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Authors

Kuptsova, Svetlana
Dragoy, Olga
Ivanova, Maria

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Switching attention deficits in post-stroke individuals with different aphasia types

Svetlana V. Kuptsova[a,b], **Olga V. Dragoy**[b,c], **Maria V. Ivanova**[d]

[a]Center for Speech Pathology and Neurorehabilitation, Moscow, Russia;

[b]HSE University, Moscow, Russia;

[c]Institute of Linguistics, Russian Academy of Sciences, Moscow, Russia;

[d]Department of Psychology, University of California Berkeley, Berkeley, CA, USA

Abstract

Background: Previous studies have shown that individuals with aphasia have impairments in switching attention compared to healthy controls. However, there is insufficient information about the characteristics of switching attention within one task and whether attention deficits vary depending on aphasia type and lesion location. We aimed to address these knowledge gaps by investigating characteristics of switching attention within one type of task in participants with different types of aphasia and distinct lesion sites.

Method: Forty individuals with post-stroke aphasia (20 with non-fluent aphasia and frontal lobe damage, and 20 with fluent aphasia and temporal lobe damage) and 20 neurologically healthy age-matched individuals performed an attention switching task. They listened to sequences of high-pitched and low-pitched tones that were presented to them one by one, tallied them separately, and, at the end of each sequence, had to say how many high- and low-pitched tones they had heard.

Results: Participants with aphasia performed significantly worse on the task compared to healthy controls, and the performance of two aphasia groups also differed. Specifically, individuals with both aphasia types made more errors than healthy individuals, and the participants with non-fluent aphasia responded more slowly than controls, while reaction times of the participants with fluent aphasia did not differ significantly from those of controls. Also, the two groups of participants with aphasia differed significantly in accuracy, with individuals in the non-fluent group making more errors.

Conclusions: The data demonstrated that people with different types of aphasia have distinct impairments in switching attention. Since cognitive deficits impact language performance, this information is important for differentially addressing their language problems and selecting more specific and optimal rehabilitation programs that target different underlying mechanisms.

CONTACT Svetlana V. Kuptsova ✉ kuptsova.svetlana.v@gmail.com Center for Speech Pathology and Neurorehabilitation, Russia.

Disclosure statement

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Keywords

Aphasia; non-fluent aphasia; Fluent aphasia; attention; switching attention

1. Introduction

Various studies have shown that people with aphasia (PWA) also have deficits in attention, thinking, memory, and executive functions (Ivanova et al., 2015; Kasselimis, 2015; Murray, 2012; Šebková & Vitásková, 2015). Moreover, a growing body of the literature demonstrates specific attention deficits in some PWA (Erickson et al., 1996; Gerritsen et al., 2003; Heuer & Hallowell, 2015; Hunting-Pompon et al., 2011; Laures, 2005; Murray, 2002, 2012; Murray et al., 1998). The observed cognitive impairments cannot be explained exclusively by language deficits, since the cognitive tasks used often include nonverbal stimuli and do not involve verbal processing (Erickson et al., 1996; Hunting-Pompon et al., 2011; Murray et al., 1998). These cognitive deficits, particularly problems with attention, in turn negatively impact language processing and can influence the recovery of PWA (Ramsing et al., 1991).

There are several types of attention, including sustained attention or vigilance (the ability to maintain focus on specific stimuli during continuous activity), selective or focused attention (the ability to respond only to specific stimuli and not respond to others), alternating or switching attention (the ability to shift focus back and forth between two or more stimuli), and divided attention (the ability to process two or more stimuli or tasks simultaneously) (Blanchet, 2016; Burda et al., 2018; Lezak et al., 2012). Previous research has indicated that all of these processes can be disrupted in PWA (Caplan & Waters, 1994; Erickson et al., 1996; Hunting-Pompon et al., 2011; Lapointe & Erickson, 1991; Laures, 2005; Murray et al., 1997, 1998; Schumacher et al., 2019; Villard & Kiran, 2018).

Most research studies on attention in PWA, where participants perform two tasks separately, simultaneously, or in an alternating manner, use verbal and nonverbal tasks in the same experiment. For example, in one study (Hunting-Pompon et al., 2011), participants with mild anomia and neurologically typical controls were tested using the *Covert Orienting of Visuospatial Attention Test* (Posner & Cohen, 1980), alone and with linguistic interference. Participants with anomia showed significantly slower responses during the automatic processing timing conditions and when interfering stimuli were present, compared to controls. Villard and Kiran (2018) used five attention tasks in their study. Participants had to perform different non-linguistic and linguistic attention tasks with visual, audio, and visual-auditory stimuli. The study showed that PWA experienced higher degrees of fluctuations in their ability to pay attention from moment to moment than controls and that further these fluctuations in attention increased in PWA with increase in task demands and addition of language demands (Villard & Kiran, 2018). Schumacher et al. (2019) tested deficits in non-verbal and language functions in PWA. To study switching ability, they used the *Trail Making Test* (Kaplan et al., 1991), where participants have to connect numbers, then letters (verbal task), and then alternating letters and numbers (verbal and non-verbal tasks) in sequential order. PWA demonstrated the most pronounced impairments in switching between letters and numbers, and in connecting letters (Schumacher et al., 2019). Other studies (Caplan & Waters, 1994; Lapointe & Erickson, 1991; Murray et al., 1998) have also shown significant differences between PWA and controls when switching between two tasks was required. In these studies, participants had to perform a verbal task (syntactic processing/picture-description task/monitoring for spoken words) and a non-verbal task (identifying tones/recalling a series of digits) at the same time. Participants with aphasia switched between both tasks (verbal and non-verbal) worse than controls, but when individuals with aphasia were tested on these tasks separately, they performed significantly better. Thus, all of these studies used at least one verbal task for studying switching attention ability, and clearly demonstrated that PWA had problems switching between tasks. But using verbal tasks to study attention in PWA leaves an open question as to whether PWA truly have a deficit in switching attention, or they have language impairments that can influence performance on such tasks.

