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Nonlinguistic Cognition Functions of Mandarin Speakers With Poststroke Aphasia

Tzu-Jung Huang,[a] Ping-Hsin Chang,[b] Hsinhuei Sheen Chiou,[c] and Hsin-jen Hsu[d,e]

[a] Ph.D. Program in Education Sciences, National Tsing Hua University, Hsinchu, Taiwan [b] Kaohsiung Veterans General Hospital, Taiwan [c] Department of Speech, Hearing and Rehabilitation Services, Minnesota State University, Mankato [d] Department of Special Education, National Tsing Hua University, Hsinchu, Taiwan [e] Research Center for Education and Mind Sciences, National Tsing Hua University, Hsinchu, Taiwan

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ABSTRACT

Purpose: The purpose of this study was to examine the cognitive functions of Mandarin speakers with poststroke aphasia and to investigate the relationship between nonlinguistic cognitive deficits and the severity of aphasia.
Method: Twenty-three adults with aphasia resulting from left-hemispheric stroke and 23 adults matched for age and educational level completed a series of six nonlinguistic cognitive tests measuring nonverbal intelligence, short-term memory, visual selective attention, visual alternating attention, auditory selective attention, and auditory alternating attention. A standardized aphasia assessment (Concise Chinese Aphasia Test [CCAT]) was also conducted to evaluate the severity of aphasia. Data analyses examined cognitive functions by comparing task performance of the two groups and examining the relationship between scores on the cognitive tasks and aphasia severity based on a hierarchical regression analysis.
Results: The aphasia group scored significantly lower than the control group on all nonlinguistic cognitive tasks with large effect sizes (d = 0.95 ~ 1.54). Significant associations between different nonlinguistic cognitive tasks and CCAT subtests were observed. Results from the hierarchical regression analysis showed that auditory alternating attention was the only factor that significantly predicted aphasia severity based on CCAT overall scores after age and education level were taken into account.
Conclusions: The findings align with prior research observing deficits in nonlinguistic cognition in individuals with aphasia. Implications for clinical practice and future research are discussed.

Aphasia is an acquired language disorder that usually results from left-hemisphere brain damage, most commonly following a stroke. Approximately 30%–35% of worldwide stroke survivors suffer from aphasia (Engelter et al., 2006; Mitchell et al., 2021). Despite the fact that the most notable symptom in aphasia concerns language abilities, impairments in various nonlinguistic cognitive domains have also been observed in individuals with aphasia (IWA; Fonseca et al., 2017; Frankel et al., 2007; Fucetola et al., 2009; Helm-Estabrooks, 2002; Mayer & Murray, 2012; Murray, 2012; Purdy, 2002; Villard & Kiran, 2017). Recent advances in the literature have shown that nonlinguistic cognitive abilities of IWA may interact with therapy outcomes, predict recovery, and affect the quality of life of IWA (Diedrichs et al., 2022; Dignam et al., 2017; Fonseca et al., 2018; Gilmore et al., 2019; Nicholas et al., 2017). This highlights the importance of considering and incorporating nonlinguistic cognitive abilities of IWA as part of the assessment in clinical practice. Currently in Taiwan, nonlinguistic cognitive impairments that may exist in IWA are largely overlooked in clinical practice. One potential reason for this is the paucity of evidence of nonverbal cognitive deficits in Taiwanese IWA, despite research findings in other languages (e.g., Fonseca et al., 2017; B. Lee & Pyun, 2014; Wong &

Correspondence to Hsin-jen Hsu: hsinjen.hsu@mx.nthu.edu.tw. ***Disclosure:*** *The authors have declared that no competing financial or nonfinancial interests existed at the time of publication.*

Law, 2022). In this study, we examined the nonlinguistic cognitive abilities of attention, working memory, and nonverbal intelligence, as well as their associations with aphasia severity in Mandarin speakers with aphasia. Our goal was to provide a foundation for evidence-based practices for Mandarin-speaking IWA.

Nonlinguistic Cognitive Functions in IWA

Attention

Previous research has investigated various cognitive abilities in aphasia, such as attention, executive function, working memory, and nonverbal intelligence. Of these, attention has generated much interest in both earlier and more recent research on aphasia. Attention is the fundamental ability to detect, select, and react to the stimuli present in the environment. It plays a crucial role in performing various language tasks, including language production, language comprehension, and reading (Coelho, 2005; Crosson et al., 2007; Sinotte & Coelho, 2007). Despite differences in terminology and the structure of attentional systems, most attention models adopted for applied research include functions of vigilance or sustained attention, selective attention, attention switching, and divided attention (Kurland, 2011; Mirsky et al., 1991; Sohlberg & Mateer, 2001). These different "types" of attention are sometimes viewed as attention processes of varying degrees of complexity. In addition, attention can be further divided in terms of its modality (e.g., visual or auditory).

Early speculation of attention deficits in aphasia arose from observations of variable performance on language tasks in IWA, even when using the same stimuli or tasks (e.g., McNeil et al., 1991). Subsequent empirical studies have indicated that all types of attention can be disrupted in IWA (Fonseca et al., 2017, 2019; Laures, 2005; Laures et al., 2003; McNeil et al., 2011; Murray, 2012; Murray et al., 1997; Petry et al., 1994; Schumacher et al., 2022; Varkanitsa et al., 2023; Villard & Kiran, 2017). For instance, Laures et al. (2003) compared auditory vigilance in a group of IWA and control participants during both a linguistic task (i.e., pressing a button upon hearing a target word) and a nonlinguistic task (i.e., pressing a button upon hearing a target sound). They observed decreased vigilance in the group with aphasia compared to the control group. Heuer and Hallowell (2015) examined the selective attention of IWA using eye tracking and observed that IWA exhibited greater difficulty allocating attention when the task demands were high. In addition to vigilance and selective attention, some studies have also revealed deficits in attention-switching abilities in IWA. Chiou and Kennedy (2009) compared the performance of 14 IWA and 14 age- and education-matched controls on attention switching using the Go/No-Go task. The group with aphasia performed less well than the control group in terms of both performance accuracy and reaction times in attention switching. Similar findings were also observed in a more recent study conducted by Kuptsova et al. (2023). Finally, there is also evidence that IWA exhibited greater difficulty with more complex attention processes. Villard and Kiran (2015) compared visual and auditory attention of various levels of complexity (sustain attention, selective attention, and integrational attention) in a group of IWA and age-matched healthy adults. In the sustained attention tasks, the participants responded by pressing specific keys on the keyboard based on the location of a tone or visual stimulus (i.e., "E" for left, "R" for right, spacebar for no tone). In the selective attention tasks, visual and auditory stimuli were presented simultaneously, and participants responded by attending to either visual or auditory stimuli. In the integrational attention task, participants pressed one key for both stimuli on the left, another for both on the right, and the spacebar if visual and auditory stimuli appeared on different sides. Villard and Kiran observed that increased attention complexity resulted in greater between-session intra-individual variability in reaction times (i.e., divided attention > selective attention > sustained attention) in the group with aphasia but not in the control group.

