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INTERFERENCE CONTROL IN APHASIA

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Absztrakt
Interferenciakontroll afáziában

Számos neuro-kognitív elmélet szerint a magasabb rendű mentális folyamatok interaktív kapcsolatban állnak egymással. Ilyetén a nyelvi funkciók sérülése összefügghet más kognitív folyamat diszfunkcionális működésével. A jelen kutatás célja afáziás személyek teljesítményének felmérése volt különböző végrehajtó funkciókat mérő feladatokban. A kutatásban 6 afáziás és 6 illesztett kontrollszemélyt vizsgáltunk. Számítógépes feladatokat alkalmaztunk az alábbi kognitív képességek vizsgálatára: figyelem, disztraktor és proaktív interferenciával szembeni ellenállás, válaszgátlás. Eredményeink jelentős különbségeket mutatnak a csoportok között a reakció idők tekintetében, míg a pontosságban nincs eltérés az afáziás és kontroll személyek között, kivéve a fegyelmi képességeket. Eredményeink arra utalnak, hogy a nyelvi feldolgozás lassúsága összefügghet a végrehajtó funkciók lassúságával. Az információ feldolgozás lassulása egyaránt befolyásolhatja a nyelvi és nem nyelvi feladatokban nyújtott teljesítményt afáziás személyeknél.
kulcsszavak: afázia, végrehajtó funkciók, proaktív interferencia, információ feldolgozás

ABSTRACT

Current neuro-cognitive research suggests that higher cognitive abilities interact with each other within a multifunctional cognitive system. Thus, acquired language dysfunctions may co-occur with impairments of other cognitive functions, such as inhibition or information processing. In the present study, we examined performance on various cognitive tasks in individuals with aphasia. These tasks included measures of vigilance, resistance to distractor and proactive interference, and response inhibition. These executive functions play significant roles in different language processes.
Six participants with aphasia and 6 control participants were involved in the study. We used computer-based tasks and measured accuracy and reaction times.
Although participants with and without aphasia did not differ in their accuracy in most tasks, individuals with aphasia showed increased reaction times compared to the controls across tasks.
Our findings suggest that individuals with aphasia show a general slowness in information processing that might affect both language and other cognitive functioning.

Keywords: aphasia ▪ executive functions ▪ inhibition ▪ information processing

INTRODUCTION

Recent research tends to move away from a language-centered understanding of aphasia toward an interactive model in which the whole cognitive system works together dynamically. Based on this view, executive functions may have an important role in compensatory processes that support language production and comprehension in individuals with brain damage.

Aphasia

Aphasia is an acquired multimodal/multifunctional language impairment which is typically associated with traumatic brain injury, stroke, or brain tumor. Aphasia might be manifested in both spoken and written language (Szentkuti-Kis, 2010). Multifunctionality has a particular importance when studying different executive functions, because different language modalities (such as naming, comprehension, repetition, and fluency) may show different interactions with executive processes. From a cognitive neuroscience perspective, the concept of multifunctionality in aphasia refers to impaired abilities on the basis of disrupted cognitive processes underlying language (Hillis, 2007). Researchers studying aphasia have found that communication problems might extend beyond language difficulties, and that symptoms are not solely due to a damage in the linguistic system (Cahana-Amitay & Albert, 2015). There is evidence in the literature indicating that successful communication in individuals with aphasia strongly depends on their executive function skills (Purdy, 2002; Keil & Kaszniak, 2010). For example, Novick and colleagues (2005) found that the Left Inferior Frontal Gyrus (LIFG) has an important role not only in sentence processing, but in the detection and resolution of incompatible stimulus representations as well. They employed garden path sentences (e.g., *The horse raced past the barn fell.*) in their experimental research and found that participants used conflict resolution to adequately process these sentences. The authors concluded that sentence processing abilities provide similar assessment of cognitive control functions than conflict resolution (Novick et al., 2005). Another study by the same authors (2010) provided further evidence for the connection between language processing and cognitive control based on findings on the heterogeneous role of Broca's complex. This area of the cortex is not only responsible for the grammatical abilities in language production and comprehension, but supervises mental activity as well during language processing. The authors assumed that Broca's complex helps to select the appropriate lexical item (1) when there are several other possible candidates during word production and (2) during sentence comprehension when the sentence includes misinterpretations. They found that during production and comprehension, when the task involved cognitive control processes, individuals with a lesion in Borca's complex demonstrated much lower performance than controls. The authors concluded that we use cognitive control processes to regulate and control behavior when competing representations are activated. This may occur in general behavior as well as in language processing (Novick et al., 2010). Further, Biegler and his colleagues' (2006) data revealed that the ability to select an unpreferable but relevant response (instead of a dominant but irrelevant answer) was severely impaired in persons with non-fluent aphasia. This deficit was manifested mostly in anomic speech production, which was reflected in word-finding problems, and indicated difficulties with lexical selection. The increased naming problem seemed to be associated with impaired semantic blocking, which in turn was due to the impairment of inhibition processes (Biegler, Crowther, & Martin, 2006).