Some of the investigations identifying attention impairments in aphasia did not directly involve the language function. For example, in Erickson et al.'s (1996) study, people with non-fluent aphasia and healthy controls performed a single task, where they had to listen to a series of nonlinguistic acoustic stimuli and try to identify target sounds interspersed with nontarget sounds, and a dual-task where, in addition to the auditory attention task, they had to simultaneously complete the *Wisconsin Card Sorting Test* (Grant & Berg, 1981). Participants with aphasia and control participants performed similarly in the single task condition, but in the dual-task condition, participants with aphasia demonstrated lower accuracy on the attention task. These findings demonstrate that PWA have specific deficits in different types of attention, especially switching and divided attention, which most likely extend beyond the language domain (Erickson et al., 1996). This type of study used two non-verbal tasks, one of which is very complex by itself (*Wisconsin Card Sorting Test*), that involve different modalities and that had to be performed at the same time, adding additional metacognitive complexity for participants with brain damage.

It has been shown that damage to different regions in the left hemisphere can lead to the different types of aphasia and specific language symptoms, for example, damage in the left inferior frontal lobe manifests in non-fluent aphasia, while damage in the left temporal and nearby parietal lobes manifests in fluent aphasia (Dronkers & Larsen, 2001; Khomskaia, 2005; Luria, 1980; Tonkonogy & Puente, 2009). But lesions in the anterior vs. posterior regions of the left hemisphere have also been shown to result in divergent patterns of cognitive deficits. For example, it has been shown in a previous lesion symptom mapping study that the damage in the left inferior frontal lobe led to problems on a working memory task (complex span task) that involved switching between two tasks, while injury in the left superior and middle temporal lobe led to deficits in the 2-back task (Ivanova et al., 2018). Also, prefrontal lesions in the left hemisphere can result in inertia, perseveration, rigidity, information processing deficits, slowing in shifting attention, disorganization, defective self-monitoring and self-correcting, and an overall decreased speed of processing, while temporal lesions in the left hemisphere can result in reduction of verbal material perception, paraphasias, decreased verbal memory, impaired retrieval of auditory information, and problems with focusing on auditory stimuli (Khomskaia, 2005; Lezak et al., 2012; Luria, 1980; Tonkonogy & Puente, 2009). So, we can expect that for the same task, participants with non-fluent and fluent aphasia will respond differently.

However, according to the existing literature, it is difficult to differentiate impairments of switching attention from a decline in other cognitive functions or domain-specific problems. These switching attention studies often employ two different tasks, in which participants have to shift their attention between them. The tasks can use different stimuli and different modalities that themselves add additional complexity, since more reliance on executive functions and working memory is required. Further, if one of the tasks employed is a language task, it in itself can be too complex for PWA, given the language deficits in aphasia. Cumulatively, these factors might lead to an inaccurate evaluation and likely overestimation of deficits in switching attention. Therefore, it seems that a better way to study switching attention would be to use a task with a single category of stimuli (preferably nonverbal) in which participants have to switch their attention from one feature of an object to another. Another limitation of the current literature is that in the vast majority of studies, PWA were studied as a uniform group, with some studies just providing information about which participants had what type of aphasia (e.g., Schumacher et al., 2019; Villard & Kiran, 2018), others not even providing that information in the participant description (e.g., Caplan & Waters, 1994; Lapointe & Erickson, 1991), while others focused specifically on comparing one type of aphasia, for example, non-fluent or anomic aphasia, with controls (e.g., Erickson et al., 1996; Hunting-Pompon et al., 2011) rather than being divided according to different aphasia types or brain lesion sites. It would be useful to contrast performance on attention tasks across different types of aphasia, with an appropriate number of participants in each group, as depending on impairment profile and lesion site different mechanisms might come into play.

The aim of this study was to investigate switching attention during the performance of a task with one type of stimuli in participants with aphasia compared to healthy age- and education-matched controls. Additionally, we specifically aimed to compare the characteristics of switching attention in individuals with non-fluent aphasia (due to an anterior lesion) vs. fluent aphasia (due to a posterior lesion). We expected that (a) PWA would perform worse than controls on an attention switching task and (b) different groups of aphasia participants would differ in accuracy and reaction times while performing this task. We anticipated that in participants with non-fluent aphasia deficits in attention switching will manifest both in accuracy and reaction times as a result of the main symptoms of this group that includes inertia, perseveration, rigidity, decreased speed of processing, while participants with fluent aphasia will mostly show problems in accuracy due to decreased verbal memory, impaired retrieval of auditory information, and problems with focusing on auditory stimuli, while their reaction times will remain in the normal range.

