NOM Ccoch-ta_Active verb.	
Passive_ Canonical sentence	The Yellow is chased by the Black. (In English) Nolangi-ka_NOM Kemcengi-eykey_OBL Ccochy-ta_Passive verb.	
Passive_ Non- canonical sentence	The Yellow is chased by the Black. (In English) Kemcengi-eykey_OBL Nolangi-ka_NOM Ccochy-ta_Passive verb.	

Note: NOM=Nominative case marker; ACC=Accusative case marker, OBL=Oblique case marker

the canonical word order, the normative is required to precede the accusative case markers, whereas in sentences following the non-canonical word order, the accusative and normative case markers must be filled in that given order. For passive sentences with canonical word orders, the normative is required to precede dative case markers, whereas the dative and normative case markers need to be filled in that order. A total of 36 items was presented with six items per condition. An example of the case marker assignment task and the target sentences are provided in Table 3.

Results from the initial assessment of sentence processing tasks

In both the sentence comprehension test and case marker assignment task, she demonstrated below-chance (<50%) level performance in total scores. For each sentence type, she demonstrated a below-chance level performance (<50%) on passive non-canonical sentences in the sentence comprehension test. In the case marker assignment task, she not only presented overall difficulties below the chance level of performance in all sentence types, but also had inconsistent error patterns, indicating that she suffered from serious deficits in the ability to select relevant case markers. The descriptive results of the initial assessments from the sentence processing tasks are summarized in Table 4.

Treatment procedures and protocols

She completed a total of 54 treatment sessions, a total of 54 hours of outpatient language rehabilitation comprised of an hour-long session 2–3 times weekly for 6 months, August 2017 to February 2018. Language and WM tests were performed before and after treatment sessions. The treatment

protocols focused on two domains: 1) sentence-level comprehension and 2) discourse-level story retelling procedures. We did not provide additional structured home practice to the patient.

Sentence-level comprehension protocol

We developed the sentence-level comprehension treatment program by modifying the previous protocols from Kiran et al. (2012) and Sung et al. (2015). All sentences were semantically reversible sentences with two syntactic structures, active and passive type. The protocol contained six steps as follows: 1) sentence-picture matching, in which the patient was asked to select the picture that corresponded to what she had just heard. 2) agent-focused stimulation: the patient was asked to point to the agent who was performing the action in the picture. 3) theme-focused stimulation: the patient was asked to point to the theme who is receiving the action. 4) object manipulation: the patient was asked to enact the target sentence using dolls with three colors, 5) case marker assignment: the patient was asked to assign the case marker cards to the relevant thematic roles for the target picture, and 6) sentence completion: the patient was asked to complete a whole target sentence with a noun phrase that SLP provides. An example of the protocol is provided in Figure 2.

Discourse-level story retelling protocol

The discourse-level story retelling protocol was developed by Sung et al. (2015) using five story scripts on themes such as going to the zoo, going on a trip, going to the hospital, going to the supermarket, and preparing to go out. The purposes of the story retelling protocol are 1) to enhance WM capacity by implementing the semantic classification of keywords from each story and 2) to develop mnemonic strategies to maximize the impact of generalization on linguistic and cognitive abilities. The

Table 3. An example of the case marker assignment task and target sentences by sentence types.



Kemcengi		Nolangi		Ccoch-ta
<i>The Black</i>		<i>The Yellow</i>		<i>Chases</i>

ka	ey
<i>NOM_CM</i>	<i>LOC_CM</i>
lul	ka
<i>ACC_CM</i>	<i>NOM_CM</i>
ey	eykey
<i>LOC_CM</i>	<i>OBL_CM</i>
eykey	lul
<i>OBL_CM</i>	<i>ACC_CM</i>