There is evidence from picture-word interference studies that individuals with aphasia demonstrate difficulties with distractor items. If the task is to name an object when competitor words are presented, individuals with aphasia demonstrate slower reaction time (RT) and higher error rate. The impairment of suppressing competitor words negatively influences lexical access, and can result in word finding problems in individuals with aphasia (Hashimoto & Thompson, 2010). Another cognitive function that has been associated with naming difficulties is semantic short-term memory (Hamilton & Martin, 2007). The authors claim that an atypical maintenance of previously presented material is responsible for lexical access difficulties. They propose that the inability to resist proactive interference is the result of control deficits in short-term memory, which influence semantic and phonological processes in aphasia (Hamilton & Martin, 2007).

Research on executive functions in aphasia often involves verbal tasks, but using non-verbal paradigms may provide further knowledge about the nature of information processing in this population. For instance, Corbett et al. (2009) used the Naturalistic Action Test, which is a non-verbal test measuring the ability of naturalistic object-use in persons with aphasia. They found that individuals with semantic aphasia revealed weaknesses in control processes underlying semantic memory impairment. Due to impaired control functions, poor performance on non-linguistic cognitive tasks correlated with performance on semantic tasks, which indicates that language impairment is accompanied at the semantic level by those control processes that direct semantic representations (Corbett, Jefferies, & Lambon Ralph, 2009). All these findings point to the influence of different cognitive functions on the processes of the language system, including the regulation and control of different behaviors.

In summary, there is evidence for interdependencies among behavior, language, and their neural substrates. Thus, the processing of linguistic information interacts with the processing of other type of information. The findings suggest that language processing involves multifunctional mechanisms (such as managing irrelevant linguistic information, controlling competing linguistic information), or engaging conflict resolution in sentence processing. Thus, language processing is based on an interactive, dynamic functional architecture in the brain (Blumstein & Amso, 2013).

Executive functions

There are numerous models and definitions of executive functions that reflect the complexity of executive processes. Generally, it has been accepted that executive functions are higher-level mental processes that allow us to adapt our behaviors flexibly in response to changing circumstances (Jurado & Rosseli, 2007). A typical example of behavioral control is when tourists walk on the streets of London. They may automatically check the left side of the road when crossing the street. When they realize that the traffic rules are different in London, they adjust their behavior and check the right side of the road first. To monitor automatic behaviors and to adjust them in response to new contexts, we apply cognitive control functions that are related to frontal lobe areas such as the Dorso-Lateral Prefrontal Gyrus (DLPFG; Novick et al., 2010).

Concerning the unity of executive functions, there are different views whether there are discrete sub-functions (that are not related to each other), or whether these functions are associated with general control abilities and interact with each other. According to the neuro-cognitive framework of Miyake and colleagues (2000), executive processes are related but independent functions. The authors distinguished 3 types of executive functions: (i) updating mental information, (ii) switching, and (iii) inhibition. In a follow up study, the authors identified three different inhibitory functions: (1) prepotent response inhibition, (2) resistance to distractor interference, and (3) resistance to proactive interference (Friedman & Miyake, 2004). Generally, inhibition processes are responsible for suppressing irrelevant behaviors or mental information according to the actual context. Prepotent response inhibition refers to the blocking of an automatic response. For example, if we are used to driving a traditional car (which has a clutch and then we switch to an automatic car), we may automatically try to push the clutch when shifting the gear. Distractor interference control refers to resisting external stimuli (e.g., choosing the appropriate words from a list that consists of target and distractor items). Resistance to proactive interference is about resisting previous memory traces. As we update our working memory contents while performing a task, old and irrelevant items need to be suppressed in order to prevent proactive interference.

