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Alerting, Orienting, Executive Control and Language Function in Post-stroke Aphasia Patients

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Abstract: Background: Aphasia is frequently observed in post-stroke patients, and this population usually presents attention impairment. Attention is considered to play an important role in the language recovery of patients with Post-Stroke Aphasia (PSA). However, it is no idea whether language function correlates with attention performance. In our study, we investigated the association between attention and language function in PSA patients. Methods: This cross-sectional study was performed from September 2020 to May 2021. A total of 26 PSA patients and 26 healthy people without neurological disorders were recruited in this study. And demographic, language performance, attention performance were recorded. The Aphasia Battery of Chinese (ABC) was applied to assess language performance. Attention network tests were used to measure attention performance. The attention scores were compared between the PSA patients and healthy people. The correlation analysis and stepwise linear regression analysis are used to explore the relationship between attention and language in the PSA group. Results: A total of 26 PSA patients (male/female = 21:5) and 26 healthy people (male/female = 21:5) were enrolled in the study. The mean ages were 50.00 ± 9.01 years, 48.88 ± 7.01, respectively. According to ABC, 14 (53.85%) patients experienced Broca's aphasia. In accordance with Attention Network Test (ANT), there were significant differences in accuracy and reaction time between the PSA group and the control group (all $P<0.05$). Orienting RT and alerting inverse efficiency (IE) were significant differences between the two groups. The spearman correlation revealed that executive control was associated with aphasia severity grade, repetition correlated with alerting, auditory comprehension correlated with orienting. And after the stepwise regression analysis, executive control RT alone emerged as a significant predictor of auditory comprehension. Alerting IE and orienting RT are the predictors of repetition. Conclusions: The results suggest that among PSA patients, language items (aphasia severity grade, auditory comprehension, and repetition) are related to three specific attention functions: alerting, orienting, and executive control. Disentangling the mechanism of attention deficits in PSA patients may provide a supplement for the rehabilitation strategies in PSA patients.

Keywords: Post-stroke Aphasia, Attention Network Test, Aphasia Battery of Chinese, Stroke, Attention

1. Introduction

Aphasia is a frequent symptom of stroke survivors, which is characterized by impairment in oral speech, comprehension, naming, repetition, reading, or writing. Language production is the result of the function of many cognitive processes including executive functions, especially attention, memory, and planning. Several studies demonstrated that non-linguistic cognitive impairments are associated with language deficits in aphasia [1-3], and most of the cognitive tests were significantly associated with language tasks. Of these cognitive skills, attention may be particularly important for studies of aphasia.

Attention is the fundamental of cognition, exerting an enormous function on the language process. Previous studies have revealed that attention and language are closely related. A study showed that the indices of intra-individual variability in response time in Conner's Continuous Performance Test were associated with speech discrimination and with performance in semantic association tasks in PSA patients [4]. Attention performance [5] in Symbol search of WAIS correlated significantly with aphasia severity and verbal comprehension ability in PSA. Executive attentional processes have been considered to act on the generation of ideas for propositional language production. What is more? Attention treatments can effectively improve language function in PSA patients, there are some treatments that were proven effective, such as gradual attention training [6], Attention Process Training-3 [7], attention process training-II [8], et al.

There are many tools for PSA patients to be screened for attention impairment. The Loewenstein Occupational Therapy Cognitive Assessment (LOTCA) [3] and the Cognitive and Linguistic Quick Test (CLQT) [9] were used to measure the several cognitive impairments. Attention deficit was such a small part of the cognitive impairments to be noticed. The Rating Scale of Attentional Behavior (the RSAB) [10], Symbol Search of WAIS [2], the Letter Cancellation Task of BLAD, and the Test of Everyday Attention [10] were designed for attention impairment. But they were used for some parts of attention assessment. It is a restricted range of attention functions to be concerned about. The Attention Network Test (ANT) has been popular in the neuropsychological literature since 2002 when it first been described. The ANT divided attention into three networks: alerting, orienting, and executive control. It is a quick and easy tool to measure the efficiency of the three networks, avoiding the influence of language-related factors on test results. Furthermore, the ANT can assess attention without space constraints.

Though scarce studies have focused on the associations between attention performance in attention network test (ANT) and aphasia, there are still studies examined alerting, orienting separately in stroke patients. One study of attention deficits in stroke patients [11], which used Test of Attentional Performance, found that patients with aphasia tended to have a greater deficit in selective attention, patients in the acute phase performed at a lower level than chronic patients in the alertness test. A population-based study on 976 stroke patients was discovered that the frequency of disturbance of orientation was up to 55% [12]. Only a study aimed to analyse the attention using ANT in patients with aphasia. Orienting and executive control effects were found in the aphasia group. Comparing their performance to a neurotypical control group, the aphasia group performed worse in the orienting cue. While these studies suggest that there are alerting and orienting attention impairments in stroke patients, no study has systematically studied the interface of attention using Posner and Petersen's model and language. There are not only attention deficits are pervasive in patients with aphasia, but also that there exist an association between attention and language.