While the evidence for attention impairments in IWA is compelling, the relationship between attention and language severity or performance is not as conclusive. Helm-Estabrooks (2002) examined the performance of 13 IWA on four nonlinguistic cognitive tests (including visual attention) and four linguistic tests of the Cognitive Linguistic Quick Test (CLQT; Helm-Estabrooks, 2001). Most IWA exhibited deficits in attention, with only two aphasia patients (one with mild aphasia and one with severe aphasia) scoring above the normal cutoff on overall nonlinguistic cognitive tests. However, significant associations between linguistic and nonlinguistic tests were not observed. A similar finding of a lack of association between language and attention impairment has also been observed in a recent study by Gordon-Pershey and Wadams (2017), who examined the relationship between language and attention in eight people with nonfluent aphasia using the CLQT. Again, all participants demonstrated impairments in language and attention, but associations between measures of language and attention were not observed. On the contrary, Murray (2012) conducted an extensive study using a series to test to assess simple and complex attention abilities in a group of participants with aphasia. The study yielded significant findings, revealing associations between aphasia severity scores and all subtests of the Test of Everyday Attention (TEA). Additionally, caregivers' ratings of the presence and frequency of behaviors linked to attention deficits in everyday situations also displayed a significant association with aphasia severity scores. Furthermore, Murray observed that auditory sustained attention and auditory attention switching could predict the performance of IWA on auditory comprehension. Similar findings, indicating a link between attention and language performance in IWA, have also been observed in other studies (B. Lee & Pyun, 2014; J. B. Lee et al., 2020; Villard & Kiran, 2015, 2018; Zakariás & Lukács, 2021; cf. Schumacher et al., 2022).

The inconsistent research findings regarding the relationship between language severity and attention underscore the necessity for further investigation of this issue. Additionally, some researchers have raised concerns and cautioned that many attention tests involve test items that require language processing (e.g., Connor & Fucetola, 2011). For example, in many visual attention tests, test items often involve materials that can be verbally named, such as digits or geometric shapes such as triangles or circles. The auditory sustained attention (Elevator Counting) subtest of the TEA requires participants to count the number of a series of tones. While these tests may represent a more functional scenario, they also leave open the question of whether people with aphasia truly have a deficit in attention or whether they have language impairments that can influence their performance on such tasks. This underscores the significance of utilizing tasks or materials that minimize the demands on linguistic processes when investigating nonlinguistic cognition in IWA.

Short-Term/Working Memory

An area of cognition that intersects with attention and has also received considerable attention in aphasia is working memory (Mirsky et al., 1991; Sohlberg & Mateer, 2001; see Fonseca et al., 2017, for a review). Working memory is involved in many linguistic processes and plays an important role in language rehabilitation, including sentence comprehension (Berndt et al., 1991; Saffran, 1990), lexical processing and learning (Martin & Saffran, 1999), and the formation of knowledge in long-term memory (Freedman & Martin, 2001). Previous studies have shown that many IWA exhibited impaired short-term or working memory, regardless of the type of aphasia types (e.g., Broca's aphasia, Wernicke's aphasia, and transcortical sensory aphasia) or the specific tasks employed (e.g., digit span, word span, and *n*-back tasks). In addition, deficits in working in IWA do not appear to be limited to the verbal modality; they are also observed in the visual modality and seem to be independent of lesion location or lesion size. For instance, Potagas et al. (2011) examined the verbal and visuospatial short-term and working memory of a group of 58 IWA. The participants' verbal short-term and working memory were assessed using the digits forward and digits backward tasks, respectively. Their visuospatial short-term and working memory were evaluated using the Corsi forward block-tapping and backward block-tapping tasks, respectively. Potagas and colleagues discovered that the IWA exhibited deficits in both short-term and working memory, in both verbal and visuospatial modalities. In addition, the severity of the IWA was significantly correlated with short-term memory and working memory.

Similar findings were observed by Kasselimis et al. (2013), who used the same verbal and visual span tasks as in the study conducted by Potagas and colleagues, comparing the performance of 64 aphasic and 15 nonaphasic individuals with left-hemisphere lesions. The group with aphasia exhibited lower-than-expected performance on all four memory tasks, whereas the nonaphasic group did not. In a subsequent analysis, Kasselimis et al. further divided the aphasia group into subgroups based on lesion location (posterior, anterior, and global) but did not identify any group differences in memory performance. Kasselimis et al. interpreted this result as suggesting that memory deficits in individuals with left-hemisphere lesions may be dependent on the presence of aphasia rather than on lesion location or size. Finally, Lang and Quitz (2012) investigated short-term memory in two groups of left-hemispheric stroke patients, one with aphasia and one without. All participants completed forward and backward digit span tests measuring verbal short-term and working memory, a block tapping test measuring spatial short-term memory, and a facial memory test measuring recognition memory. Once again, the group with aphasia performed significantly lower on all memory measures than the nonaphasic group. Additionally, the scores on all memory tests showed significant correlations with performance on an aphasia test. When the aphasia group was further divided into subgroups based on aphasia type, there was a general tendency for individuals with more severe aphasia (i.e., global aphasia) to display more pronounced memory impairments.

Nonverbal Intelligence

Nonverbal intelligence is another area of cognition in which IWA often exhibit lower performance compared to healthy adults, as evidenced by numerous studies (Bailey et al., 1981; Baldo et al., 2015; Bonini & Radanovic, 2015; De Renzi et al., 1966; Falconer & Antonucci, 2012; Fucetola et al., 2009; Kang et al., 2016; Kertesz & McCabe, 1975; Senióẃ et al., 2009; Theiling et al., 2013; Villardita, 1985). However, it is noted that results are not always consistent across studies (e.g., B. Lee & Pyun, 2014).

Senióẃ et al. (2009) examined nonlinguistic cognitive abilities and language recovery in people with aphasia. In their study, the Raven's Standard Progressive Matrices (+SPM) was used to assess general intelligence. They observed that the aphasia group performed significantly poorer on the +SPM than healthy adults matched for age, gender, and education level, even though the majority of the participants with aphasia had a +SPM score within the normal range. Gonzalez et al. (2020) examined the nonverbal abilities of 200 stroke patients with aphasia. They discovered decreased performance on the Raven's Colored Progressive Matrices in all aphasia types, with patients with global aphasia scoring the lowest among all types. Additionally, scores on the Raven's Colored Progressive Matrices, as well as other nonverbal cognitive tasks (e.g., drawing, block design, calculation), were significantly correlated with the participants' language abilities.

Conversely, some studies did not find evidence of compromised nonverbal intelligence in IWA. B. Lee and Pyun (2014) conducted a study that examined the cognitive abilities of three groups of Korean speakers: individuals who had experienced right-hemispheric stroke, those with left-hemispheric lesions but without aphasia, and those with left-hemispheric lesions and aphasia. The group with aphasia exhibited a significantly lower group mean in verbal working memory and auditory sustained attention compared to the other two groups. However, there were no significant group differences in Raven's Colored Progressive Matrices. In addition, the severity of aphasia was significantly correlated with some attention tests but not the Raven's Colored Progressive Matrices. Likewise, other studies have also reported a lack of significant association between decreased nonverbal intelligence and aphasia severity (e.g., Christy & Friedman, 2005; Maeshima et al., 2002). These findings collectively point to the need for further investigation into nonverbal intelligence in IWA and its association with aphasia severity.

The Study

Previous studies have generally found deficits in nonlinguistic cognition in IWA, but findings on the relationship between cognitive deficits and the severity of aphasia have not always been consistent. Additionally, findings regarding some aspects of nonverbal cognition, such as nonverbal intelligence, in IWA have yielded inconclusive results. Furthermore, the majority of prior research on nonverbal cognitive functions in IWA has focused on English-speaking populations. To the best of our knowledge, no studies have directly examined nonlinguistic cognitive abilities in Mandarin-speaking IWA. At present, the standard procedure for assessing IWA in Taiwan does not involve evaluating nonlinguistic cognitive functions. Additionally, there are no standardized nonlinguistic cognitive tests tailored to measure Mandarin speakers with aphasia, nor are there any language intervention programs for aphasia that directly focus on or integrate nonlinguistic cognitive skills. Examinations of nonlinguistic cognitive abilities and their associations with aphasia severity in Mandarin-speaking IWA will provide empirical evidence essential for developing a better assessment protocol that incorporates nonverbal functioning as an integral part of the assessment of IWA (Braley et al., 2021; Crosson et al., 2007; Peach, 2017).