Target Sentence						
Active-2	Canonical	Kemcengi-ka The Black _{NOM}	Nolangi-lul The Yellow _{ACC}	Ccoch-ta Chases		
	Non-canonical	Nolangi-lul The Yellow _{ACC}	Kemcengi-ka The Black _{NOM}	Ccoch-ta Chases		
Active-3	Canonical	Kemcengi-ka The Black _{NOM}	Nolangi-eykey The Yellow _{OBL}	Sangcha-lul The box _{ACC}	Chu-ta Gives	
	Non-canonical	Nolangi-eykey The Yellow _{OBL}	Kemcengi-ka The Black _{NOM}	Sangcha-lul The box _{ACC}	Chu-ta Gives	
Passive	Canonical	Kemcengi-ka The Black _{NOM}	Palangi-eykey The Yellow _{OBL}	Ccochki-ta Chases _{PASSIVE}		
	Non-canonical	Palangi-eykey The Yellow _{OBL}	Kemcengi-ka The Black _{NOM}	Ccochki-ta Chases _{PASSIVE}		

Note: NOM=Nominative case marker; ACC=Accusative case marker, LOC=Locative case marker; OBL=Oblique case marker

protocol consisted of five steps as follows: 1) the production and comprehension of information units from the story – the patient listened to the story and was asked to retell it and answer the comprehension questions; 2) comprehending the sequence of whole story – the patient was provided with visuospatial picture cues and asked to rearrange them in the order of the story; 3) improving the WM capacity – the patient performed a word span task consisting of the keywords from the target stories. The

keywords used in the word span task were selected as words with high semantic typicality and familiarity for Korean elderly individuals by referring to the study of Sung (2015). Moreover, the keywords are common nouns with 2–3 syllables in Korean; 4) implementing the semantic classification and facilitating the word fluency – the patient was asked to sort out picture cards that correspond to the correct semantic category and to produce as many words as they could that were related to target semantic

Table 4. Scores of sentence comprehension test and case marker assignment task from the initial assessment.

	Active sentence with 2-place verbs		Active sentence with 3-place verbs		Passive sentence	
	Canonical	Non-canonical	Canonical	Non-canonical	Canonical	Non-canonical
Sentence comprehension test	4/6	4/6	2/6	3/6	4/6	2/6
Total score	19/36					
Case marker assignment task	1/6	1/6	1/6	1/6	3/6	0/6
Total score	7/36					

**Figure 2.** An example of the sentence-level comprehension protocol. *Note:* NOM = Nominative case marker; ACC = Accusative case marker; OBL = Oblique case marker

categories. The semantic categories were selected based on the results from Sung (2015), who investigated the appropriate semantic categories required for naming treatments in Korean. The number of semantic categories consisted of 3–5 categories according to the story scripts. For example, the theme of "going to the supermarket" is represented in the target semantic categories of food, fruits, vegetables, fishes, and transportation; 5) developing the mnemonic and discourse strategies – the patient was made to retell the whole story using keyword pictures. An example of this protocol is provided in Figure 3.

Results

Language treatment effects (1): pre-post comparisons of standardized tests

PK-WAB-R

After treatment, the scores of AQ from PK-WAB-R increased from 58.8 to 81.6. Her aphasia type was changed from Broca's (moderate-severe) to Anomic (mild-moderate) after treatment. Compared to the patient's pretreatment results, the subtest scores of fluency and naming improved by more

than three points in post-treatment. And the patient's scores in the other subtest (informational content, comprehension, and repetition) improved modestly by around one point. In the PK-WAB-R test, aphasia types are classified based on the criteria for aphasia classification as expounded by Kertesz and Poole (1974). A score in the 0–4 range is considered non-fluent, and the score in the 5–10 range is considered fluent. The patient's score of fluency improved from 4 points to 7 points, changing her classification on the fluency scale from non-fluent to fluent. Although she still had A slow speech rate and inaccurate articulation, the production of complete sentences, instead of telegraphic speech was frequently observed. Also, hesitations caused by a deficiency in word finding and repetitions of the syllable, word, and phrase were occasionally observed. The scores for each subtest are summarized in Figure 4.