This study aims to evaluate the attention performance of PSA patients by ANT and to compare the attention performance between PSA group and the control group, furtherly to analyse the relationship between attention dysfunction and language impairment.

2. Material and Methods

2.1. Participants

A total of 26 PSA patients and 26 healthy control people from The First Affiliated Hospital of Jinan University and Guangzhou Red-Cross Hospital, were recruited between Oct 2020 and May 2021. Aphasia Battery of Chinese was used to diagnose aphasia. The inclusion criteria for the PSA group were as follow: (a) native Chinese speaker, (b) PSA patients ranged in age from 28 to 65 years, (c) diagnosed with aphasia, (d) first stroke with lesions located in the left brain hemisphere, (e) right-handedness, and (f) signed informed consent. The inclusion criteria for the control group were as follow: (a) native Chinese speaker, (b) ranged in age from 28 to 65 years, (c) without aphasia, (d) with no self-reported history of neurological disease, stroke, head trauma, or psychiatric disturbances. Exclude criteria for the PSA group were as follows: (a) Pre-stroke language and cognitive impairment or other neurological diseases, (b) Repeated stroke, cerebellar stroke, or brain stem stroke, (c) Severe dysarthria, (d) Severe medical illness, hearing or vision impairment. Exclude criteria for the control group were as follows: (a) unable to complete all neuropsychological assessments, (b) Visual impairment, (c) cognitive impairment.

2.2. Demographic and Clinical Data

Demographic and clinical variables of PSA patients were as follows: age, gender, educational level, month after stroke onset, stroke type, lesions location. All these demographic and clinical variables were presented in Table 1.

Table 1. *Demographic characteristic of the PSA patients.*

participant	Age	Gender	Education	MPSO	Stroke type	Lesion location
PSA1	48	M	Bachelor	7	Hemorrhagic	the left internal capsule
PSA2	57	M	Associate	4	Hemorrhagic	the left basal ganglia
PSA3	55	M	Bachelor	5	Ischemic	the left middle cerebral artery
PSA4	47	M	Bachelor	12	Hemorrhagic	the left frontal lobe and temporal lobe
PSA5	40	M	Junior high school	9	Hemorrhagic	the left basal ganglia
PSA6	37	M	High school	7	Hemorrhagic	the left basal ganglia
PSA7	28	M	Primary school	3	Hemorrhagic	the left frontal lobe and temporal lobe
PSA8	52	M	Bachelor	10	Hemorrhagic	the left external capsule
PSA9	65	M	High school	3	Ischemic	the left middle cerebral artery
PSA10	49	M	High school	10	Ischemic	the left basal ganglia

participant	Age	Gender	Education	MPSO	Stroke type	Lesion location
PSA11	48	M	Bachelor	3	Hemorrhagic	the left parietal and frontal lobe
PSA12	48	M	High school	7	Hemorrhagic	the left basal ganglia
PSA13	53	M	High school	3	Ischemic	the left parietal and frontal lobe
PSA14	53	M	Associate	10	Hemorrhagic	the left basal ganglia
PSA15	60	M	Junior high school	3	Hemorrhagic	the left basal ganglia
PSA16	47	F	High school	4	Hemorrhagic	the left basal ganglia
PSA17	55	F	Bachelor	3	Hemorrhagic	the left basal ganglia and the temporal lobe and the frontal lobe
PSA18	62	M	Junior high school	9	Hemorrhagic	the left basal ganglia
PSA19	46	F	Bachelor	2	Hemorrhagic	the left temporal lobe
PSA20	63	F	Junior high school	2	Hemorrhagic	the left basal ganglia and the temporal lobe and the frontal lobe
PSA21	60	F	Primary school	12	Hemorrhagic	the left basal ganglia
PSA22	44	M	Associate	3	Hemorrhagic	the left basal ganglia
PSA23	48	M	Associate	1	Hemorrhagic	the left temporal lobe and parietal lobe
PSA24	52	M	Bachelor	3	Hemorrhagic	the left basal ganglia
PSA25	32	M	High school	2	Hemorrhagic	the left basal ganglia
PSA26	51	M	Bachelor	4	Hemorrhagic	the left basal ganglia and the temporal lobe and the parietal

Note. MPSO, months post-stroke onset; M, male; F, female.

2.3. Language Assessment

All PSA patients were required to accept language assessment, performed by a trained speech and language therapist. The Aphasia Battery of Chinese was edited by Gao [13]. It was the Chinese version of the Western Aphasia Battery used to diagnose aphasia and score for spontaneous speech (information volume and fluency), auditory comprehension, repetition, naming, and calculate aphasia quotient (AQ). Specifically, it includes sub-items such as information, fluency, repetition, word naming, color naming, response naming, hearing recognition, verbal instruction, etc. The fluency score ranges from 9 to 27, which includes three degrees: non-fluent aphasia (from 9 to 13), intermediate aphasia (from 14 to 20), and fluent aphasia (from 21 to 27). Boston diagnostic aphasia examination (BDAE) was used to evaluate aphasia severity grades: grade 0: expression dysfunction, grade 1: Can speak a small amount of vocabulary; grade 2: express simple phrases, but with obvious grammatical errors; grade 3: There are no obvious errors in the expression of everyday language; grade 4: Can express oneself well, but the speech is not smooth; Grade 5: Very slight expression disorder, only the patient can feel it. AQ= [(spontaneous speech + auditory comprehension) /20 + (repetition + naming) /10] × 2. AQ is to assess whether a patient has aphasia, and it also reflects the severity of aphasia and can be used as an evaluation index for the improvement and deterioration of aphasia. Efficacy criteria: AQ=98.4~99.6 is normal; AQ<93.8 is aphasia.