The purpose of this study was to explore nonlinguistic cognitive performance of a group of Mandarin-speaking aphasiac individuals who were in the chronic phase postonset of aphasia due to a left-hemispheric stroke. Specifically, we compared the performance of a group of Mandarin-speaking IWA to that of a group of control participants matched for age and education in three nonlinguistic cognitive domains: nonverbal intelligence, short-term memory, and attention. These cognitive functions have been widely examined in previous aphasia research. Furthermore, we explored the associations between nonlinguistic cognitive abilities and scores on a standardized test used to establish the severity of aphasia in Mandarin-speaking individuals.

The key questions addressed in this study were as follows:

1. Do Mandarin speakers with aphasia exhibit poorer performance in one or more areas of nonlinguistic cognitive functions compared to healthy adults?
2. Is there an association between nonlinguistic cognitive abilities and language performance in Mandarin speakers with aphasia? If such an association exists, do nonlinguistic cognitive abilities predict overall aphasia severity?

Method

Research Ethics

This study was approved by the Research Ethics Committee of the Kaohsiung Veterans General Hospital in Taiwan (18-CT1–05[171115–3]). Written informed consent was obtained from all participants prior to their participation.

Participants

Twenty-three IWA and 23 control adults with no history of neurological impairments participated in this study. The two groups were matched for age (no more than 5 years of difference) and education level. All the participants were native speakers of Mandarin Chinese. Participants in the aphasia group had experienced a left-hemisphere stroke with postonset time greater than 6 months and had no history of traumatic brain injury, progressive neurogenic etiologies (e.g., dementia and

Parkinson's disease), or hearing and visual impairments, as confirmed through self-reports, caregiver reports, and medical records. The current study involved experimental tasks that required participants to provide responses using a pen or a computer mouse. Therefore, the inclusion criteria also required the ability to use at least one hand for controlling a computer mouse and performing simple line and circle drawings on paper with a pen.

All the participants successfully passed visual and auditory discrimination screening tests to eliminate potential visual or auditory processing impairments. The visual screening test involved a matching task where the participants viewed a single target picture (comprising line drawings of complex shapes) and were required to identify the same picture from an array of two pictures (one target and one foil), with a total of 10 trials. In the auditory screening test, participants first listened to a target tone (e.g., 500 Hz) and subsequently determined whether the tone that followed was the same or different from the target tone, also with a total of 10 trials. The criterion for inclusion was no more than one incorrect response in each screening test. Table 1 summarizes the demographic information of the participants. Group differences in age or years of education were not significant.

Procedure

Both groups of participants completed a battery of six nonlinguistic cognitive tasks. These tasks included the +SPM, which provided a global measure of nonverbal intelligence, a computerized version of the forward Corsi block-tapping task to assess visual short-term memory, two selective attention tasks (one visual and one auditory), and two alternating attention tasks (one visual and one auditory). Participants with aphasia also completed a standardized aphasia test (Concise Chinese Aphasia Test [CCAT]; Chung et al., 2003; see the Method section) to characterize the severity of their language deficits.

The battery of tests was individually administered to each participant on separate days over a 2-week period. Participants with aphasia completed the standardized aphasia test in a single session lasting approximately 1 hr before the administration of the nonlinguistic cognitive tasks. All nonlinguistic cognitive tasks were completed in two separate sessions, each lasting approximately 1 hr, with short breaks included. The order of the tasks was counterbalanced to reduce potential order effects.

Tasks

Standardized Aphasia Test

We administered the CCAT, a standardized assessment tool for Mandarin-speaking IWA, to evaluate the severity of aphasia in our study participants. The CCAT was developed based on the Porch Index of Communicative Ability (Porch, 1971) with some modifications for linguistic and cultural appropriateness. Currently, it is the only standardized assessment tool with locally established norms for assessing aphasia in Taiwan (Chung et al., 1998). The CCAT comprises a total of nine subtests, with each subtest containing 10 test items (for a total of 90 test items) that assess primary communication modalities and linguistic functions. In Subtest 1 (Answering Simple Questions), participants listened to and answered 10 simple questions, such as "What is your name?" and "Which year is this year?" In Subtest 2 (Picture Description), participants were shown a picture containing multiple characters and scenes (e.g., fishing by a lake, camping under a bridge) related to outdoor activities and were asked to verbally describe it as comprehensively as possible. In Subtest 3 (Picture-to-Object Matching), participants saw two arrays of eight real objects (e.g., a hat, a mug, a sock, etc.) placed on a desk in front of them. They were provided with a set of pictures, one at a time, and asked to match each picture with one of the objects on the desk. In Subtest 4 (Auditory Sentence Comprehension), participants listened to 10 sentences, one at a time, and performed an action based on the content of the sentence (e.g., pick up the mobile phone). None of the responses in this subtest required a verbal response. In Subtest 5 (Object Names and Object Functions), participants were asked to name five objects and provided verbal description of the function of another five objects. In Subtest 6 (Reading comprehension), participants silently read 10 sentences, one at a time, printed on cards and performed actions (e.g., point to the apple) based on the content of the sentences. In Subtest 7 (Sentence Repetition), participants listened to 10 sentences, one at a time, and provided verbal repetition of the sentences they heard. In Subtest 8 (Copying Figures and Words), participants were presented with a card containing geometric shapes and Chinese characters. They were asked to copy these shapes and characters on a separate sheet of paper, striving for as much accuracy and resemblance to the characters and shapes on the card as possible. Finally, in Subtest 9 (Writing and Dictation), participants listened to a set of 10 questions or sentences (e.g., "What is this? Write it down" or "Write down the word 'hat'"), one at a time, and wrote down their responses on paper.

During the assessment, each participant with aphasia was individually evaluated by a speech-language pathologist. The duration of the test was approximately 1–1.5 hr. Each test item within a subtest was scored on a 12-point scale based on the accuracy, completeness, and response promptness of the participants' responses. A mean score for each subtest was calculated by averaging

Table 1. Participant characteristics of individuals with aphasia and control participants.

Aphasia group	Gender	Age[a]	Education[b]	Postonset[c]	Control group	Gender	Age[a]	Education[b]	Difference in age[a]	Difference in education[b]
A01	F	23	12	45	C01	F	18	12	5	0
A02	M	57	16	18	C02	F	55	16	2	0
A03	M	50	16	50	C03	M	50	16	0	0
A04	M	48	18	60	C04	F	50	18	2	0
A05	M	58	16	134	C05	M	59	16	1	0
A06	M	66	12	215	C06	M	61	12	5	0
A07	M	44	16	21	C07	F	46	16	2	0
A08	M	53	18	20	C08	M	54	18	1	0
A09	M	47	16	94	C09	F	43	16	4	0
A10	F	54	16	70	C10	M	55	16	1	0
A11	M	57	16	46	C11	M	60	16	3	0
A12	M	47	16	71	C12	F	51	16	4	0
A13	M	67	9	184	C13	F	66	9	1	0
A14	M	34	12	85	C14	M	36	12	2	0
A15	F	60	16	45	C15	F	59	16	1	0
A16	M	51	18	24	C16	F	48	18	3	0
A17	M	63	12	202	C17	M	58	12	5	0
A18	M	53	16	99	C18	F	53	16	0	0
A19	M	41	9	35	C19	F	42	9	1	0
A20	M	78	16	42	C20	M	80	16	2	0
A21	M	29	16	8	C21	M	31	16	2	0
A22	F	51	18	29	C22	F	50	18	1	0
A23	M	58	18	105	C23	M	61	18	3	0

[a]Age in years. [b]Years of education. [c]Months postonset.

the scores of the 10 test items within the same subtest. A grand mean score (i.e., CCAT overall score) was calculated by averaging the mean scores of all the subtests for each participant. This score was used to establish the overall severity of aphasia: a score below 3 points indicates "profound" aphasia, a score between 3 and 5 points indicates "severe" aphasia, a score between 5 to and points indicates "moderate to severe" aphasia, a score between 7 and 9 points indicates "moderate" aphasia, a score between 9 and 10 points indicates "mild to moderate" aphasia, a score between 10 and 11 points indicates "mild" aphasia, and a score above 11 points indicates "nearly normal" language abilities.