2. Methods and materials

2.1. Participants

The control group consisted of 20 healthy participants (10 male). None of the participants had psychiatric or neurological disorders. All were right-handed and native speakers of Russian. The aphasia group included 40 individuals with aphasia following stroke (23 male) who were recruited at the Center for Speech Pathology and Neurorehabilitation in Moscow, Russia. All participants with aphasia were also pre-morbidly right-handed and native speakers of Russian. None of the participants had diagnosed neurodegenerative disorders, epilepsy, other psychiatric disorders such as depression (as diagnosed by certified psychiatrists), or history of alcohol or drug abuse. All participants (PWA and controls) passed a hearing screening prior to administration of the experimental tasks. They had to correctly distinguish tones of frequency at 500, 1000, and 2000 Hz, and at both 40 and 60 dB HL. Participants had education levels ranging from a vocational education to a university degree. Demographic data are presented in Table 1.

Participants with aphasia included in the study were diagnosed either with a non-fluent or a fluent type of aphasia of various severity resulting from a single left-hemisphere stroke; the minimum time post-onset was 2 months, with the group of PWA ranging from subacute to chronic stages of recovery. Each person with aphasia was examined by a speech-language pathologist and a neuropsychologist of the Center, and their language deficits were classified using Luria's aphasia classification system (Akhutina, 2016; Luria, 1980). According to Luria's classification, each type of aphasia is characterized by a disturbance of a specific neuropsychological factor (it is a morpho-functional unit of the work of the brain, and when it is damaged, it leads to specific combinations of symptoms, which together make up a specific neuropsychological syndrome) and each type has its own lesion location, primary deficits, and symptoms (Akhutina, 2016; Khomskaia, 2005; Luria, 1980). Only individuals who were unanimously identified as having exclusively non-fluent or fluent types of aphasia by both the speech-language pathologist and the neuropsychologist were included in the respective groups. If PWA did not understand language at all, they were not recruited for the experiment. Only PWA who could understand at least simple instructions were included in the study. Also, according to the neuropsychological assessment, none of the PWA had problems with numbers, tallying, visual function, or non-verbal auditory function. Furthermore, in order to avoid a mixture of symptoms from non-fluent and fluent aphasias and to be able to discuss the neural mechanisms of these types of aphasias, we verified by written MRI or CT medical reports (available in patients' medical records) that non-fluent and fluent aphasia types corresponded to distinct anterior and posterior lesion sites, respectively, in accordance with Luria's classification of aphasia. Those individuals who had damage to both frontal and posterior temporal brain regions were not included in the study. While we would like to emphasize that there is no accepted one-to-one correspondence between aphasia types within Luria's classification and the western multidimensional approach (for more on this see Akhutina, 2016), the general distinction made between individuals with non-fluent and fluent aphasias is shared and accepted within both approaches, as is the general localization of corresponding brain lesions (Ardila, 2010; Ivanova et al., 2015, 2017). For instance, a recent large voxel-based lesion–symptom mapping study demonstrated that Broca's (non-fluent) and Wernicke's (fluent) aphasia types correspond to distinct non-overlapping anterior and posterior lesion sites (Henseler et al., 2014).

The group with non-fluent aphasia consisted of participants with efferent motor aphasia or/and dynamic aphasia (most similar to Broca's aphasia and possibly transcortical motor aphasia, again for more on this see Akhutina, 2016), who had lesions in the left frontal lobe of the brain (number of participants with non-fluent aphasia = 20; 10 male; 10 female). Some of these individuals had lesions involving also the postcentral gyrus or/and partially the anterior temporal pole. This is consistent with Luria's classification of aphasia, in which efferent motor and dynamic aphasias result from damage to the inferior part of left frontal lobe.

The group with fluent aphasia included individuals with sensory aphasia or/and acoustic-mnestic aphasia (coarsely corresponding to Wernicke's aphasia and anomic aphasia, Akhutina, 2016), with lesions in the left temporal lobe of the brain (number of participants with fluent aphasia = 20; 13 male; 7 female). The majority of participants in this group also had damage to nearby inferior parietal and occipital areas. Again, this is in line with Luria's classification, in which sensory and acoustic-mnestic aphasias arise from lesions to the posterior part of the left temporal lobe. None of the individuals with fluent aphasia had a lesion in the frontal lobe and, respectively, none of the individuals with non-fluent aphasia had a lesion in the posterior part of the temporal lobe. Demographic data for participants with aphasia are presented in Table 1.

Aphasia severity, as indexed by the overall score on the *Assessment of Speech in Aphasia* (see its description below (Tsvetkova et al., 1981)), ranged from mild to severe. There were no significant differences in age ($z = -0.447$, $p = .659$), education ($z = -1.448$, $p = .231$), month post-onset ($z = -0.176$, $p = .862$) or overall aphasia severity ($z = -1.907$, $p = .056$) between individuals with non-fluent and fluent aphasia. There were also no significant differences in age and education between healthy participants and individuals with non-fluent (age: $z = -1.070$, $p = .289$; education: $z = -0.453$, $p = .738$) and fluent aphasia (age: $z = -0.962$, $p = .341$; education: $z = -0.967$, $p = .429$). Individual participant data are presented in Appendix A (Table A.1).

This study was approved by the Ethics Committee of the Center for Speech Pathology and Neurorehabilitation. All participants gave their consent for participation in the study.