Taken together, executive functions have an important role in behavior control. They share neural substrates with linguistic processes and interact, for instance, with semantic (Jefferies, Baker, Doran, & Lambon Ralph, 2007) and syntactic (Novick et al., 2009) language processes. Inhibition processes are part of the executive system and include different functions such as prepotent response inhibition, resistance to distractor interference and to proactive interference. The majority of executive function tasks include verbal components; therefore, they are difficult for individuals with language impairment. Even if we employ non-verbal paradigms, poor comprehension abilities may influence performance in executive function tasks. Based on previous findings that indicated the importance of control processes in linguistic performance (Keil & Kaszniak, 2010; Purdy, 2002; Novick et al., 2009; Cahana-Amitay & Albert, 2015), we decided to examine vigilance, response inhibition, resistance to distractor and to proactive interference in individuals with aphasia.

HYPOTHESIS

1. We proposed that while individuals with aphasia would show similar vigilance to the controls in a simple non-verbal task, their response time would be slower due to a general slowness in information processing.

2. We proposed that people with and without aphasia would show similar accuracy in blocking an automatic response in a task measuring response inhibition; however, the former group would indicate slower responses than the latter group.

3. Concerning resistance to interference, we expected both lower accuracy and increased reaction time in the aphasia group compared to the controls. Based on findings suggesting that individuals with aphasia demonstrate difficulties in situations where conflicting items are presented (Biegler et al., 2008; Novick et al., 2005), we assumed that individuals with aphasia show different patterns of performance than the control group.

PARTICIPANTS

Six right-handed Hungarian individuals with aphasia with left hemisphere lesion and six age- and gender-matched controls participated in this study. Participants with aphasia were recruited from the National Medical Rehabilitation Center in Budapest. Their demographic data and Computer Tomography (CT) results are presented in Table 1.

Table 1.

Neurolinguistic data of participants with aphasia

Participants	WAB (AQ)	WAB					Token language comprehension test	Boston naming test (Z score)
		Information content	Fluency	Comprehension	Repetition	Naming		
1. T.I.	63,4	7	4	8,4	4,8	7,5	20,5	-3,5
2. B.A.	38,6	4	3	7,5	3,2	1,6	6	-14,89
3. D.I.	64,8	5	6	7,2	7,2	7	19	-1,69
4. N.P.	72,6	7	5	8,7	7,4	8,2	12	-3,66
5. Sz.I.	76,8	8	6	9,2	5,4	9,8	24,5	-6,28
6. Cs.I.	56,6	4	6	6,5	5,4	6,4	14,5	-4,482

Participants demonstrated different types of aphasia, but their language symptoms were similar. All of them had difficulties with naming, but had intact word reading abilities and normal comprehension of simple sentences (Table 2).

Table 2.

Demographic and laesion data of the participants

	Participants	Gender	Age	School (years)	Aphasia category	CT results
Participants with aphasia	T.I.	2	45	12	Broca	Left hemisphere: extended vascular lesion. Right hemisphere: old ischemic lesion.
	B. A.	2	40	16	Broca	Left arteria cerebri media (ACM): 85*50 mm diffusion in the fronto-parietal cortex Nucleus caudate.
	D.I.	1	55	12	Anomic	Left cortical hemorrhage (49*40 mm).
	N.P.	1	59	12	Transcortical motor	04.28. Left hemisphere: hypodens areas in capsula interna, capsula externa and in the putamen. 05.04. Left ACM: insular area and parietal lobe.
	Sz. I.	1	63	12	Anomic	Left hemisphere: carotis interna occlusion.
	Cs.I.	1	67	12	Wernicke	Left hemisphere: temporal cortical area. Capsula externa, thalamus.