Nonlinguistic Cognitive Tests

A total of six tests were administered to measure three aspects of nonverbal cognitive abilities of the study participants: nonverbal intelligence, short-term memory, and attention. Currently, there are no standardized cognitive tests with local norms tailored for assessing nonlinguistic cognitive abilities of Mandarin-speaking IWA. Several standardized cognitive tests for aphasia are available in other languages and could potentially be translated and adopted, but many of the existing tools include test items or materials that rely considerably on the language skills of the participants. In light of this, for this study, we modified the standard Corsi block-tapping task and developed selective and alternating tasks based on the Symbol Cancellation subtest of the CLQT and the Trail Making Test (Reitan & Wolfson, 1995) to minimize the language demands of the test materials. Details about each task are provided below.

Nonverbal Intelligence

The Chinese version of the Raven's Standard Progressive Matrices Plus–Fourth Edition (SPM+) was used as a global measure of the participants' nonverbal intelligence. The original English version of the test was developed by Raven et al. (2008). The Chinese version of the test was developed and validated by J. H. Chen and Chen (2014), demonstrating a split-half reliability of .80–.86 and a test–retest reliability of .87 over a 4-week period. Concurrent validity was also established by demonstrating significant associations with standardized measures of nonverbal intelligence and a differential aptitude test (r = .60–.65). The test consists of 60 items, divided into five groups of 12 items each, with a maximum score of 60 points. The test items were arranged in ascending order of difficulty, and participants were allowed 30 min to complete the test. In each test item, participants viewed a main pattern in the upper part of the page with a missing part, and they were instructed to choose the missing element from an array of six choices to complete the main pattern.

Short-Term Memory

The participants' memory span was assessed using a computerized version of the Corsi block-tapping task developed by the authors, which was based on a web version of a Corsi block-tapping test (https://www.psytoolkit.org/experiment-library/experiment_corsi.html). During a pilot study, we observed a floor effect with a backward version of the task. Because previous studies often observed difficulties in both short-term and working memory in IWA and a strong association between short-term and working memory performance, we included only forward tapping version of the task in the current study.

Prior to starting the task, participants were informed that they would be playing a game in which their objective was to collect as many "money bags" (i.e., target object) as possible by memorizing the order and location of the "money bags" that appeared on the computer screen. Each trial started with a visual cue (1000 ms), followed by the appearance of nine empty boxes that indicate possible locations of the target object to appear on the computer screen. The locations of these nine empty boxes changed from trial to trial to prevent participants from predicting the target locations in order to deter verbal strategies, such as numbering the boxes that consistently appeared in the same spot.

The task began with a two-target sequence and increased to a maximum of nine, with two trials for each span level. In each trial, the target object (i.e., the money bag) appeared one by one in different boxes (stimulus duration = 1500 ms, interstimulus interval = 1000 ms). After the presentation, participants had to click on each box in the same order in which the target object had appeared. To ensure that participants understood the instructions and to check for their preferred way of giving responses (mouse clicking or pointing), three practice trials with a two-target sequence were given before the beginning of the test. The test terminated either when participants responded incorrectly to both trials of a given span level or when they completed the maximal level of the nine-target sequence. The short-term memory span of each participant was recorded based on the highest number of targets that they correctly responded to on at least one of the two trials for a given span level.

Visual Selective Attention

A visual selective attention task was developed based on the Symbol Cancellation Task from the CLQT (Helm-Estabrooks, 2001). In each trial of this task, participants were presented with a sheet of A4 paper (paper size = 21 cm × 29.7 cm) containing different figures printed in black and white. Before the test, the examiner circled a predetermined target figure and then asked the participant to circle all the figures identical to the target figure. Previous research has shown that performance in such tasks is affected by the similarity between the targets and distractors and the ratio between the target and the number of different distractors (Carrasco, 2011; Duncan & Humphreys, 1989). In this task, we controlled the similarities of targets and distractors so that, for each trial, the target and distractors shared the same basic shape (e.g., swirly; see Figure 1) but manipulated the target–distractor ratio. All the figures (i.e., shapes) used in this task were obtained from open resources on this website (https://openclipart.org/).

The task consisted of seven test trials with increasing difficulty levels achieved by changing the ratio of the target–distractor types from 1:1 to 1:7. For each trial, there were eight tokens for the target and an additional eight tokens for each type of distractor. In the trial with a target–distractor ratio of 1:1, there were eight tokens of the target figure and eight tokens of a distractor (resulting in a total of 16 figures on the sheet). For the trial with a target–distractor ratio of 1:7, there were eight tokens of the target figure and eight tokens of each of the seven different distractors (resulting in a total of 64 figures on the sheet). The locations of target figures and distractors were randomly arranged on the sheets. Each trial ended when participants verbally indicated that they had completed of the given trial. Mean accuracy was calculated by dividing the total of correct trials by the total number of trials in the task.

Visual Alternating Attention

A visual alternating attention task was developed based on the alternating subtest of the Trail Making Test (Reitan & Wolfson, 1995). In the original alternating subtest, participants connected a series of digit numbers and letters in order while alternating letters and numbers (e.g., 1-A-2-B-3-C . . .). In this study, we replaced the use of numbers and letters with line-drawing shapes (see Figure 2A). The task was presented as a series of eight 6 × 6 grid maze puzzles and composed of a total of eight test items. The eight test items were given in order of increasing difficulty, with two test items for each difficulty level: alternating between two different shapes, alternating between three different shapes, alternating between two different shapes of two different sizes each, and alternating between three different shapes of two different sizes each. For any difficulty level, one of the two test items was printed on a white background, and the other was printed on a paper with a distracting background (see Figure 2B). For each test item, the correct sequence of alternation of the figures was always provided on the left side of the task sheet to reduce memory demands. Participants started from the "entrance" of the maze (marked with an arrow; see Figure 2) and used a highlighter to draw the correct path by connecting the figures based on the pattern of alternation provided to them before the beginning of each test trial. For each test item, there was only one pathway that could go from the "entrance" of the maze to the goal with the correct alternation. A test item stopped if participants failed to reach the goal within 5 min of time. Mean accuracy was

Figure 1. A sample test trial of the visual selective attention task. The gray dotted circle indicated the target figure of this test trial. There were eight tokens of each of the six types of the distractors (total number of distractors = 48). At the beginning of the test, the examiner circled the target figure with a pen and asked participants to circle all the figures that were the same as the target figure.