2.2. Language assessment

All participants with aphasia were tested with a comprehensive aphasia battery in Russian – the *Assessment of Speech in Aphasia* (ASA; Tsvetkova et al., 1981). This is a traditional standard Russian language battery for aphasia that is used in clinical practice to assess aphasia severity and rehabilitation progress. This battery includes production and comprehension subtests. The production subtests include naming objects and actions, sentence construction, picture description, and answering questions in a dialogue. The comprehension subtests include single-word auditory comprehension (both nouns and verbs), sentence comprehension, following commands, and question comprehension in a dialogue (the same questions are used for both the production and comprehension sections). For each task, a maximum score of 30 can be obtained, with a maximum overall score of 300 for the whole battery. The higher the score, the fewer language impairments PWA have. In the current study, we used the overall score from the whole battery (general measure of aphasia severity), as well as the individual cumulative scores for the production and comprehension subtests.

2.3. Experimental task

The experimental task for switching attention was based on Garavan's task (Garavan, 1998), where participants have to shift their attention within one category of objects, relying on different characteristics of similar stimuli. This type of task allows the exploration of switching attention with one type of stimulus rather than switching between two different types of stimuli/tasks, minimizing reliance on executive skills and maintenance of complex task instruction. Additionally, by incorporating nonverbal auditory stimuli, the task minimizes linguistic processing demands.

In the current study, the participants had to switch their attention between counting high-pitched (2000 Hz) and low-pitched (500 Hz) tones that lasted 500 ms and were presented to them one by one in pseudorandom order. Each trial consisted of a sequence of 7–9 tones. There were 30 trials total, half of which had high switching frequency (four switches within a trial between high- and low-pitched tones, 15 trials), and half of which had low switching frequency (two switches, 15 trials). The participants had to press the space bar to advance to the next tone in the trial (all participants including controls had to press the space bar using their left hand, as many participants with aphasia have right-hand paresis). The duration of the pause between when the participant pressed the space bar and presentation of the next tone varied in a pseudorandom order and lasted 150, 300, or 600 ms. The participants had to listen to these tones and covertly (i.e., without speaking aloud) count high- and low-pitched tones separately. At the end of each sequence, the participant had to say how many high- and low-pitched tones they had heard (see Figure 1 for a schematic representation of the task). If the participant could not respond orally, they would write the answer or show it using their fingers. The participants were prompted to perform as quickly and accurately as possible and this was further emphasized during training, but at the end of each trial they answered at their own speed. The experimental task took between 8 and 15 minutes per participant. Participants were instructed that they could take a break in between trials if they needed one, but no participants opted to do so.

Experimental task instructions were presented in written form on a laptop screen and also delivered verbally by the examiner. Then, the examiner demonstrated how to do the task and performed it together with the participant. If participants could not understand the task, the instructions were repeated once. Prior to starting the experimental task, participants had to complete three short practice trials on their own (consisting of five tones). They had to correctly perform two trials out of three to participate in the study.

The task instructions, practice, and experimental trials were presented on a laptop in an automated mode using E-Prime 2.0. Participants' responses were recorded by the examiner. Reaction times were automatically recorded by the computer program.

The following parameters were used to assess performance on the task:

- *Accuracy*, as indexed by the number of correct responses: overall and separately for trials with low and high switching frequencies. Accuracy reflected the overall efficiency of attention switching abilities.

- *Reaction times* (only for correct trials): overall and separately for non-switching (same stimuli as the previous one: low–low or high–high) and switching (different stimuli from the previous one: high–low) stimuli. Reaction times indicated the current processing load. We computed reaction times only for correct trials because it is difficult to predict why participants made mistakes (whether they counted or not during that trial) and how they behaved if they noticed their mistakes (e.g., some of them stopped and asked what to do, while some continued to press the button and tried to guess the correct count).

2.4. Statistical analysis

Statistical analysis was performed with SPSS Statistics for Windows, Version 22. The data were checked for normal distribution using the Kolmogorov–Smirnov test. None of the dependent variables corresponded to the normal distribution ($p < 0.01$). Therefore, the non-parametric Wilcoxon test was conducted to compare variables within each group (accuracy in low and high switching frequencies, and reaction times for non-switching and switching stimuli), and Spearman correlation analysis was performed to study the relationships between task performance and other variables (aphasia severity, months post-onset, age, education levels). The Mann–Whitney U-test was used to study the differences between the groups (all aphasia, non-fluent aphasia, fluent aphasia, controls). The comparison between the control and the aphasia group was followed up with a comparison between fluent and non-fluent groups. To control the familywise error, we adjusted the p-value for the number of between-group comparisons ($p = .05/3 = .017$).

3. Results

3.1. Comparison of accuracy and reaction times within each group

In the first part of the analysis, we compared differences in the number of correct responses between trials with low and high switching frequencies and the mean reaction times between non-switching and switching stimuli. Outliers for reaction time measurements (that were ± 3 SD from the mean for each participant) were excluded from further analysis and are not presented in the descriptive statistics below. Fewer than 2.85% were excluded in the controls and fewer than 3.42% of outliers were excluded in PWA. Descriptive statistics for the number of correct responses and reaction times for each group are presented in Figure 2 and Appendix A, Table A.2. In each group, the mean number of correct responses between trials with low and high switching frequencies did not differ significantly, while the mean reaction times for switching stimuli were significantly longer compared to non-switching stimuli (controls: $z = -3.920$, $p < .001$; non-fluent aphasia: $z = -3.385$, $p = .001$; fluent aphasia: $z = -3.432$, $p = .001$).