Control Participants	F.Gy.	1	60	12
	T.J.	1	65	12
	S.H.	2	40	15
	R.Zs.	2	43	16
	N.I.	1	51	12
	K.A.	1	67	12

STIMULI AND PROCEDURES

We used computer-based tasks (which were part of a larger information processing paradigm) to measure vigilance, response inhibition and resistance to distractor and proactive interference (Marton, Campanelli, Eichorn, Scheuer, & Yoon, 2014). Participants were presented with one verbal and three non-verbal tasks. There were 3 response buttons in front of the computer (two black and a red one). E-Prime 2.0 software was used to present the stimuli and to record the data. In all conditions, reaction time and accuracy were recorded automatically by the computer. Stimuli were presented on either the right or the left side of the screen. When detecting a target stimulus, participants had to press the black button on the corresponding side. When detecting distractor stimuli, participants had to press the red button which was located in the center between the two black buttons. All participants with aphasia had hemiplegia on the right side; therefore, they used their intact left (non-dominant) hand to press the buttons. To control for this factor, participants in the control group were also instructed to use their non-dominant hand when pressing the buttons. All participants were tested individually. Practice items were provided prior to testing.

Vigilance

We examined participants' vigilance with a simple non-verbal task. Participants were presented with green dots either on the right or on the left side of the screen, and were instructed to press the corresponding black button every time they noticed a stimulus. There were 10 trials in this task. The vigilance measure was used as a baseline attention task.

Resistance to distractor interference

In this task, participants saw a green dot on the screen, either alone or near a blue dot. The task was to press the black button according to the location of the green dot (either on the right or on the left side). Participants had to ignore the blue dots that served as distractors. Ten trials were presented in this condition.

Response inhibition

In this task, participants were presented with either a green or a blue dot. The green and blue items were not presented simultaneously. If a green item (target) appeared on the screen, then participants had to press the black button on the corresponding side. When a blue (distractor) item was presented, participants had to block their automatic response and regardless of the side of presentation, they had to press the red button in the center. This subtask was a variation of a traditional Go/No-go task which typically measures response inhibition abilities. Participants were presented with 5 practice trials and 20 experimental trials.

Resistance to proactive interference

Resistance to proactive interference was measured using a simple verbal categorization task. It included a baseline and an interference condition. The interference condition was based on a conflict paradigm, in which distractor (interference) items had been targets in previous trials. Participants saw a category name on the top of the screen (e.g., furniture) and then a target word (e.g., table), or a distractor item (e.g., father) on one side of the screen. In all conditions, participants were asked to read the stimulus word silently and decide whether the word belonged to the given category (figure 1).

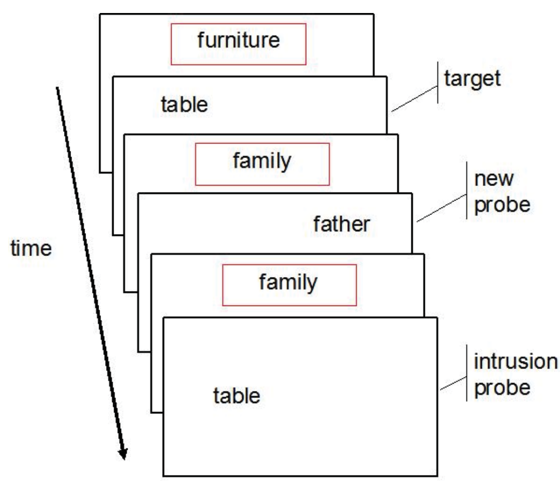

Figure 1. Proactive Interference Task

We used three types of stimuli: (1) target words: words that belonged to the given category, (2) new distractor words: words that did not belong to the category and had not been presented previously, (3) interfering distractor words: words that did not belong to the category and appeared as a target word in the previous trial (intrusion probe). There were six categories; the 84 experimental trials were preceded by 15 practice trials. In the first part, participants were presented with a baseline measure that did not include interfering distractors, only target words and new distractor items. In the second part of the task, participants were presented with target words and interfering distractors. All items were frequent words that children acquire early. The task was very simple for adults because we were not interested in participants' categorization skills.

RESULTS

Accuracy and reaction time (RT) data were analyzed in each task across all conditions (Table 3). The analyses included RT measures of correct responses only. We used non-parametric tests for non-normally distributed data and for reducing the effect of the small sample sizes (see normality analysis in Appendix Table 1, Table 2).

Table 3.