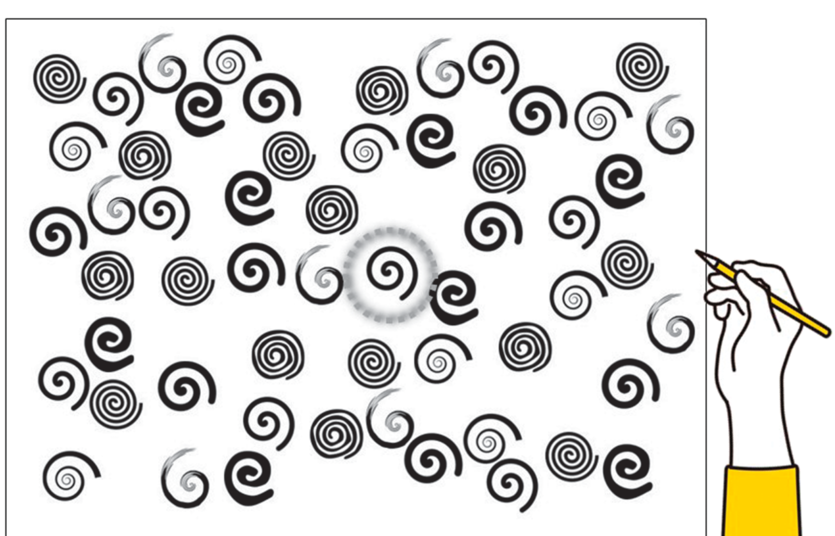
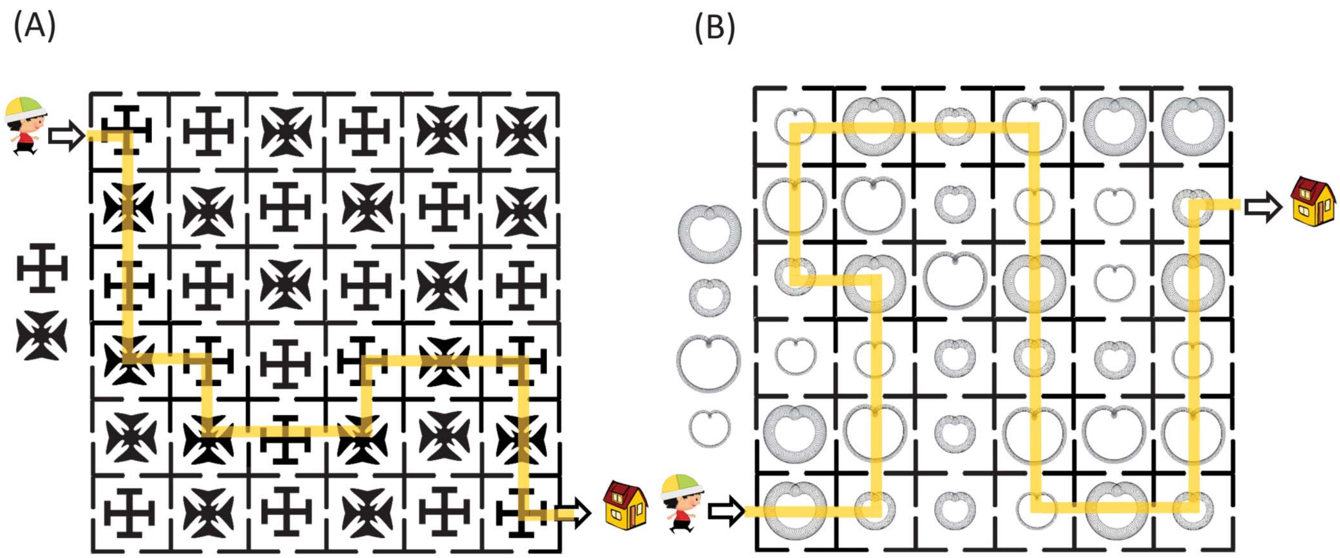


Figure 2. (A). A sample test trial of the visual alternating attention task that involves switching between two different shapes without a distracting background. (B) A sample test trial of the visual alternating attention task with a distracting background. The "entrance" to the maze was indicated by an arrow on the left and the "goal" on the right. Participants were told to help the child find his way home by altering between figures that were printed on the left.



calculated for each participant by dividing the number of successful test items by the total number of test items.

Auditory Selective Attention

An auditory selective attention task was developed to examine participants' ability to selectively attend to a given target when distractors were presented. Participants were presented with a target sound (e.g., 500 Hz pure tone, stimulus duration = 2000 ms) and instructed to press a button on an external response panel when they heard the target sound and not to respond when they hear a nontarget sound (e.g., 2000 Hz pure tone, stimulus duration = 2000 ms). The testing procedure commenced with a familiarization phase in which participants listened to the target tone 3 times. The familiarization phase was followed by a practice phase in which participants had to provide correct responses (two target tones and two distractors) before continuing onto a test phase. In the test phase, a total of 30 trials were administered, consisting of 10 target tones and 20 nontarget tones. Mean accuracy was calculated for each participant at the end of the test.

Auditory Alternating Attention

Four sound stimuli constituted the materials of this task: two short /a/ sounds respectively produced by a male and a female and two long /a/ sounds respectively produced by the same male and female. These four sounds were prerecorded and then processed using the Praat software (Boersma, 2001) to edit the duration of the sounds and incorporated into PowerPoint presentations for administration of the task.

In this task, participants pressed the appropriate button on a four-button response panel in response to each sound they heard, based on the feature of the sound they were instructed to pay attention to (a male or a female voice vs. a long or a short sound). The task consisted of a total of six trials, each containing eight sounds. For the first sound of each trial, participants had to determine whether it was a male or a female voice. For the second sound of the same trial, participants had to shift their attention to focus on the sound's length, determining whether it was long or short. This pattern continued for the third sound of the same trial, with participants shifting their attention again to determine whether it was a male or a female voice, and so on, up to the eighth sound of the same trial. The test comprised a total of six trials (i.e., a total of 48 sounds). Mean accuracy for each participant was determined by dividing the number of correct responses by the total number of responses.

Before the task began, participants were provided with instructions and then completed five practice trials. These practice trials were shorter versions of the test items, each containing only four sounds (for a total of 20 sounds). Participants needed to attain a minimum accuracy rate of 80% before proceeding to the test. If participants failed to reach this accuracy level in the initial round of practice, they were required to complete another round of practice until they achieved an 80% accuracy rate, ensuring their comprehension of the task instructions.

Results

Aphasia Severity

Table 2 presents the CCAT subtest scores for each IWA. A total score representing the overall severity of the aphasia was also calculated for each IWA by averaging their scores on the subtests. Two IWA (10%) had CCAT overall scores in the moderate-to-severe range (A19 and A20), three (15%) in the moderate range (A13, A16, and A23), seven (35%) in the mild-to-moderate range (A03, A07, A09, A11, A12, A14, and A15), five (20%) in the mild range (A02, A04, A05, A10, and A21), and finally six (30%) in the nearly normal range (A01, A06, A08, A17, A18, and A22).

It is noted that variations in the pattern of performance across subtests exist, even for IWA with the same level of severity. For example, both A16 and A23 were in the moderate range of severity. However, A16 outperformed A23 in Picture Description (subtest mean: A16 = 5.60; A23 = 3.00, max = 12 for all subtests), Auditory Sentence Comprehension (subtest mean: A16 = 9.90; A23 = 6.60), and Reading Comprehension (subtest mean: A16 = 7.10; A23 = 6.80), while A23 scored higher than A16 in Sentence Repetition (subtest mean: A16 = 8.80; A23 = 10.00). In addition, for IWA who performed relatively well on the standardized test, certain deficits can still be observed in their performance. For instance, of the six IWA who had a CCAT overall score within the "nearly normal" range, five of these participants (A06, A08, A17, A18, and A22) scored less than 11 points (i.e., below the cutoff for the "nearly normal" range) on at least one subtest, indicating that these IWA continue to have deficits in some aspects of language (see Table 2). Furthermore, some IWA scored within the "severe" range (i.e., < 5 points) on some of the CCAT subtests (e.g., A14, A20, A 23), even though their overall severity level based on CCAT overall score (the average score of all subtests) is lower, indicating uneven profiles across different aspects in these participants.

Table 2. CCAT subtest scores and overall scores (maximal score = 12 for each subtest).