DST

After treatment, DST scores increased from pre-treatment scores, improving from –2 Standard Deviation (SD) to the normal range for both forward and backward tests. In detail,

the patient's DST-forward score improved from 2 to 9 and was included in the range (Mean = 7.10, SD = 1.37) matching the normal range for those in her age and education level. Even in DST-backward, the performance of the patient was within the norm (Mean = 4.93, SD = 1.44) after the treatment, and the score increased from 2 to 4. Her performance of the word span task remained at the same level. We provide scores for each task in Figure 5.

Language treatment effects (2): pre-post comparisons for sentence processing tests

Sentence comprehension test

The total sentence comprehension test scores improved after treatment from 19 to 23 out of 36 points. In sentence comprehension test subtest scores, the patient demonstrated improved or maintained her performance on all sentence types except for the two subtests of non-canonical word order of 2-place active sentences and the canonical word order of passive sentences (See Figure 6).

Case Marker Assignment Task

Step 1. Retell the story with comprehension questions

"Now let me tell you a story.
Listen carefully and retell the story in as much detail as possible."

Going to the Supermarket

Semantic Category	Food	Fruits	Vegetables	Fishes	Transportation
This Sunday, my son's family decided to have dinner at our house. I went shopping to prepare my grandson's favorite food. I forgot that the mart near my house was closed today, and when I went to the other mart, it was closed. So, I decided to go shopping at a traditional market that is two stops away by bus. First, I bought beef to make bulgogi. Next, I went to a vegetable store and bought onions, garlic, and carrots. I stopped by a fish shop and bought a cutlassfish and a mackerel each. Finally, I went to the fruit store and bought watermelon, grapes, and bananas. As I was about to come home, it suddenly rained. So, I took a taxi home. The total cost of shopping today was 54,000 won, and the taxi fare was 3,000 won.					

Step 1. Retell the story with comprehension questions

"Listen to the questions related to the story you have been told and answer them"

Comprehension Questions	
Person	Who decided to have dinner at our house?
Time	On what day of the week did your son's family come home?
Place	Where did you shop to prepare food?
Detailed	How much money did you spend on shopping in total?
Detailed	When you went to the traditional market, what form of transportation did you use?
Detailed	What fruit did you buy at the fruit store?
Detailed	How many fish did you buy in total?
Detailed	How many bus is the traditional market from the mart?

Step 2. Story regeneration with visuo-spatial cues

Step 3. Retell the word span task with key-words

"I will call out the words from the story.
Listen to the words and retell them in order."

Bulgogi

Cutlass fish

Grape

Step 4. Semantic category facilitation with word cards

"I'll give you a picture card for the words I told you a while ago.
Place the picture card under the corresponding semantic category card."

Food	Fish	Fruits

Step 5. Retell the whole story with key-words pictures

"I'll show you the picture cards of the words in the story in order.
Look at the picture cards and retell the story from beginning to end."

Figure 3. An example of the discourse-level story retelling protocol.

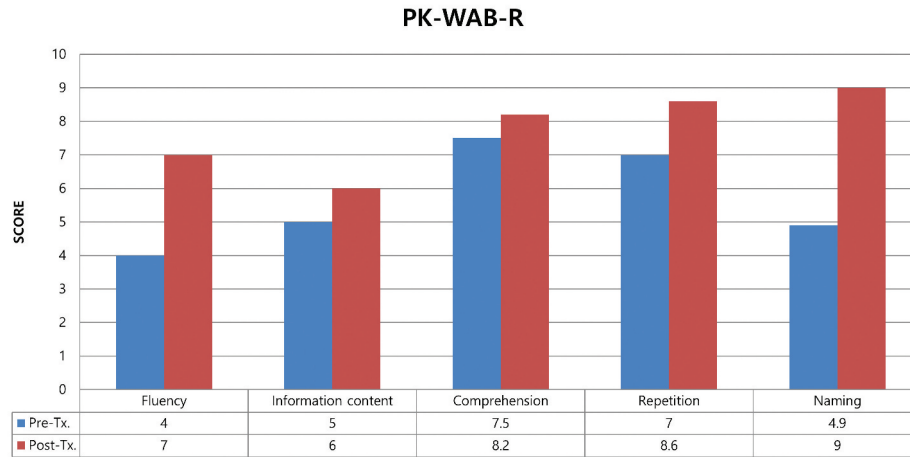


Figure 4. Scores of PK-WAB-R for pre- and post-treatment. NOTE: Paradise Korean-Western Aphasia Battery-Revised (PK-WAB-R; Kim & Na, 2012)