Also, we qualitatively analyzed the types of errors which PWA made. All participants (100% in the non-fluent group and 100% in the fluent group) made plus-minus-one (±1) types of mistakes, meaning that they provided a number one away from the correct response, for example, four or six instead of five. In addition to these ±1 mistakes, a few participants (15% in the non-fluent group and 15% in the fluent group) did not provide an answer at all (e.g., just stated that “I lost track”). Also, a small subset of participants (20% in the non-fluent group and 10% in the fluent group) sometimes provided an incorrect number, which was not close (within ±1) to the correct response. Qualitatively, no specific difficulties (increased fatigue, systematic requests to restart a trial or regularly providing random answers) in task performance were observed. Overall, the observed pattern of performance supports the task use in a varied aphasia population.

In the correlational analysis (see Appendix A, Table A.3), no significant associations were identified among aphasia severity (general measure of aphasia severity, cumulative scores for the production and comprehension), months post-onset, age, education levels of the participants and the number of correct responses, and reaction times for all aphasia groups (aphasia combined, non-fluent, and fluent aphasia).

Additionally, a correlation analysis between accuracy and reaction times was performed within each group. None of the correlations for the three groups were significant (controls: $r = .008$, $p = .972$; non-fluent aphasia: $r = .145$, $p = .542$; fluent aphasia: $r = -.393$, $p = .086$).

3.2. Comparison of aphasia groups and healthy controls

In the second part of the analysis, we compared the performance of the whole aphasia group (participants with non-fluent and fluent aphasia combined) to the control group. The two groups were significantly different on all measures of performance: the aphasia group demonstrated lower accuracy and longer reaction times across all conditions (see Figure 2, Appendix A, Table A.4). Then, the control group was compared to the non-fluent and fluent aphasia groups separately (see again Appendix A, Table A.4). The non-fluent group again performed significantly worse than healthy controls on all measures of performance. However, while participants with fluent aphasia also made significantly more errors than the controls, the difference in mean reaction times between the fluent aphasia group and the controls was not significant.

Additionally, to evaluate how many participants in each group performed significantly worse than the control group, we calculated a 95% Confidence Interval (CI) around the mean of the control group for each parameter and calculated for each PWA group how many participants performed below this CI (see Figure 3, Appendix A, Table A.5). For all parameters of accuracy and reaction times, more than half of the PWA performed below the CI, with individuals in the non-fluent group demonstrating poorer performance, particularly in accuracy.

3.3. Comparison of non-fluent and fluent aphasia groups

Finally, we contrasted performance of the two aphasia groups. It was found that participants with non-fluent aphasia made significantly more errors at low and high switching frequencies than did participants with fluent aphasia (see again Figure 2, Appendix A, Table A.4 for results of this comparison). There were no significant differences in mean reaction times between the two aphasia groups.

4. Discussion

The aim of this study was to investigate the characteristics of switching attention while performing a task with one type of stimuli in participants with aphasia in comparison to healthy controls, as well as to compare the features of switching attention in participants with fluent and non-fluent aphasia. Previous studies have shown that participants with aphasia have switching attention deficits, but there is still a question of whether participants with different types of aphasia have distinct deficits, and it is also not clear whether these impairments will appear in tasks with one type of stimuli as opposed to tasks with multiple types. We found differences in the performance of the switching attention task between participants with aphasia and controls, which is consistent with the existing literature (Caplan & Waters, 1994; Erickson et al., 1996; Hunting-Pompon et al., 2011; Murray et al., 1998). Also, specific differences between the two aphasia groups (fluent and non-fluent) in attention switching were observed.

We first conducted a within group analysis of differences in performance on the various task conditions. No statistical differences in accuracy between trials with low- and high switching frequency were observed across all participant groups (although numerically the trials with high switching frequency led to more errors across all participant groups), likely indicating that participants found both types of trials sufficiently challenging and that even two switches within a sequence of 7–9 tones provided a necessary attentional challenge. At the same time, significant differences in reaction times between switching and non-switching stimuli were detected. Specifically, the results showed that the mean reaction times for switching stimuli were significantly longer than for non-switching stimuli for all groups of participants reflecting greater processing load. This is consistent with the literature, which indicates that the reaction times for switching from one type of stimulus to another, or from one task to another, are longer compared to situations where there is no need to switch attention (Kuptsova et al., 2015; Pashler et al., 2001; Ward, 2010). The main explanation for this mechanism is that the switching process involves additional control (a top-down process), which results in extra time being required, and this happens in both complex and easy tasks (Pashler et al., 2001). Also, we performed a correlation analysis between accuracy and reaction times within each group to check if the participants slowed down during the task to be more accurate. We did not find any significant correlations within either group. The observed lack of a positive correlation (with longer reaction times leading to higher accuracy) can indicate that participant did not resort to a special metacognitive strategy (i.e., intentionally slowing down to be more accurate) to perform the task.

For PWA, no significant associations were found between aphasia severity, education levels or time post-onset and task performance (both accuracy and reaction times). In this case, it is worth noting that aphasia severity varied greatly from mild to severe, but still no relationship with attention switching ability could be established for the combined aphasia group and for the two groups separately. This finding is in line with previous studies, which also found no relationship between nonlinguistic abilities and aphasia severity or other participant variables, such as education level or time post onset (Helm-Estabrooks et al., 2002; Murray et al., 1997). Therefore, this finding together with prior literature likely indicates that attentional deficits are independent of language deficits at a coarse level of analysis and that aphasia severity on its own is insufficient to predict concomitant cognitive deficits in aphasia. However, a relationship between attention and specific linguistic abilities cannot be excluded, as has been shown in previous studies of specific language deficits and different cognitive functions such as working memory, executive functions, attention (Caspari et al., 1998; Glosser & Goodglass, 1990; Ivanova et al., 2015; Murray et al., 1998). Age also did not influence the number of correct responses and reaction times in any of the groups. Although some studies, which examined neurotypical persons with no history of aphasia, have noted that the age of participants can affect reaction times and accuracy (Bielak & Anstey, 2019; Oosterman et al., 2010), no age differences were found in our study. This may be because our participant group had a relatively limited age range.