Aphasia group	Subtest 1	Subtest 2	Subtest 3	Subtest 4	Subtest 5	Subtest 6	Subtest 7	Subtest 8	Subtest 9	CCAT overall
A01	11.30	11.70	12.00	11.30	11.60	12.00	11.80	11.60	11.40	11.63
A02	12.00	8.50	12.00	8.50	9.50	8.50	10.40	12.00	8.70	10.01
A03	10.20	8.80	12.00	10.60	7.40	8.30	10.10	11.00	5.80	9.36
A04	12.00	9.50	12.00	9.80	10.50	12.00	8.10	12.00	10.30	10.69
A05	10.80	9.40	11.40	10.30	11.50	9.20	11.20	12.00	8.90	10.52
A06	11.60	10.10	12.00	10.50	11.30	11.80	11.20	12.00	11.00	11.28
A07	6.60	6.20	12.00	12.00	8.00	9.70	10.60	10.20	7.80	9.23
A08	11.10	11.00	12.00	11.90	11.70	12.00	10.30	12.00	11.70	11.52
A09	8.80	8.30	12.00	9.00	8.60	10.40	9.40	11.10	6.60	9.36
A10	9.10	10.30	12.00	11.50	10.70	11.80	11.30	11.80	5.80	10.48
A11	8.80	8.50	12.00	11.00	8.00	12.00	8.60	10.30	5.80	9.44
A12	9.50	10.20	12.00	9.90	9.50	11.50	8.60	10.20	7.90	9.92
A13	9.20	6.30	12.00	9.70	7.10	9.30	9.10	11.20	5.70	8.84
A14	8.90	7.80	12.00	10.80	10.80	10.10	7.10	11.40	4.80	9.30
A15	8.00	7.90	12.00	8.60	9.70	9.40	8.50	11.70	5.40	9.02
A16	7.40	5.60	12.00	9.90	5.80	7.10	8.80	11.20	4.10	7.99
A17	11.20	11.30	12.00	12.00	11.30	11.40	11.10	12.00	10.00	11.37
A18	11.70	9.40	12.00	11.40	11.50	11.40	11.70	12.00	11.50	11.40
A19	6.10	4.30	12.00	8.10	4.90	6.20	4.30	11.20	3.40	6.72
A20	6.10	4.10	10.60	7.60	4.80	6.40	6.20	10.30	3.90	6.67
A21	10.90	9.20	12.00	8.40	9.70	10.80	10.80	11.80	8.50	10.23
A22	11.10	11.90	12.00	11.40	12.00	12.00	11.70	11.30	10.80	11.58
A23	7.40	3.00	12.00	6.60	5.30	6.80	10.00	11.60	3.90	7.40
M (*SD*)[a]	9.56 (1.92)	8.40 (2.47)	11.91 (0.31)	10.03 (1.52)	9.18 (2.35)	10.00 (1.98)	9.60 (1.91)	11.39 (0.63)	7.55 (2.77)	9.74 (1.50)

Note. Subtest 1: Answering simple questions. Subtest 2: Picture description. Subtest 3: Picture-to-object matching. Subtest 4: Auditory sentence comprehension. Subtest 5: Object names and object functions. Subtest 6: Reading comprehension. Subtest 7: Sentence repetition. Subtest 8: Copying figures and words. Subtest 9: Writing and dictation. CCAT overall score: the average score of the nine subtests. CCAT = Concise Chinese Aphasia Test.

[a]Mean scores and standard deviations of the CCAT subtests across all participants with aphasia.

Nonlinguistic Cognitive Performance

Table 3 summarizes the mean scores and standard deviations of the two groups on the nonlinguistic cognitive tasks, as well as the results of the group comparisons based on *t* tests. To control for Type 1 error inflation due to multiple comparisons, an alpha level adjusted for the number of tests conducted was used (α level = .05/6 = .008; Bender & Lange, 2001; S. Y. Chen et al., 2017).

All participants had +SPM scores within the normal range (i.e., standard score > 70). However, the mean score of the aphasia group was significantly lower than that of the control group, with a large effect size, $t_{(44)} = 4.28$, $p < .001$, $d = 1.26$. Additionally, differences in short-term memory between the groups were also observed. The mean score of the aphasia group in the Corsi block-tapping task was significantly lower than that of the control group, $t_{(44)} = 3.7$, $p = .001$, $d = 1.09$.

In the two visual attention tasks, the aphasia group showed lower group means than those of the control group. The results of the *t* tests indicated that in both the visual selective attention task, $t_{(44)} = 3.22$, $p = .002$, $d = 0.95$, and the visual alternating attention task, $t_{(44)} = 5.24$, $p < .001$, $d = 1.54$, there were significant group differences with large effect sizes. Finally, significant group differences with large effect sizes were also observed in the auditory selective attention task, $t_{(44)} = 4.48$, $p < .001$, $d = 1.32$, and the auditory alternating attention task, $t_{(44)} = 5.01$, $p < .001$, $d = 1.48$, tasks. The aphasia group had lower group mean scores than the control group in both the auditory selective attention task and the auditory alternating attention task.

As six IWA had CCAT overall scores in the "nearly normal" range (see Table 2), we conducted the same *t* tests by excluding data from these IWA and the matched control participants. Again, significant group differences were observed in the comparisons of group means in all nonlinguistic cognitive task (*p*s < .009). Interestingly, in all tasks, the effect sizes of group differences also increased slightly (+SPM: $d = 1.28$; Corsi block-tapping: $d = 1.11$; visual selective attention: $d = 0.98$; visual alternating attention: $d = 1.62$; auditory selective attention: $d = 1.72$; auditory alternating attention task: $d = 1.70$), indicating that the severity of aphasia might covary with the degree of deviation in nonlinguistic cognitive abilities in IWA.

Correlations Between Language and Nonlinguistic Cognitive Tests

Table 4 presents the correlation coefficients between nonverbal cognitive tasks and CCAT subtest scores in the IWA. The performance of the IWA on the +SPM was significantly correlated with all nonlinguistic cognitive tasks except for the visual alternating task. Their short-term memory, measured with the Corsi block-tapping task, was significantly correlated with both the visual and auditory alternating tasks. In addition, there was a significant correlation between the two visual attention task and the two alternating attention tasks.

In addition to these associations between nonlinguistic cognitive tasks, what is also interesting is the associations between different aspects of language ability and nonlinguistic cognitive performance in IWA. Although the CCAT test scores can only be used to establish the severity but not the types of aphasia, some of the subtests assessed specific language processes (e.g., Auditory Sentence Comprehension, Sentence Repetition) and therefore could provide useful information about potential associations between various aspects of language deficits (e.g., auditory comprehension, oral repetition, oral expression) and nonlinguistic cognitive abilities in IWA.

Here, we focused on the correlation coefficients associated with four CCAT subtests (i.e., Subtests 2, 4, 6, and 7). These subtests were chosen because they assess specific linguistic processes, and the scores of the IWA on

Table 3. Mean scores (*SD*) of the aphasia and control groups and independent sample *t* tests comparing scores of the two groups in the cognitive measures.

Cognitive measures	Aphasia group (*n* = 23)	Control group (*n* = 23)	*t*	*p*
+SPM[a]	28.30 ± 5.75	36.22 ± 6.74	4.28	< .001*
Corsi block-tapping[b]	4.74 ± 1.45	6.35 ± 1.50	3.70	.001*
VSA[c]	52.26 ± 24.49	83.39 ± 20.88	3.22	.002*
VAA[c]	56.26 ± 24.42	84.57 ± 8.68	5.24	< .001*
ASA[c]	78.46 ± 22.83	99.78 ± 0.78	4.48	< .001*
AAA[c]	89.17 ± 24.65	98.22 ± 5.53	5.01	< .001*

Note. An asterisk (*) indicates statistical significance at the adjusted alpha level of .008. +SPM = Raven's Standard Progressive Matrices; VSA = visual selective attention; VAA = visual alternating attention; ASA = auditory selective attention; AAA = auditory alternating attention.
[a]Raven's SPM raw score (maximal score = 60). [b]Memory span (maximal length = 9). [c]% mean accuracy.