2.4. Attention Assessment

The attention network test was created using E-Prime (Version 2.0, Psychology Software Tools). Stimuli were presented on a 14-in screen. Participants viewed the stimuli shown on a computer screen, and responses were collected via two response buttons (“n” for left, “m” for right). All the details of the tasks were shown in figure 1. The stimuli was presented in the follow order: (a) fixation (400-1,600ms), (b) asterisk cue (100ms), (c) pre-target fixation (400ms), (c) an array of stimuli containing the target (≤1,700ms), (d) post-target fixation (1,900-3,100ms). The asterisk cue includes the following four types: no cue (only fixation without asterisk), central cue (an asterisk appears at the fixation point), double cue (an asterisk appears at both above and below fixation), spatial cue (an asterisk appears either above or under the fixation). The array of stimuli contains the target (in the middle) and flankers. The target points either left or right. And the three flankers are as follows: neutral (lines), congruent (arrows pointing the same as target), incongruent (arrows pointing opposite to the target). Participants were required to press the response button depending on the target arrow direction as quickly and accurately as possible. The press direction and the response time (since the target appeared to the pressing) were recorded. One practice block and three experimental blocks were included in the task. The practice block contained 36 trials, which included feedback to make sure participants understand. Each experimental block contained 96 trials with 48 conditions repeated twice: 4 cue types X 2 target locations X 2 target directions X 3 flanker conditions. The trials were presented in random order in each block, and there were rests between blocks.

Three processes were collected from the Attention network test as follows: alerting, orientation, executive control. RT/ACC data include all trials but that the alerting, orienting, and executive control effect data for RT/ACC include only correct trials:

(a) Alerting effect = no cue –double cue;
(b) Orienting effect = center cue –spatial cue;
(c) Executive control effect = incongruent –congruent.

Inverse efficiency (IE) is an adjusted RT measure derived by dividing RT by its corresponding percentage accuracy. Compared to the conventional RT, the IE score is not based on accurate trials. It adjusts RT performance at the expense of accuracy that may be in favor of speed. The accuracy performance was also calculated as the proportion of errors (PE). To account for trade-off effects between the RT and PE, an inverse efficiency (IE) index was calculated [14]: IE = RT / 1- PE=RT/ACC.