Basic Statistics

	Aphasia			**Control**		
	Mean	*SD*	*Mdn*	*Mean*	*SD*	*Mdn*
Vigilance RT	1070,67	762,48	873,00	650,50	441,29	534,00
Vigilance ACC	96,40	2,52	95,74	99,33	1,63	100,00
Distractor inerference RT	960,33	464,70	834,00	686,58	236,24	622,50
Distractor inerference ACC	46,51	2,03	47,00	46,46	2,89	47,50
Response inhibition distractor RT	1291,00	462,51	1 217,00	1034,35	896,87	824,00
Response inhibition target RT	1953,33	852,24	1 766,00	968,59	500,55	839,00
Response inhibition distractor ACC	93,00	10,95	100,00	96,97	7,42	100,00
Response inhibition target ACC	81,59	14,74	81,82	95,92	6,63	100,00
Proactive interference baseline RT	2120,89	1070,14	1 822,00	1434,19	874,19	1 050,00
Proactive interference interference RT	2077,87	994,49	1 805,00	1320,32	508,05	1 100,00
Proactive interference target baseline RT	1756,83	704,96	1 396,00	1164,88	622,39	1 039,00

	Aphasia			**Control**		
	Mean	*SD*	*Mdn*	*Mean*	*SD*	*Mdn*
Proactive interference target interference RT	1811,45	805,78	1 378,00	1189,62	707,84	1 059,00
Proactive interference baseline ACC	90,05	11,07	93,61	98,03	2,19	98,33
Proactive interference interference ACC	87,91	23,74	98,28	83,06	14,64	85,04
Proactive interference target baseline ACC	92,45	8,35	94,72	96,45	2,48	96,05
Proactive interference target interference ACC	88,33	11,14	92,61	98,01	3,13	100,00

Vigilance

Both groups performed with high accuracy. The Mann-Whitney test however, showed a significant difference between the groups in both accuracy (Z=-2,04, p<0,05, r=-0,65) and reaction time (Z=-5,97, p<0,001, r=-0,65). Individuals with aphasia were generally slower than the control group. Both groups performed above 95% in accuracy, therefore, the difference between the groups in accuracy should not be interpreted.

Distractor interference

The two groups did not differ in accuracy (*t*(7)=0,03, n.s., Cohen's d=0,001), but there was a significant difference between the groups in RT of the correct answers (Z=-3,41, p<0,05, r=-0,037). Although individuals with aphasia demonstrated nearly the same number of correct responses than controls, they were significantly slower in processing the stimuli.

Response inhibition

For accuracy, the Kruskal Wallis test showed no difference between the groups (Distractor: $\chi^2(1)=0,66$, n.s.; Target: $\chi^2(1)=3,33$, n.s.). We compared response times between the groups in 2 conditions (Distractor condition: a target and a distractor were presented simultaneously; Target condition: only the target item was presented). The Kruskal Wallis test showed a significant differences in RT between the groups for both conditions: Distractor condition ($\chi^2(1)=19,28$, p<0,001, r=1,81); Target condition ($\chi^2(1)=45,53$, p<0,001, r=4,55) (figure 2).

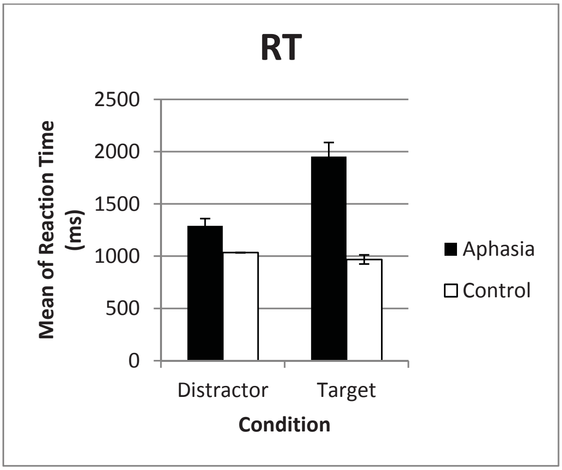

Figure 2. Response Inhibition Task. Differences in Reaction Time. Vertical lines present SE

Resistance to proactive interference

We examined the ability to reject new and interfering distractor items. Four stimulus types were examined across 2 conditions: (1) new distractors, (2) interfering distractors, (3) target items in baseline condition, and (4) target items in interference condition (figure 3). To measure accuracy, the Kruskal Wallis test was applied with Group and Condition variables. Only the target items in the interference condition showed a group difference in accuracy (New distractor: $\chi^2(1)=2{,}23$, n.s.; Interference: $\chi^2(1)= 1{,}31$, n.s.; Target in Baseline condition: $\chi^2(1)= 0{,}92$, n.s.; Target in Interference condition: $\chi^2(1)= 5{,}61$, $p<0{,}05$, $r=1{,}62$). Participants with aphasia were significantly less accurate than the controls in response to target items in the interference condition.