Table 4. Correlations between CCAT subtests and +SPM, Corsi block-tapping, VSA, VAA, ASA, and AAA.

CCAT subtests	+SPM	Corsi block-tapping	VSA	VAA	ASA	AAA
+SPM	—	.56**	.31	.70**	.47*	.64**
Corsi block-tapping		—	.35	.48*	.39	.48*
VSA			—	.42*	.43*	.23
VAA				—	.31	.44*
ASA					—	.38
Answering Simple Questions (Subtest 1)	.35	.27	.16	.22	.51*	.58**
Picture Description (Subtest 2)	.51*	.30	.28	.36	.55**	.78**
Picture-to-Object Matching (Subtest 3)	.28	.29	−.01	.45*	−.04	.52*
Auditory Sentence Comprehension (Subtest 4)	.20	.24	.10	.18	.23	.68**
Object Names and Object Functions (Subtest 5)	.39	.26	.24	.31	.40	.70**
Reading Comprehension (Subtest 6)	.40	.45*	.41	.32	.42*	.80**
Sentence Repetition (Subtest 7)	.24	.24	.08	.31	.23	.51*
Copying Figures and Words (Subtest 8)	.12	.01	.06	.12	.01	.13
Writing and Dictation (Subtest 9)	.39	.27	.17	.21	.45*	.63**
CCAT Overall Scores	.42*	.33	.21	.32	.46*	.76**

Note. CCAT = Concise Chinese Aphasia Test; +SPM = Raven's Standard Progressive Matrices; VSA = visual selective attention; VAA = visual alternating attention; ASA = auditory selective attention; AAA = auditory alternating attention.
*p < .05. **p < .01.

these subtests exhibited variability, enabling valid conclusions to be drawn based on correlational analyses. Both Subtest 1 (i.e., Answering Simple Questions) and Subtest 9 (i.e., Writing and Dictation) required participants to understand verbally presented question for each test item (a total of 10 test items for each subtest) before responding. Performance on these two subtests was jointly influenced by auditory comprehension and verbal expression abilities. Some of the test items on Subtest 5 (Object Names and Object Functions subtest) required naming objects, while others required describing the function of objects; therefore, scores on this subtest did not solely reflect one's ability in lexical retrieval. Moreover, the variability in scores on Subtest 3 and Subtest 8 was very small, making it difficult to draw reliable conclusions based on the correlations associated with these two subtests.

Subtest 2 assessed verbal expression. In this subtest, participants saw a picture containing multiple characters and activities related to an outdoor picnic and verbally described what was happening in the picture. Scores on this subtest were significantly correlated with the +SPM (r = .51, p = .01) as well as the two auditory attention tasks (auditory selective attention: r = .55, p = .006; auditory alternating attention: r = .78, p < .001). Different from Subtest 2, Subtest 4 assessed auditory comprehension of spoken sentences. Scores on this subtest were only significantly correlated with the auditory selective attention task (r = .68, p < .001). Subtest 6 assessed reading comprehension. Each test item in this subtest required the participants to quietly read a written sentence printed on a card and perform an action based on the content of the sentence. Therefore, performance on this task did not involve verbal responses or the understanding of different verbal instructions for each test item. The participants' scores on Subtest 6 were significantly correlated with Corsi block-tapping (r = .45, p = .03) and the two auditory attention tasks (auditory selective attention: r = .42, p = .04; auditory alternating attention: r = .80, p < .01), but not with the two visual attention tasks. Furthermore, Subtest 7 assessed verbal repetition of sentences. As shown in Table 5, the only nonlinguistic cognitive task that significantly correlated with the scores on Subtest 7 was the auditory alternating task (r = .51, p = .01).

Prediction of Nonlinguistic Cognitive Measures on CCAT Performance

A regression analysis was conducted to examine the extent to which the measures of cognitive abilities predict aphasia severity based on the CCAT overall scores of the participants with aphasia. As such, a two-step hierarchical regression analysis with CCAT overall scores as the dependent variable was conducted to determine the change in R^2, with age and years of education comprising Block 1 and cognitive measures in Block 2.

Table 5 presents the regression coefficients. Age and years of education did not explain significant variance in CCAT overall scores. The regression model was significant at Step 2, $F(8, 22) = 4.3$, p = .009. Cognitive tasks significantly explained an additional 66% of the variance

Table 5. Hierarchical regression analysis examining prediction of cognitive abilities and fluency type on CCAT overall scores.

Predictor variables	β	*t*	R^2	R^2 change	*p*
Step 1			.05	.05	.62
Age	−0.03	−0.98			.34
Education (years)	−0.03	−0.12			.91
Step 2			.71	.66	.005*
Age	0.04	1.46			.17
Education (years)	−0.01	−0.04			.97
+SPM	−0.02	−0.18			.86
Corsi block-tapping	−0.18	−0.85			.41
VSA	−0.44	−0.65			.53
VAA	1.13	0.81			.43
ASA	0.02	1.52			.15
AAA	6.08	4.56			< .001*

Note. CCAT = Concise Chinese Aphasia Test; +SPM = Raven's Standard Progressive Matrices; VSA = visual selective attention; VAA = visual alternating attention; ASA = auditory selective attention; AAA = auditory alternating attention.

*$p < .01$.

in CCAT overall scores after controlling for age and education. An examination of the beta coefficients indicated that auditory alternating attention is the only significant predictor (β = 6.08, $t = 4.56$, $p < .001$).

Discussion

Compromised Nonlinguistic Cognition in IWA

This study examined the nonlinguistic cognitive abilities of Mandarin-speaking individuals with poststroke aphasia. We compared the performance of a group of IWA with a group of healthy adults matched for age and education level in three aspects of nonlinguistic cognitive abilities. The most notable finding of this study was that, compared to the control group, the aphasia group performed significantly poorer in all nonlinguistic cognitive tasks. We observed poor performance of the IWA on all attention tasks. This result is consistent with previous findings of a deficit in both visual and auditory attention in many IWA (Chiou & Kennedy, 2009; Erickson et al., 1996; Kuptsova et al., 2023; Laures, 2005; Laures et al., 2003; Robin & Rizzo, 1989; Villard & Kiran, 2015). In this study, we included visual and auditory attention tasks of two different levels of complexity (i.e., selective attention vs. alternating attention). Previous studies have observed that IWA may be disproportionately affected by increased attentional demands (Villard & Kiran, 2015). This was confirmed in this study. The effect sizes for between-group comparisons of the two alternating attention tasks were larger than those for the two selective attention tasks, although the difference in effect sizes for the two auditory attention tasks (auditory selective attention: $d = 1.32$; auditory alternating attention: $d = 1.48$) was smaller than that for the visual attention task (visual selective attention: $d = 0.95$; visual alternating attention: $d = 1.54$).

Similar to previous studies, we observed poorer short-term memory in IWA (Kasselimis et al., 2013; Lang & Quitz, 2012; Martin & Ayala, 2004; Potagas et al., 2011). Although the short-term memory task used in this study involved only visual material, existing literature has provided evidence of impairments in both visual and auditory short-term memory in IWA (De Renzi & Nichelli, 1975; Kasselimis et al., 2013; Lang & Quitz, 2012; Martin & Ayala, 2004; Ostergaard & Meudell, 1984; Potagas et al., 2011). Some researchers have argued that the information stored in short-term memory is the result of attentional processing, which involves allocating limited resources to external or internal information to which an individual selectively attends (Cowan et al., 1990; Morey & Bieler, 2013). The correlation analyses revealed an interesting result, showing that there was a significant association between the visual short-term memory span of the IWA and their performance in the visual and auditory alternating attention tasks, while no such association was observed in less complex attention tasks (i.e., auditory and visual selective attention). This result suggests a close relationship between short-term; memory and attentional processing, especially when task demands (or task complexity) on attentional resources are high (Lewis-Peacock et al., 2012; Makovski & Jiang, 2007).