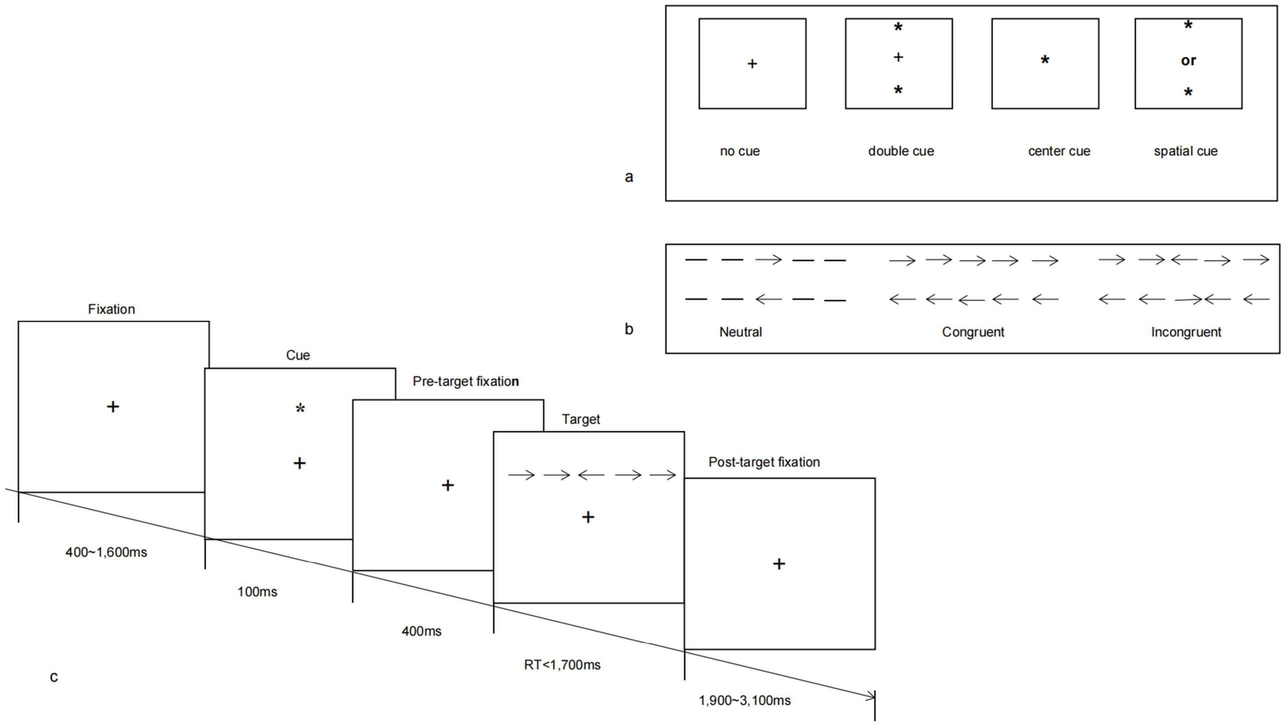

Figure 1. *Experimental paradigim of the attention network test (ANT): (a) the four cue conditions; (b) the six types of stimuli used in the target conditions; and (c) an example of the procedure.*

2.5. Statistical Analysis

Statistical analysis was performed with SPSS version 26.0. The Continuous variables with normal distribution were presented as mean ± standard deviation and compared using dependent-samples t. Categorical variables were presented with numbers and percentages, compared using the X^2-test. Demographic information was reported with the mean and standard deviation or frequency counts. The gender distribution difference between the PSA group and control group were compared using the X^2-test. Language ability was assessed by six subtest scores from the ABC. While attention performance was measured by ANT. The sub-scores of ANT between the PSA group and the control group were compared using independent-samples t. The relationships between aphasia quotient, spontaneous speech, auditory comprehension, repetition, naming, and attention performance were tested using separate multivariate linear regressions (controlling for age, sex, education, and MPSO) for each attention sub-item. If assumptions were not met the multiple linear regressions, logistic regressions were used. Patients with aphasia severity grade <3 were defined as having a severe communication disturbance. The relationships between aphasia severity grades and attention performance were tested using multivariate binary logistic regressions. A two-sided P < 0.05 was considered to be statistically significant.

3. Results

3.1. Characteristics of Study Population

In line with the previous studies of the sample size [4], a total of 52 participants were recruited, of which 26 were PSA patients and 26 were healthy control people. The general demographic characteristics comparisons between these two groups were shown in Table 2. There were no significant differences in age, gender, or education between the PSA group and the control group.

Table 2. *Demographic comparisons between PSA group and control group.*

	PSA (n=26)	Control (n=26)	t/X^2	P value
Age, years±(SD)	50.00±(9.01)	48.88±(7.01)	0.50	p=0.67
Gender, (male/female)	21/5	21/5	0.00	p=1.00
Education, (primary/secondary/superior)	2/12/12	2/7/17	2.18	p =0.38

3.2. Language Assessment of the PSA Patients

Table 3 displays the individual performance of language tasks in the PSA group. AQ is to assess whether a patient has aphasia, and it also reflects the severity of aphasia and can be used as an evaluation index for the improvement and deterioration of aphasia. Efficacy criteria: AQ=98.4~99.6 is normal; AQ<93.8 is aphasia. All the PSA patients had AQ scores below 93.8, which mean that all the PSA groups are aphasia. Boston diagnostic aphasia examination (BDAE) was used to evaluate aphasia severity grades. Most (80.77%) of participants had aphasia severity grade below 3, including 12 participants graded 3. spontaneous speech included content and fluency. The total score of fluency was 27. The fluency was divided into three levels: non-fluency (from 9 to 13 scores), Intermediate fluency (from 14 to 20 scores), and fluency (from 21 to 27 scores). Ten (38.46%) participants belonged to non-fluency, 53.85% (N=4) were intermediate fluency, and only 2 participants belonged to fluency. The majority of participants had poor performance (N=17, 65%) in naming tasks. Only 2 participants were scored above 70 (100 scores in total). While the great mass of PSA patients had lower repetition scores, about 61.54% below 50 scores (100 scores in total).

Table 3. *Linguistic performance in ABC of PSA group.*

Participant	Aphasia quotient	Aphasia severity grade	Fluency	Spontaneous speech	Naming	Repetition	Auditory comprehension
PSA1	32.6	3	12	35	16.5	58	104
PSA2	30.1	3	10	27	9.5	15	120
PSA3	27.9	1	13	18	15	39	96
PSA4	47.7	3	18	37	50.5	52	141
PSA5	29.4	1	18	31	16	43	94
PSA6	46.6	3	11	32	31.5	43	164
PSA7	72.5	4	21	45	71	100	210
PSA8	34.0	3	13	31	22	45	110
PSA9	51.8	3	15	38	53.5	43	165
PSA10	12.5	1	12	13	0	0	56
PSA11	27.8	1	13	14	53.5	43	132
PSA12	37.7	2	14	36	34	70	101.5
PSA13	20.3	1	11	22	0	7	37
PSA14	25.0	3	13	16	13.5	39	84
PSA15	47.1	3	17	40	47.5	54	141
PSA16	68.1	4	17	41	63	80	217
PSA17	24.7	2	11	22	2	35	93
PSA18	38.1	3	16	37	27.5	57	116
PSA19	38.6	3	20	38	39.5	41	114
PSA20	3.2	1	17	18	0	33	116
PSA21	37.5	3	18	41	36	36	113
PSA22	68.4	4	17	41	68	97	205
PSA23	73.5	4	21	45	81	50	230
PSA24	38.6	3	15	27	17	27	149
PSA25	48.9	4	16	40	48	93	130
PSA26	34.5	1	18	25	12	32	132