The case marker assignment task performance substantially increased after treatment, suggesting that the total case marker assignment task score improved from 7 to 22 out of 36 points (See Figure 7).

Language treatment effects (3): self-report

After the treatment sessions were completed, she reported that her language abilities, including fluency, memory, and communication skills with others, had improved and were better than pre-treatment. But she said that word-finding difficulty in sentence construction and within communication situations remained.

Discussion

The current study presented the language treatment pre-eficacy and its generalization effects for a case with agrammatic Broca's aphasia following an MMD-induced stroke. After sentence- and discourse-level language treatment, she exhibited an overall increase in several domains, including the AQ,

WM area, sentence comprehension, and case marker assignment ability. First, overall communicative abilities, indexed by the AQ scores, improved substantially (approximately a 20-point increase). Considering that a five-point increase in AQ scores indicates clinically significant improvement (Katz & Wertz, 1997), the participant's improvement can be considered clinically meaningful. Among the subtests of the PK-WAB-R, there was a marked increase in the score on the fluency and naming subtest. This increase is thought to be related to the improvement of the lexical retrieval ability. It is expected that the step of conducting semantic classification and promoting word fluency in the discourse-level treatment protocol may have improved her lexical retrieval ability.

Second, WM ability was improved. WM ability was measured through DST and the word span task. In DST, the scores of both the forward and backward test after the treatment increased to a normal level. However, the scores of the word span task were the same before and after treatment. These results are possibly due to the discourse-level treatment protocol that contains WM facilitation. Furthermore, considering

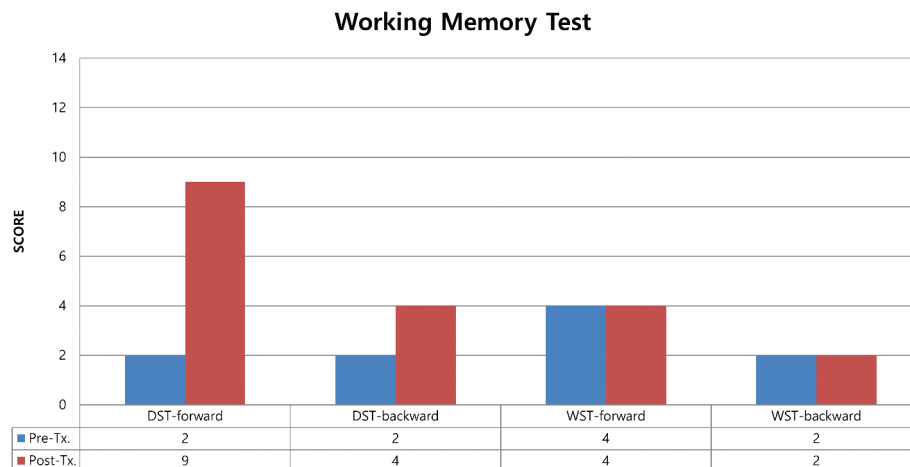


Figure 5. Scores of working memory measure for pre- and post-treatment. NOTE: DST = Digit Span Test (Kim & Na, 2012); WST = Word span task (Sung, 2011)