In this study, all the IWA scored within the normal range on the +SPM. However, the IWA, as a group, exhibited a lower group mean on the test, a result that is consistent with the findings of previous studies (Bailey et al., 1981; Baldo et al., 2015; Kertesz & McCabe, 1975; Senіów et al., 2009). Furthermore, scores on the +SPM were positively correlated with the visual short-term memory task and the visual alternating attention task in IWA. Given that all the test items of the +SPM involved solving visual analogy problems of geometric graphical matrices, this finding was somewhat expected. What was unexpected, however, is that the scores of the +SPM were also correlated with the scores on the two auditory attention tasks. Although performing the +SPM did not require verbal expression or auditory comprehension, it is possible that some participants used verbal mediation as a strategy to guide their performance on the test (Perrone-Bertolotti et al., 2014). If this is the case, then the lower group mean for the IWA on the +SPM could be attributed to the difficulties in utilizing a cognitive–linguistic strategy due to their impaired language abilities.

Associations of Different Aspects of Language and Nonlinguistic Cognition

Associations between nonlinguistic cognitive abilities and performance on certain subtests of the CCAT that assessed specific language processes were also examined. We discovered that the IWA who showed greater deficits in auditory sentence comprehension (Subtest 4) also performed less well on the auditory alternating attention task, suggesting a possible restriction of auditory attention on the auditory comprehension of linguistic materials in the IWA. Similarly, we observed a link between sentence repetition (Subtest 7) and auditory alternating attention in the IWA. In fact, sentence repetition is a complex task that involves multiple sound–related processes, including phonological coding of auditory inputs and temporary storage of auditory verbal information in one's short-term memory (Gathercole, 1994; Gathercole & Baddeley, 2014; Polišenská et al., 2015). Limitations in auditory attention are likely to affect any one or more of these processes, which in turn may restrict performance in sentence repetition.

The only aspect of language deficits associated with the +SPM was discovered in the performance of the IWA on the Picture Description subtest. The material of the Picture Description subtest involved complex scenes with multiple characters and events. Thus, the observed association between +SPM and the performance in this subtest might reflect a restriction of the compromised visual analogical abilities of the IWA on their abilities to process complex visual stimuli. Similarly, the only language subtest associated with the performance on the Corsi block-tapping task is the reading comprehension subtest, indicating a constraint of compromised visual short-term memory on the reading comprehension of the IWA. Interestingly, the degree of deficits in both the Picture Description and Reading Comprehension subtests in the IWA was correlated with the performance of the two auditory attention tasks. One possible explanation is that performance in both the Picture Description and Reading Comprehension subtests, as well as other CCAT subtests, all involved understanding verbally presented instructions (e.g., "Tell me what was happening in this picture" in Subtest 2). If this is the case, then subtests requiring listening to different questions for different test items (e.g., Answering Simple Questions, Sentence Repetition) should have shown a stronger association with auditory attention than subtests involving only simple verbal instructions presented at the beginning of a subtest (e.g., Picture Description). However, this does not seem to be the case. An alternative explanation is that the observed associations might, at least in part, reflect the fact that both verbal expression and reading comprehension involve accessing phonological information of words or sentences. Behavioral studies on reading comprehension have shown that successful reading relies on an interaction between decoding linguistic visual input and accessing phonological information (Booth et al., 1999, 2000). More importantly, active retrieval of phonological information during reading is not limited to the reading of alphabetic languages but also occurs in the reading of logographic languages, such as Mandarin (Perfetti & Zhang, 1995; Perfetti et al., 1992; Zhou & Marslen-Wilson, 2000). While the auditory stimuli used in the two auditory attention tasks were nonverbal materials, there is evidence that processing meaningful sounds might involve the same neural resources as those used for processing nonverbal auditory materials (e.g., Saygin et al., 2003).

Prediction of Aphasia Severity by Nonlinguistic Cognitive Abilities

Given the poor performance of the aphasia group on all nonverbal cognitive tasks and the correlations between these cognitive tasks and language performance, examining the prediction of aphasia severity by different cognitive measures, after controlling for age and education, will further elucidate the relative contribution of different cognitive factors to language severity. Our findings revealed that performance in auditory alternating attention is the only significant predictor, explaining over 65% of variance in the CCAT overall scores, which represent the severity of aphasia. The strong association between auditory alternating attention and the severity of impairments is also evident in the results of the correlation analysis, with moderate-to-strong correlations observed between auditory alternating attention and nearly all CCAT subtests (except for the Copying Figures and

Words subtest). Notably, the CCAT contains several subtests that primarily concern visual processing (e.g., Picture-to-Object Matching, Copying Figures and Words, Reading Comprehension). It is intriguing that neither visual attention nor visual short-term memory turned out to be significant predictors of performance on CCAT, especially when considering the findings that the aphasia group performed poorer than the control group on both the visual attention tasks and the visual short-term memory task. This result is likely due to the small performance variations on the Picture-to-Object Matching and Copying Figures and Words subtests of the CCAT.

Currently, the CCAT is the only standardized language assessment tool for aphasia with published local norms in Taiwan. This standardized test is extensively used in clinical practices, not only to determine the severity of aphasia but also to monitor the progress of language recovery. The current findings show that an individual's auditory alternating attention is highly predictive of performance on this test. This result suggests that CCAT scores may indicate both linguistic and cognitive abilities. Prerequisite cognitive abilities are required for specific subtests in the CCAT and may impact the results of language evaluations for IWA. Future development of aphasia-friendly measures with a cognitive–linguistic focus may help interpret overall communicative performance for IWA in Taiwan.

Limitations and Future Research

This exploratory study was undertaken to gain an understanding of the nonlinguistic cognitive abilities of Mandarin-speaking IWA. There are several limitations to our study. First, the examinations of nonlinguistic cognitive abilities in this study were not comprehensive. For instance, only one measure of visual short-term memory was included in this study. Previous studies have also reported impairments in executive functions and other attention functions (e.g., divided attention) in IWA (Dutta et al., 2022; Mohapatra & Marshall, 2020; Schumacher et al., 2022). Future studies could more comprehensively measure all nonverbal cognitive performance in Mandarin speakers with aphasia. This would provide the empirical evidence necessary for evidence-based practice in the rehabilitation of IWA. Second, the nonverbal cognitive measures used in this study were not standardized tests, except for the +SPM. Therefore, the severity or the degree in which the cognitive abilities of the IWA deviate from those of the individuals in the comparison group was unknown. In addition, information about the concurrent validity of the current tasks, which is important for evaluating the validity of the current findings, was also not available. This reflects a lack of standardized nonlinguistic cognitive tests with local norms for IWA and highlights the need to develop standardized tests tailored for assessing nonlinguistic cognitive abilities and their associations with language abilities in Mandarin speakers with IWA.

The CCAT provides a useful tool for establishing the severity (based on overall scores) of language impairment in IWA. However, the test scores from CCAT cannot be used to determine the type of aphasia (e.g., anomic aphasia, Broca's aphasia, Wernicke's aphasia). In addition, the current sample was somewhat skewed, with no IWA with severe or profound aphasia. Therefore, caution is needed when extrapolating the results of this study to understand the nonlinguistic cognitive abilities of IWA of specific types or different levels of severity. A comprehensive understanding of the nonlinguistic cognitive abilities of Mandarin speakers with IWA requires further investigations based on a more representative sample that closely reflects the heterogeneity of aphasia.

Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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