To compare response times, the Kruskal Wallis test was conducted with Group (Aphasia, Control) and Condition (New distractor, Interference, Target in Baseline condition, Target in Interference condition) variables. We predicted superior performance in the control group compared to the aphasia group in each condition. Verifying this prediction, there was a significant difference between the groups in all conditions (New distractor: $\chi^2(1)=73{,}21$, $p<0{,}005$, $r=4{,}42$; Interference: $\chi^2(1)=70{,}82$, $p<0{,}005$, $r=4{,}52$; Target in Baseline condition: $\chi^2(1)=207{,}15$, $p<0{,}005$, $r=8{,}01$; Target in Interference condition: $\chi^2(1)=192{,}72$, $p<0{,}005$, $r=7{,}47$).

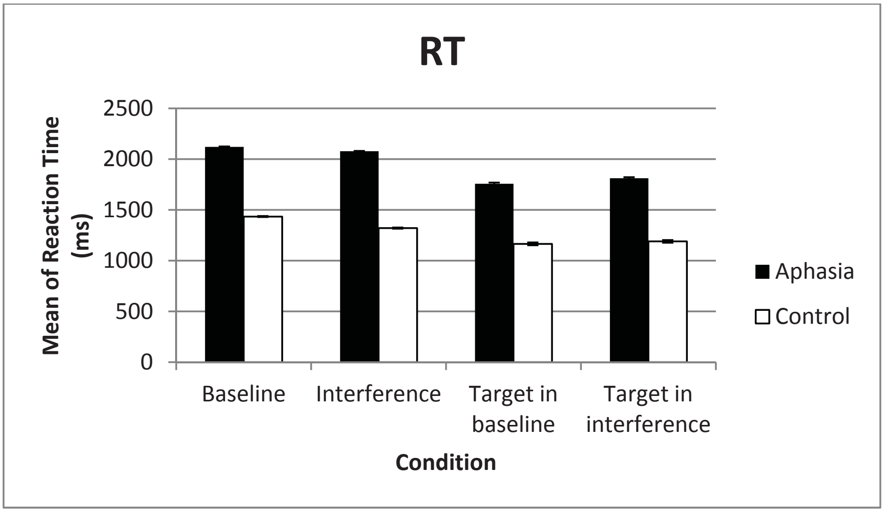

Figure 3. Resistance to Proactive Interference Task. Differences in Reaction Time. Vertical lines present SE

Task Comparisons

To test our hypothesis that individuals with aphasia show a different performance pattern than the controls, we measured reaction times across tasks. There was a group difference with the Kruskal Wallis test. Participants with aphasia demonstrated significantly slower responses than the controls in each task ($\chi^2(1)$= 32,96, $p<0{,}005$, r=2,23; $\chi^2(1)$= 28,12, $p<0{,}005$, r=2,98; $\chi^2(1)$= 23,38, $p<0{,}005$, r=2,2; $\chi^2(1)$= 70,82, $p<0{,}005$, r=4,52; see also figure 4).