3.3. ANT Performance in the PSA Group and the Control Group Accuracy

As was shown in Table 4, the accuracy (ACC) on the center cue of ANT was 0.68 for PSA and 0.98 for the control group, and there was a huge significant difference between the groups (P=0.000). There was also a significant difference between the PSA group and the control group on ACC of double cue (P=0.000), spatial cue (P=0.000), no cue (P=0.000). The great between-group differences on four cues of ACC were presented in Table 4. As for ACC of congruent and incongruent, the accuracy of the PSA group was significantly worse than the control group. The incongruent accuracy of the PSA group (ACC=0.4814) was far lower than the control group (ACC=0.9754).

Table 4. *ANT performance between PSA group and control group.*

	PSA group	Control group	P value
ACC (±SD)			
Center	0.6796+0.23	0.9796±0.23	0.000*
double	0.7018±0.21	0.9888±0.01	0.000*
spatial	0.6973±0.22	0.9862±0.02	0.000*
No cue	0.6576±0.24	0.9835±0.02	0.000*
Congruent	0.7909±0.21	0.9885±0.02	0.000*
Incongruent	0.4814±0.35	0.9754±0.02	0.000*
RT (±SD /ms)			
center	1239.67±228.64	674.61±135.11	0.000*
double	1251.27±242.08	673.86±132.19	0.000*
spatial	1205.18±235.31	664.93±139.42	0.000*
No cue	1277.88±258.35	680.18±135.82	0.000*
Congruent	1204.74±224.81	647.67±139.77	0.000*
Incongruent	1319.11±281.03	715.96±143.05	0.000*

Note. ms: millisecond *: P<0.05.

3.4. Reaction Time

It was demonstrated in Table 4 that the control group reacted fast in center trials (674.61ms), double trials (673.86ms), spatial trials (664.93ms), and no cue trials (680.18ms). While PSA group need more time to react in center trials (1239.67ms), double trials (1251.27ms), spatial trials (1205.18ms), and no cue trials (1277.88ms). The control group performed well than the PSA group incongruent trials and incongruent trials. The mean of reaction time (RT) incongruent trials and incongruent trials of the control group were 647.67ms and 715.96ms, respectively.

3.5. Alerting, Orienting and Executive Control

Alerting, orienting and executive control effects between control and aphasia group are shown in Figure 2. In general, the control group performed better than the aphasia group. In the alerting effect, although there was no significant difference (p= 0.227) between the two groups, the alerting RT for the aphasia group was longer than the control group, the alerting IE for the aphasia group was bigger than the control group. There were significant between-group differences on alerting ACC and IE. This suggests that the PSA group and the control group had different alerting effects. Regarding of orienting effect, there were no significant effect on orienting ACC (P=0.374) or IE (P=0.153) between PSA and control groups, but the effect was significant on RT (P=0.013), suggesting that there is still a different orienting effect between the PSA group and the control group. Although executive control RT (p=0.108) and IE (p=0.107) had no significant between-group difference, there was a significant difference between the two groups on executive control ACC (p=0.000).

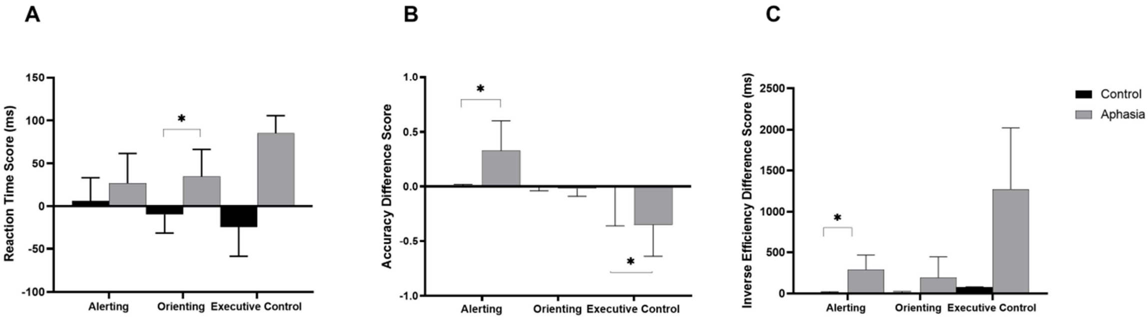

Figure 2. *Between-group comparisons for alerting, orienting, and executive control in reaction time (A), accuracy (B) and inverse efficiency difference (C). Error bars represent ± one standard error.*

3.6. Association Between Attention Performance and Language Function in the PSA Group

To investigate the interaction of non-linguistic cognitive impairment and language function in the PSA group (in table 5), the relationship between ANT scores and ABC scores was analyzed. In the Spearman correlation analysis, aphasia severity grade was correlated with executive control IE (R=-0.602, p=0.001). Pearson correlation analysis showed that repetition was correlated with alerting IE (R=-0.426, P-0.030), auditory comprehension was correlated with orienting IE (R=-0.448, p=0.022).