Next, we explored between group differences in attention switching. Accuracy and reaction times were significantly lower in the aphasia group overall compared to controls. This is in line with previous studies that have shown that persons with aphasia have significant difficulty with shifting attention between two different tasks (Erickson et al., 1996; Hunting-Pompon et al., 2011). Difficulties in attention switching have been related to limited cognitive flexibility and difficulties resisting interference among PWA. For example, Chiou and Kennedy (2009) demonstrated that PWA were slower, less accurate, and less likely to disregard the previous rule when switching from one rule to another compared to controls. In our study, we additionally showed that participants with aphasia also had problems with switching attention between one type of stimuli, resulting in an increase in the number of errors and longer reaction times to stimuli, regardless of whether they needed to switch to another count or not. Possibly, this is due to the use of additional resources needed for processing information or due to different mechanisms in participants with different aphasia types.

Subsequently, participants with different types of aphasia were separately compared to the healthy controls. Participants with non-fluent aphasia differed significantly from the control group in the number of correct responses (overall, low and high switching frequency trials), and in their reaction times (overall, non-switching, and switching stimuli). These differences can also be seen in the prevalence of these deficits in participants with non-fluent aphasia, while assessing them at the individual level versus controls with all except one individual in this group performing below the 95% confidence interval for healthy controls. However, participants with fluent aphasia showed a slightly different pattern. This group of participants had a significantly higher number of errors (overall, low and high switching frequency trials), but their reaction times did not significantly differ from the controls. These differences may be explained by distinct mechanisms that occur in each of the two groups of participants with aphasia while performing this task.

The significant number of errors made by participants with non-fluent aphasia could possibly be attributed to primary switching attention deficits, since such attentional impairments are associated with prefrontal brain damage in areas specifically compromised in this aphasia group (Petrides & Pandya, 2002; Tonkonogy & Puente, 2009; Wager et al., 2004). According to Petersen and Posner's model of attention, there is a frontoparietal attention network, which is thought to be responsible for initiating tasks, switching between tasks, and correcting them in real time (Petersen & Posner, 2012). Also, in a previous lesion symptom mapping study, it was shown that specifically left frontal lobe damage, rather than left temporal lobe damage, led to problems on a working memory task (complex span task) that involved switching between two tasks (Ivanova et al., 2018). Since the areas of the brain responsible for language and switching attention are located very close to each other (or possibly even in the same functional unit) in the prefrontal regions, both functions can be simultaneously impaired. Also, participants with non-fluent aphasia responded to stimuli (both non-switching and switching) significantly longer than the controls. This slowed performance of participants with non-fluent aphasia is typical of patients with prefrontal damage. Prefrontal lesions often result in inertia and an overall decreased speed of processing (Tonkonogy & Puente, 2009), in addition to the primary switching attention disorder, which itself can appear as perseveration, rigidity, or inertia (Lezak et al., 2012). This explanation is further supported by the fact that, in participants with fluent aphasia with posterior brain damage, reaction times did not significantly differ from the controls, and also, they were not slower in contrast to participants with non-fluent aphasia.

Participants with fluent aphasia made significantly more errors (overall, low and high switching frequency trials) than controls. It is unlikely that impaired task performance was due to naming deficits or inability to self-monitor their tallies, as then PWA would respond with random incorrect numbers, but the most common types of mistakes were ±1 (i.e., near the target stimuli) likely indicating attentional problems. It is more likely that these participants have a modality-specific attention impairment, which is known to occur after damage in specific brain areas that are responsible for processing stimuli in one specific modality. In this case, damage to the temporal lobe led to specific challenges with focusing on auditory stimuli (Khomskaia, 2005). Accordingly, these modality specific attention deficits might underlie the reduction of their auditory memory span, as well as problems accurately updating auditory information. Previous research has shown that brain areas responsible for these functions are mainly located in the temporal lobe (Ivanova et al., 2018; Kasselimis, 2015; Luria, 1980). Furthermore, participants with damage to the temporal areas had reaction times that were not significantly different from those of healthy controls. This lends additional support to the notion that the fluent aphasia group does not have any inert or primary switching attention impairment (Petrides & Pandya, 2002; Tonkonogy & Puente, 2009; Wager et al., 2004), as they could efficiently switch between two distinct counts, but lacked sufficient attentional or working memory resources to maintain an accurate tally.