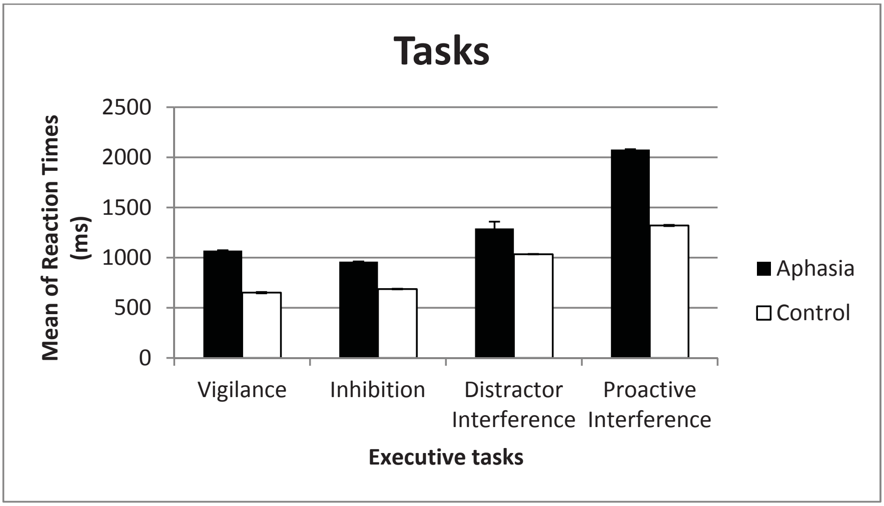

Figure 4. Differences in Reaction Times across tasks. Vertical lines present SE

DISCUSSION

Four tasks were used to examine executive functions in individuals with aphasia. We employed computer-based tasks that required participants' motor responses to visually presented stimuli. The tasks measured different control processes: response inhibition, resistance to distractor interference, resistance to proactive interference, and vigilance, as a baseline measure of attention. There is evidence in the literature that individuals with aphasia exhibit executive control impairments, such as weaknesses in managing irrelevant linguistic information, controlling competing linguistic information (Novick, et al., 2005; 2010), or resisting proactive interference (Hamilton & Martin, 2007).

Our overall findings show high accuracy rates across tasks indicating that individuals with aphasia were able to understand the tasks, follow instructions, and maintain attention. Individuals with aphasia showed similar pattern of performance in most tasks than the controls but they did this at a much slower rate. The results support the idea of nonlinguistic contributions to language processes, and imply that executive functions and language processes constitute interactive parts of a multifunctional cognitive network.

In the present study, we used experimental manipulations to examine different aspects of inhibitory control. A vigilance task was used to measure basic attention skills to ensure that participants with aphasia were able to pay attention to visually presented stimuli. Individuals with aphasia performed with high accuracy but significantly slower than the control participants. This group difference in reaction time indicates that, even at a basic level, individuals with aphasia demonstrate slower processing rate compared to controls. Attentional deficits are often apparent in individuals who had a stroke. It is not clear, however, whether impaired attentional abilities are related to aphasia or are the consequences of the brain attack. Our findings suggest that participants with aphasia were able to recruit more cognitive resources as task demands increased.

The second hypothesis of the present study proposed that, although individuals with aphasia can block an automatic response with great accuracy, they demonstrate longer reaction times compared to the control group as a reflection of an overall slowness in information processing. Verifying this assumption, we found significant differences in reaction time between the groups but not in response accuracy. Individuals with aphasia demonstrated slower reaction time compared to the controls but they were accurate in their responses.

Although we expected a difference in both accuracy and reaction time in the interference tasks, there was no group effect in accuracy in resisting distractor interference. We based our hypothesis on previous findings that showed weaker resistance to interference in different picture-word interference paradigms (e.g., Hashimoto & Thompson, 2010). Although these authors reported increased semantic interference in individuals with aphasia, and we used a non-verbal task to measure resistance to distractor interference, previous studies indicated a correlation between semantic functions and executive control processes in non-verbal tasks (Biegler et al., 2008). Our task was very simple, therefore all participants performed with high accuracy, but the reaction time results showed a weakness in resistance to distractor interference in individuals with aphasia. This is an important finding, because slowness in deciding which items are irrelevant may influence information processing in general.

Resistance to proactive interference was measured with a verbal conflict paradigm. The results were similar to the outcomes from the previous tasks. Individuals with aphasia provided a high number of correct responses but showed significantly slower processing speed than the controls. These results may reflect a trade-off between accuracy and speed. In the present study, individuals with aphasia may have prioritized accuracy over speed. Furthermore, the processing rate of linguistic information in aphasia is generally slower than in average adults. The consistent finding of slow processing rate across tasks in our study is in line with the notion of Blumstein et al. (2013) who stated that processing of linguistic information interacts with the processing of non-linguistic information. It is widely accepted in the literature that people with aphasia have difficulties with information processing as indicated by deficits in working memory performance and strategy use. The impairment of these functions can be manifested in problems with maintaining information, manipulating information or using an adequate strategy for the task (Haaland, 1979). Based on the multifunctional network account, the slowness in executive processes may be related to the systematic interaction between linguistic and executive functions (Cahana-Amitay & Albert, 2015).