Table 5. *Correlation analysis between ANT scores and ABC scores of the PSA group.*

		AQ	Aphasia severity rate	Fluency	Spontaneous speech	Repetition	Naming
Alerting RT	R	-0.074	-0.058	0.079	-0.099	-0.350	-0.065
	P	0.720	0.777	0.700	0.631	0.080	0.751
Orienting RT	R	-0.174	-0.262	0.255	-0.185	-0.371	-0.129
	P	0.395	0.196	0.209	0.366	0.062	0.531
Executive control RT	R	0.314	0.384	0.206	0.369	0.293	0.298
	P	0.119	0.053	0.312	0.064	0.147	0.139
Alerting ACC	R	0.088	0.086	0.086	-0.143	-0.114	-0.114
	P	0.669	0.675	0.675	0.485	0.485	0.579
Orienting ACC	R	0.223	0.305	0.350	0.043	0.101	0.330
	P	0.273	0.129	0.290	0.834	0.625	0.099
Executive control ACC	R	-0.053	-0.002	-0.020	0.159	0.161	0.053
	P	0.797	0.992	0.890	0.439	0.432	0.795
Alerting IE	R	-0.375	-0.226	-0.182	-0.216	-0.426*	-0.290
	P	0.059	0.267	0.373	0.289	0.030*	0.150
Orienting IE	R	-0.376	-0.335	0.133	-0.212	-0.277	-0.201
	P	0.059	0.094	0.518	0.298	0.170	0.325
Executive control IE	R	-0.142	-0.602*	-0.186	-0.065	0.025	-0.100
	P	0.490	0.001*	0.363	0.753	0.903	0.628

Note. RT: Reaction Time; ACC: Accuracy; IE: Inverse Efficiency;
R, correlation coefficient; *, P<0.05.

Finally, Table 6 shows the results of stepwise linear regressions for PSA patients using ABC tasks as dependent variables and attention performance as predictors. In the stepwise linear regression analysis, executive control RT alone emerged as a significant predictor of auditory comprehension. Alerting IE and orienting RT are the predictors of repetition.

Table 6. *Association between ANT and ABC (by stepwise linear regressions).*

Model					Variables entered			
Dependent variable	**Adjusted R^2**	**F**	**df**	**p-value**	**Variables**	**Change in R^2**	**Beta**	**p-value**
Auditory comprehension	0.155	4.39	1	0.047	executive control RT	0.120	0.393	0.047
Repetition	0.311	5.202	2	0.014	alerting IE	0.145	-0.456	0.015
					orienting RT	0.252	-0.366	0.047

4. Discussion

Our study was aimed to determine the relationship between ABC scores and attention (alerting, orienting, and executive control) in PSA patients. In the Spearman correlation analysis, aphasia severity grade was correlated with executive control IE (R=-0.602, p=0.001). Pearson correlation analysis showed that repetition was correlated with alerting IE (R=-0.426, P-0.030), auditory comprehension was correlated with orienting IE (R=-0.448, p=0.022). And after stepwise linear regression analyses, there was an association between auditory comprehension and executive control RT, the scores for repetition positively correlated with the scores for alerting IE. Repetition was also associated with orienting RT.

Our study revealed that the PSA patients suffered from obvious attention impairment. Attention is fundamental to the cognitive process. Sohlberg and Mateer [15] categorized attention as the following types: focused attention, sustained attention, selective attention, alternating attention, divided attention. In the perspective of a neuropsychological construct, attention was divided into three parts by Posner and Petersen: alerting, orienting, executive control. Attention deficits had been reported to co-occur with aphasia. Yao et al. [3] have analyzed 86 stroke patients and found that the Loewenstein Occupational Therapy Cognitive Assessment (LOTCA) scores in post-stroke aphasia patients were significantly lower than the control group. Compared to the control group, the PSA patients gave a poor performance in attention. In a prospective cross-sectional study [2], patients with non-fluent aphasia had lower scores in attention tests than the control group. The poor performance of attention in the PSA patients can be attributed to the impairment of the language network [16]. Another reason could be that many language assessments involvement of attention in the tasks of language assessment [17].