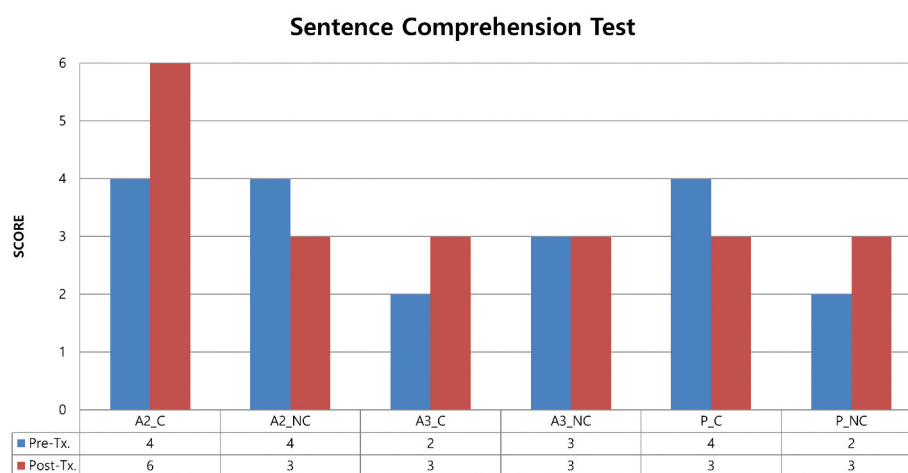


Figure 6. Scores of sentence comprehension test for pre- and post- treatment. NOTE: A2_C = Active sentence with 2- place verbs in a Canonical word order; A2_NC = Active sentence with 2-place verbs in a Non-Canonical word order; A3_C = Active sentence with 3-place verbs in a Canonical word order; A3_NC = Active sentence with 3-place verbs in a Non-Canonical word order; P_C = Passive sentence in a Canonical word order; P_NC = Passive sentence in a Non-Canonical word order.

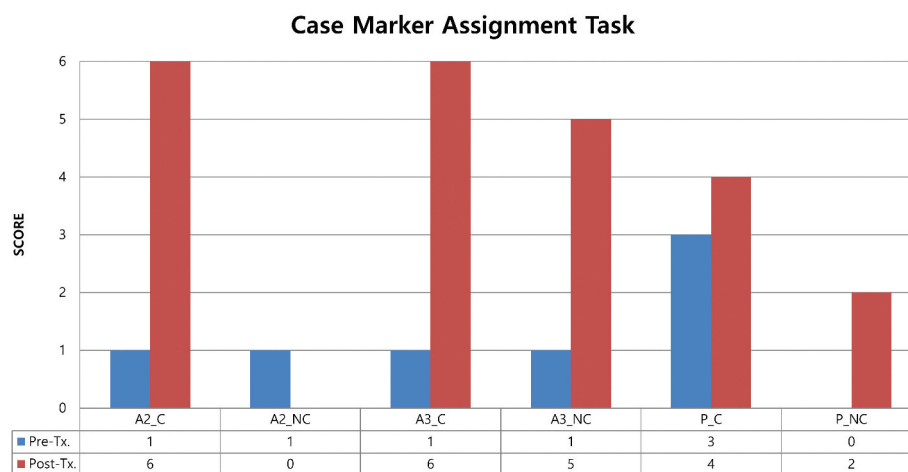


Figure 7. Scores of CMAT for pre- and post- treatment. Note: CMAT = Case Marker Assignment Task (Sung, 2017); A2_C = Active sentence with 2-place verbs in a Canonical word order; A2_NC = Active sentence with 2-place verbs in a Non-Canonical word order; A3_C = Active sentence with 3-place verbs in a Canonical word order; A3_NC = Active sentence with 3-place verbs in a Non-Canonical word order; P_C = Passive sentence in a Canonical word order; P_NC = Passive sentence in a Non-Canonical word order.

that several previous studies have reported that WM is closely related to sentence processing ability (Baldo et al., 2012; Caplan & Waters, 1995; Kohn et al., 1990; Tompkins et al., 1994), it is expected that some underlying mechanisms are shared between aspects of the linguistic domain, such as sentence processing, and the WM domain. In addition, the generalization effect of language intervention within the WM domain has been reported in several previous studies (Eom & Sung, 2016; Kalinyak-Fliszar et al., 2011; Salis, 2012). The post-treatment improvement in WM in this study seems to be also attributed to the generalization of the sentence-level treatment effect on the WM domain.