To test our final hypothesis (there is a difference in performance pattern between the groups), we compared reaction time data across tasks and found a consistent pattern. Individuals with aphasia were slower in every single task than the controls. Large effect sizes indicate that individuals with aphasia processed information across different conditions with slower rate than control participants. The results in resistance to proactive interference showed the largest difference between the groups. It is important to note that this was the only verbal task in the present study. However, other researchers using different tasks also found weaker resistance to proactive interference in individuals with aphasia compared to controls (Hamilton & Martin, 2007). If individuals with aphasia show general slowness in information processing, then they may also show slower working memory updating. If working memory is not updated frequently and efficiently, then irrelevant and relevant items may compete for the same limited capacity. This may lead to difficulty in resisting proactive interference.

In summary, individuals with aphasia exhibit weak executive functions including interference control. Supporting previous findings (Novick and colleagues, 2005; Purdy, 2002; Biegler and colleagues, 2008), we found further evidence using experimental manipulations for a general slowness in executive functions. Our tasks were quite simple, so participants' responses were highly accurate. Despite the simplicity of the tasks, individuals with aphasia showed slow processing. In more complex tasks, this overall slowness may lead to decreased accuracy. Our findings support the notion that language processes and executive functions show a dynamic relationship. Future research is needed to better understand whether these weaknesses in executive functions are specific to aphasia or are associated in a more general way with brain damage.

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APPENDIX

1. Table

Normality analysis for RT

Shapiro-wilk RT						
Tasks	**Group**	**Conditions**	**Statistics**	**df**	**Sig.**	**Mdn**
Vigilance	Aphasia		0,75	83,00	0,00	873,00
	Control		0,41	83,00	0,00	534,00
Distractor interference	Aphasia		0,87	39,00	0,00	834,00
	Control		0,92	39,00	0,01	622,50
Response inhibition	Aphasia	Distractor	0,94	48,00	0,02	1 217,00
	Aphasia	Target	0,75	48,00	0,00	1 766,00
	Control	Distractor	0,58	48,00	0,00	824,00
	Control	Target	0,78	48,00	0,00	839,00
Resistance to proactive interference	Aphasia	Baseline	0,74	121,00	0,00	1 822,00
	Aphasia	Interference	0,82	121,00	0,00	1 805,00
	Aphasia	Target baseline	0,54	121,00	0,00	1 396,00
	Aphasia	Target interference	0,59	121,00	0,00	1 378,00
	Control	Baseline	0,45	121,00	0,00	1 050,00
	Control	Interference	0,78	121,00	0,00	1 100,00
	Control	Target baseline	0,54	121,00	0,00	1 039,00
	Control	Target interference	0,93	121,00	0,00	1 059,00

2. Table

Normality analysis for ACC

Shapiro-wilk ACC						
Tasks	**Group**	**Conditions**	**Statistics**	**df**	**Sig.**	**Mdn**
Vigilance	Aphasia		0,87	4,00	0,30	95,74
	Control		0,63	4,00	0,00	100,00
Distractor interference	Aphasia		0,80	4,00	0,10	47,00
	Control		0,95	4,00	0,73	47,50
Response inhibition	Aphasia	Distractor	0,75	5,00	0,03	100,00
	Aphasia	Target	0,99	5,00	0,98	81,82
	Control	Distractor	0,55	5,00	0,00	100,00
	Control	Target	0,77	5,00	0,05	100,00
Resistance to proactive interference	Aphasia	Baseline	0,86	6,00	0,20	93,61
	Aphasia	Interference	0,61	6,00	0,00	98,28
	Aphasia	Target in baseline	0,75	6,00	0,02	94,72
	Aphasia	Target in interference	0,66	6,00	0,00	92,61
	Control	Baseline	0,76	6,00	0,02	98,33
	Control	Interference	0,93	6,00	0,59	85,04
	Control	Taget baseline	0,96	6,00	0,82	96,05
	Control	Target interference	0,69	6,00	0,00	100,00