Our study also found that the control group performed significantly better than the aphasia group in the ANT test. Our present study showed that the accuracy of the center cue, double cue, spatial cues, no cue, congruent trials, and incongruent trials in the PSA group was significantly lower than that in the control group. The reaction time of center cue, double cue, spatial cues, no cue, congruent trials, and incongruent trials in the control group was observably faster than that in the PSA group. Furthermore, there were significant between-group differences in alerting IE and orienting RT. These indicate that patients with aphasia have concurrent serious attention impairments compared with the control people. In line with our study, Lacroix et al. [18] have used ANT to quantify three subtypes of attention (alerting, orienting, and executive control) in PSA patients and matched controls, and found that the control group was significantly faster than the aphasia group. However, Lacroix et al. also found that there were no group differences for alerting RT, orienting RT, or executive control RT and the two groups did not differ on accuracy of alerting or executive control. The control group only exhibited a greater orienting cue benefit than the aphasia group. Lacroix et al. included 22 patients with aphasia who experienced a single left hemisphere cerebral stroke at least 6 months prior to testing. All the participants have accepted rehabilitation therapy for at least 6 months. And most of the participants in our study experienced a stroke at most 6 months prior to the test. What is more? From the stroke participant's aphasia diagnosis, most of the participants in Lacroix's study suffered mild aphasia, while 80.77% of participants in our study had severe aphasia. These can possibly account for the participants with aphasia did better than ours.

Whether there is an association between language and attention has been controversial. When Yao et al. [3] researched the association between language function and non-linguistic cognitive functions, they found that there was no association between language and attention. Another study [19] showed that the result didn't establish a trend between measures of language and attention. And each participant showed unique strengths and weaknesses in language and attention. However, other studies maintained that language is intimately related to attention. A prospective cross-sectional study [2] figured out the relationship between nonverbal cognitive and language function, which showed that verbal comprehension abilities correlated with attention (Cancellation task of BLAD). Using Conner's Continuous Performance Test II to measure attention [20], the study showed that response speed variability was significantly correlated with speech discrimination and with performance in semantic association tasks. It also revealed that the indices of intra-individual variability can predict linguistic performance in the aphasia group. Moreover, language-specific attention treatment (L-SAT) [21] has been demonstrated that two of four people with aphasia had good language recovery whereas three of the four participants improved significantly in auditory-verbal working memory. A study used Attention Process Training-3 to train attention directly [7], which showed the potential to improve reading in individuals with aphasia. Our study supported that there was an association between language and attention, and provided more concrete evidence for this association. In our study, aphasia severity grade was correlated with executive control IE, repetition was correlated with alerting IE, and auditory comprehension negatively correlated with orienting. Executive control RT alone emerged as a significant predictor of auditory comprehension. Alerting IE and orienting RT are the predictors of repetition.

4.1. Alerting and Repetition

Alerting is a part of attention achieving and maintaining a state of increased sensitivity to incoming information. A higher alert state made information processing perform faster. One study [22] showed that the left hemisphere (Anterior intraparietal, inferior parietal, frontal) acted stronger than the right hemisphere for the alerting activation. Sustained attention means that we can voluntarily maintain alerting state over time. It was measured by reaction time differences between no cue and double cue. The double cue provided information of when the target will appear. Repetition assessment included word repetition, phrase repetition, and sentence repetition. Among them, there were non-word tasks that were meaningless. Non-word [23] repetition was involved phonological memory, speech perception, phonological encoding, sequencing abilities, phonological assembly, oromotor skills, and articulation. Repetition correlated with alerting. There were the reasons as follows. Firstly, speech perception is a process requesting a high level of alert. Secondly, it was that auditory-verbal short-term memory played a significant role in word repetition and sentence repetition [24]. Furthermore, working memory capacity [25] was modulated noise masker to contribute to the perception of speech. Working memory capacity has an association with alerting because of speech perception. Because of working capacity, word repetition and sentence repetition correlate with alerting. In all, repetition has an association with alerting.

4.2. Orienting and Repetition

Orienting tends to prioritize and select from various stimuli. It included three parts [26], (1) disengage attention from the current stimulus; (2) shift attention to the new target; and (3) engage attention on the new target. Orienting cues offered information as to where to direct attention. It was measured by reaction time differences between center and spatial cues. Our study aligned with the previous study [18], the orienting effect had a significant difference between the PSA group and the control group. Our study also demonstrated that orienting correlated with repetition. The assumption was as follows. Speech perception was a process of repetition. The working memory benefitted speech perception a lot in noise [25]. There were various stimuli when the working memory played a part in perceiving target. Orienting allowed to selecting from various stimuli. Orienting and working memory were considered to have the same selecting function from various stimuli. And orienting had an association with repetition by working memory.