Finally, sentence processing ability, including sentence comprehension and case marker assignment ability, was improved. Compared with the pre-treatment score, the patient's overall score increased in both the sentence comprehension test and

the case marker assignment task after treatment. These results may be due to the sentence-level treatment protocol that directly promoted sentence comprehension and case marker assignment ability. However, given the patient's performance according to sentence type and word order canonicity, she still demonstrated relatively greater difficulty in agrammatic linguistic features, such as forming sentences with 2 place verbs in non-canonical and passive sentences. These results indicated that her chief complaints that were agrammatic symptoms remained after treatment. But, overall, the combination of sentence- and discourse-level treatment protocols was efficacious for an adult MMD case. To the best of our knowledge, this study is the first case report on language treatment pre-efficacy for Korean-speaking individuals with MMD-induced agrammatic Broca's aphasia.

Previous studies on MMD mostly focused on case reports involving pathological features or clinical symptoms from

neuropsychological tests. However, there are relatively few studies on the effects of behavioral treatment for patients with MMD. A couple of studies have reported on the effects of cognitive treatment for individuals with MMD. A report of case series of two adults with MMD presented that after a cognitive rehabilitation program focusing on such issues as short-term memory, alternating attention skills, and speed of processing, both patients showed significant improvement in various cognitive abilities (Perna & McGee, 2017). But this study was meaningful in that we administered language treatment focused on linguistic features.

In the current study, we administered intensive language treatment programs that heavily tapped into facilitating sentence- and discourse-level language processing abilities. We focused on these domains, given that the patient with MMD demonstrated clear linguistic symptoms with agrammatic features in both production and comprehension domains. Korean agrammatic symptoms emerged in linguistic tasks in which she presented differentially greater difficulties in more complex syntactic structures (such as passive) and sentences with non-canonical word order (Sung et al., 2020). Especially, she exhibited severely impaired abilities in selecting relevant case markers. Considering that case markers play a critical role in assigning the thematic roles of the nouns associated with the verbs in Korean, deficits in case marker assignment are regarded as one of the representative features of agrammatism in Korean. After intensive language treatment, her abilities in the case marker assignment increased dramatically. The current results have clinical implications given that Korean agrammatic cases induced by MMD can benefit from intensive language treatment that focuses on sentence- and discourse-level language processing programs. These two-level treatment protocols. Even further, it is clinically important that the treatment effects are generalizable to other domains such as WM, which is not directly targeted by our program. The treatment protocols used in this study promoted the patient's comprehensive linguistic abilities such as the reduction of agrammatic symptoms and the improvement of WM by manipulating the sentences in sentence- and discourse-level environments. In addition, the biggest advantage of these protocols is that the focus of treatment is on the level of sentences and discourse used in real conversational situations, not disconnected words or phrases, and will therefore be useful in actual clinical practice. The results of our study were primarily exploratory and preliminary to the task of identifying pre-efficacy before and after language treatment in Korean MMD patients. In addition, the positive outcomes of the treatment will act as the grounds for motivating the next steps of research, which will focus on proving the efficacy of treatment by expanding language treatment studies to more patients with MMD.

Although the current study conveys clinically meaningful results, several limitations must be noted. The current research results were based on only a single case report; thus, the external validity is limited to be generalized to other cases with MMD. Additional factors that may affect treatment effects include facts such as she was relatively young and had a high level of motivation with good family support. Environmental and demographic factors need to be taken into consideration when interpreting treatment efficacy, given that this is a single case report.

People with MMD may have significant linguistic deficits, but the prevalence of MMD is relatively low, and more

geographically prevalent in Asia. This limitation makes it hard to conduct corpus-based linguistic studies and challenging to provide evidence-based speech-language services for individuals with MMD. Although the current study reports a single case of language treatment pre-efficacy, we hope that this evidence can contribute to developing and facilitating language-based treatment for MMD.

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