When studying the differences between participants with aphasia, it was found that the participants with non-fluent aphasia made significantly more errors compared to those with fluent aphasia. This is likely explained by the primary impairment in switching attention in participants with non-fluent aphasia, leading to more pronounced deficits. Also, there were no differences in reaction times between the two groups of participants with aphasia (both with non-switching and switching stimuli), although as stated above individuals with non-fluent aphasia had significantly longer reaction times relative to controls, while reaction times of those with fluent aphasia did not significantly differ from controls. However, the underlying mechanisms for more errors relative to controls seem to be different for each aphasia group. For participants with non-fluent aphasia, it may be due to both their primary switching attention deficits and increased inertness, but for individuals with fluent aphasia, it may be caused by their modality-specific auditory attention deficits in combination with reduced auditory memory span and problems updating auditory information. Overall, current findings of differential attention deficits between participant with different aphasia types echo previous studies showing diverging patterns of non-linguistic cognitive deficits (Ivanova et al., 2015, 2017; Yao et al., 2020) and language impairments (Hazamy & Obermeyer, 2020; Laurinavichyute et al., 2014) in non-fluent vs. fluent aphasia.

One of the clear constraints of the current study is that we did not present other cognitive tasks to participants, and we did not use any specific control conditions for the experimental task, such as a non-switching reaction time task while tallying tones, or a task which did not involve processing auditory tones (e.g., a visual attention switching task) to evaluate how the PWA would have performed on such tasks. Since we did not administer a control task in which participants only had to tally one type of stimuli without having to switch from one type of tone to the another, we could not reliably measure switching costs. Direct comparison of switching and non-switching trials from the experimental task is flawed because in this task, a lot of parameters influence participants' reaction times in non-switching trials, such as having to maintain two separate tallies in their focus of attention, thinking about to which tally the current tone should be added to, constantly anticipating for the stimuli to change, thus their reaction times were influenced by similar factors in both instances. So, the experimental task is uninformative for measuring switching costs, which is a limitation of the current study that we hope to address in future work. Thus, we could not investigate other cognitive deficits that may be related to and influence switching attention, limiting our understanding of the mechanisms of impaired task performance. Also, a productive avenue for future investigation would be to explore impact of attentional impairments on specific linguistic abilities. Further, another limitation of the study is that we did not have access to MRI scans, but only to resulting MRI reports written by certified radiologists. Therefore, we could not perform proper examination of the lesion location or implement any kind of lesion symptom mapping analysis. Future studies will need to address these limitations and further disentangle the possible underlying mechanisms of the observed attentional impairments.

In the current study, we showed that participants with different types of aphasia have switching attention impairments that vary for each group. Different mechanisms are probably involved depending on the location of each participant's brain damage and the subsequent specific disorders of linguistic, cognitive, and executive functions that stem from the lesioned areas. Most likely, the more profound deficits in non-fluent aphasia are due to both primary switching attention deficits and increased inertness, while for individuals with fluent aphasia modality-specific auditory attention and memory impairments play a significant role. Further work is required to pinpoint the specific mechanisms involved. As this study showed diverse switching attention impairments for different aphasia groups, it is important to continue to investigate in more detail the different types of cognitive deficits that might impact language outcomes in different aphasia subgroups. Hopefully, in the future, considering the specific attention characteristics of people with aphasia will lead to more optimal rehabilitation programs and improved individual outcomes.

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APPENDIX A

Table A1.

Individual characteristics of participants.

№	Age	Sex	Years of education	Months post-onset	Group	Localization of lesion based on MRI or CT	Type of aphasia	ASA total score	ASA for comprehension	Number of correct responses (overall)	Number of correct responses for low frequency trials	Number of correct responses for high frequency trials
1	41	m	15		controls					30	15	15
2	42	m	15		controls					30	15	15
3	46	m	15		controls					24	12	12
4	46	m	12		controls					25	14	11
5	50	m	15		controls					26	12	14
6	50	m	12		controls					26	15	11
7	51	m	12		controls					22	15	7
8	54	m	15		controls					28	14	14
9	63	m	12		controls					27	15	12
10	38	m	15		controls					29	14	15
11	45	f	15		controls					28	14	14
12	46	f	15		controls					26	13	13
13	49	f	12		controls					26	12	14
14	52	f	15		controls					26	14	12
15	53	f	12		controls					25	13	12
16	53	f	15		controls					23	10	13
17	55	f	15		controls					27	13	14
18	59	f	15		controls					29	14	15
19	64	f	15		controls					22	11	11
20	68	f	15		controls					29	15	14
21	38	m	15	2	PWA	Left frontal area	non-fluent (MA & DA)	200.0	118.0	27	14	13
22	42	m	15	13	PWA	Left frontal area, precentral gyrus,	non-fluent (MA)	167.0	119.5	21	10	11

Nº	Age	Sex	Years of education	Months post-onset	Group	Localization of lesion based on MRI or CT	Type of aphasia	ASA total score	ASA for comprehension	Number of correct responses (overall)	Number of correct responses for low frequency trials	Number of correct responses for high frequency trials
						temporal pole						
23	46	m	15	18	PWA	Left frontal area, precentral gyrus	non-fluent (MA)	215	140.0	12	8	4
24	48	m	12	11	PWA	Left frontal area	non-fluent (MA)	234.0	141.5	17	8	9
25	49	m	12	24	PWA	Left frontal area, precentral gyrus, temporal pole	non-fluent (MA & DA)	189	103.5	23	13	10
26	54	m	15	47	PWA	Left frontal area, precentral gyrus, temporal pole	non-fluent (MA)	255.5	142.0	17	10	7
27	56	m	15	120	PWA	Left frontal area, precentral gyrus	non-fluent (MA)	267.0	142.0	15	7	8
28	60	m	15	10	PWA	Left frontal area, precentral gyrus	non-fluent (MA)	253.0	137.5	24	12	12
29	61	m	15	3	PWA	Left frontal area	non-fluent (MA)	244.5	138.5	19	11	8
30	67	m	15	9	PWA	Left frontal area, precentral gyrus	non-fluent (MA)	209.0	121.5	9	6	3
31	42	f	15	14	PWA	Left frontal area	non-fluent (MA)	207.0	147.0	22	10	12
32	48	f	12	5	PWA	Left frontal area	non-fluent (MA)	271.0	148.0	15	8	7
33	50	f	15	8	PWA	Left frontal area, precentral gyrus, temporal pole	non-fluent (MA)	139.0	105.0	17	8	9
34	54	f	15	15	PWA	Left frontal area	non-fluent (MA)	259.0	142.5	17	8	9
35	55	f	15	6	PWA	Left frontal area, temporal pole	non-fluent (MA)	231.5	131.5	22	12	10
36	55	f	12	12	PWA	Left frontal area,	non-fluent (MA)	238.0	138.5	14	7	7