4.3. Orienting and Auditory Comprehension

Auditory comprehension is a complex and multifaceted process, including phoneme perception, retrieval of single word meanings, and various processes to integrate multiple words meanings. Sentence comprehension must also be combined using syntactic, relational semantic, and pragmatic information. In terms of the classic model of language function, auditory comprehension is localized in Wernicke's area. With the neuro-imaging and stimulation mapping development [25], the middle temporal gyrus was considered to be associated with the meaning of single words, which is through the middle longitudinal fasciculus and inferior longitudinal fasciculus. The posterior middle temporal gyrus, inferior parietal lobule (angular gyrus), inferior frontal cortex (part of Broca's area), and interlobar connections mediated involved in the sentence and context comprehension via inferior frontal occipital fasciculus. Our study revealed that auditory comprehension correlated with orienting. There are some possible explanations as follows. The previous study [27] showed that the frontoparietal type of periventricular white-matter hyperintensities (WMHs) and deep WMH in the parietal lobe were considered to associate with orienting efficiency. The lesion location of auditory comprehension and orienting are fed by the middle cerebral artery. This suggests that auditory comprehension and orienting were both impaired when the middle cerebral artery was damaged. Moreover, individuals with PSA showed impairments of the orienting because of being slow to engage, disengage, and shift attention. The PSA was difficult to pay attention to the target stimuli or shift attention away from one stimulus to another one. There were several sentences among a paragraph. It’s the shift of attention to play an important role in the inter-sentence shift.

4.4. Executive Control and Aphasia Severity Grade

Executive control is responsible for monitoring and resolving conflict between target stimuli and distractors. It was measured by reaction time differences between congruent and incongruent flankers. A previous study [25] has shown that the anterior cingulate cortex and dorsal lateral prefrontal cortex play important roles during executive control processing. In our study, we found that the PSA group and the control group were significantly faster and more accurate during congruent flanker conditions compared with incongruent flanker conditions, which demonstrates a typical flanker congruency effect. Executive control was top-down progress to make sure the behavior was consistent with the task goal, which was involved in action planning. Previous studies have demonstrated that patients with aphasia couldn’t be capable of dealing with speech production [25]. A review [5] made a conclusion that executive attentional processes have been implicated in the generation of ideas for propositional language production. Aphasia severity grades test examines the ability of oral speech and articulation by asking patients for basic questions. Fluent speech requires the planning of sound sequences, which are followed by the execution of corresponding motor plans [28]. Fluent speech needs to coordinate respiration, phonation, articulation, resonance, and prosody. Both fluent speech and executive control are involved in action planning.

4.5. Executive Control and Auditory Comprehension

Executive control measures the efficiency of correct response when relevant stimulus information conflicts with irrelevant stimulus information. It is top-down progress to make sure the behavior is consistent with the task goal, which was involved in action planning. Auditory comprehension is a complex and multifaceted process, including phoneme perception, retrieval of single word meanings, and various processes to integrate multiple words meanings. Our study showed that executive control is associated with auditory comprehension. The reason may be that the coherent implementation of multiple steps of auditory comprehension is inseparable from execution control. The correlation between phonological short-term memory and executive control tasks was found by Allen [28]. Auditory discrimination and word comprehension tasks had correlations with verbal short-term memory tasks [29]. Another reason is that short-term memory is the intermediary to link executive control to auditory comprehension.

5. Limitation

To a certain extent, the results of our study are convincing because, after the stepwise linear regression analysis, executive control RT alone emerged as a significant predictor of auditory comprehension. Alerting IE and orienting RT are the predictors of repetition. But admittedly, there have been a few limitations in our study. First, as this was a cross-sectional and observational study, and although we could note a possible association between attention and language, no conclusions towards causation could be drawn. Second, our study recruited such a small sample size that we should interpret cautiously to avoid unknown bias. Thirdly, there are only 5 (19.23%) females in our PSA group and matched control group. Limited by the small size of female aphasia patients in the First Affiliated Hospital of Jinan University and Guangzhou Red-Cross Hospital, respecting the patients' willingness, we have recruited 5 female aphasia patients in total. A study of the Neurology Department of Assiut University Hospital showed that the relative frequency of vascular aphasia was 7.1% and more common among male patients (57.9%) [30]. This suggests that female patients are in relatively small size of aphasia patients. Lastly, there is no MRI for the mechanism of attention and language impairment.

6. Conclusion

Rare studies have involved the association between attention (alerting, orienting, and executive control) and language (ABC) in PSA, and hence, this is the first study indicating an association between executive control and aphasia severity grade, repetition correlated with alerting, auditory comprehension correlated with orienting. And after the stepwise linear regression analysis, executive control RT alone emerged as a significant predictor of auditory comprehension. Alerting IE and orienting RT are the predictors of repetition. Nonetheless, a prospective study with larger sample size and attention training effect in PSA patients is needed to confirm our results.

Conflict of Interest Statement

All the authors do not have any possible conflicts of interest.

Author Contributions

QH contributed to data collection, data analysis, discussion on results, writing, and preparation of the manuscript. TS contributed to data collection. WX and ZC contributed to study design, data collection, discussion of results, and preparation of the manuscript. All authors read and approved the final manuscript.

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Statement of Ethics

This study was carried out in accordance with the recommendations of the Declaration of Helsinki with written informed consent obtained from all subjects. The protocol was approved by the Ethics Committee of Guangzhou Red-Cross Hospital of Jinan University, China. The study approval reference number is 202116401.

Data Availability Statement

All data generated or analyzed during this study are included in this article. Further enquiries can be directed to the corresponding author.

Disclosure Statement

The authors have no conflicts of interest to declare.

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