№	Age	Sex	Years of education	Months post-onset	Group	Localization of lesion based on MRI or CT	Type of aphasia	ASA total score	ASA for comprehension	Number of correct responses (overall)	Number of correct responses for low frequency trials	Number of correct responses for high frequency trials
						temporal pole						
37	56	f	15	30	PWA	Left frontal area, precentral gyrus	non-fluent (MA)	239.5	141.5	16	8	3
38	57	f	15	12	PWA	Left frontal area, temporal pole	non-fluent (MA)	227.5	122.5	20	12	8
39	64	f	12	36	PWA	Left frontal area, precentral gyrus	non-fluent (MA)	218	147.5	23	12	11
40	64	f	15	13	PWA	Left frontal area	non-fluent (MA)	262.0	141.0	24	11	13
41	44	m	12	6	PWA	Left temporal and partly parietal areas	fluent (SA)	196.0	110.0	22	11	11
42	44	m	12	8	PWA	Left temporal and partly occipital areas	fluent (SA & AA)	225.0	123.5	26	12	14
43	44	m	12	19	PWA	Left temporal and partly parietal areas	fluent (SA & AA)	234.5	114.0	15	9	6
44	50	m	12	4	PWA	Left temporal and partly parietal areas	fluent (SA & AA)	113	74.5	23	12	11
45	51	m	15	30	PWA	Left temporal, partly parieto-occipital areas	fluent (SA)	216.5	129.5	22	9	8
46	57	m	15	16	PWA	Left temporal, partly parieto-occipital areas	fluent (SA)	150.0	104.0	19	10	9
47	57	m	15	36	PWA	Left temporal and partly occipital areas	fluent (AA)	213.0	128.5	23	11	12
48	58	m	15	14	PWA	Left temporal area	fluent (SA & AA)	225.5	125.5	18	9	9
49	59	m	15	3	PWA	Left temporal and	fluent (SA)	216.0	121.5	28	15	13

№	Age	Sex	Years of education	Months post-onset	Group	Localization of lesion based on MRI or CT	Type of aphasia	ASA total score	ASA for comprehension	Number of correct responses (overall)	Number of correct responses for low frequency trials	Number of correct responses for high frequency trials
						partly parietal areas						
50	59	m	15	6	PWA	Left temporal, partly parieto-occipital areas	fluent (SA)	227.0	123.0	28	15	13
51	59	m	12	8	PWA	Left temporal area	fluent (SA)	241.0	129.5	27	15	12
52	63	m	15	72	PWA	Left temporal and partly parietal areas	fluent (SA)	121.0	66.0	20	9	11
53	68	m	12	4	PWA	Left temporal and partly parietal areas	fluent (AA)	158.0	80.5	17	12	5
54	34	f	12	18	PWA	Left temporal area	fluent (SA & AA)	251.0	146.0	24	13	11
55	45	f	12	2	PWA	Left temporal and partly parietal areas	fluent (SA)	229.5	109.0	26	13	13
56	45	f	15	30	PWA	Left temporal and partly parietal areas	fluent (AA)	224.5	121.5	28	13	15
57	56	f	12	48	PWA	Left temporal, partly parieto-occipital areas	fluent (SA)	126.5	84.5	24	11	13
58	58	f	15	66	PWA	Left temporal and partly parietal areas	fluent (AA)	265.5	140.5	26	13	13
59	58	f	15	95	PWA	Left temporal and partly occipital areas	fluent (SA & AA)	158.5	91.5	23	11	12
60	63	f	15	4	PWA	Left temporal and partly parietal areas	fluent (AA)	215.0	105.0	19	8	11

Notes: m – male; f – female; ASA – the Assessment of Speech in Aphasia; PWA – participants with aphasia; MA – efferent motor aphasia under Russian classification (similar to Broca's aphasia); DA – dynamic aphasia under Russian classification (similar to transcortical motor aphasia); SA – sensory aphasia under Russian classification (similar to Wernicke's aphasia);

AA – acoustic-mnestic aphasia under Russian classification (corresponding to anomic aphasia). Reaction times presented in milliseconds.

Table A2.

Descriptive statistics for correct responses and reaction times.

Performance measure		Controls		Aphasia combined (fluent + non-fluent)		Non-fluent aphasia		Fluent aphasia	
		M(SD)	**Range**	***M(SD)***	**Range**	***M(SD)***	**Range**	***M(SD)***	**Range**
Accuracy (number of correct answers)	Overall	26.40 (2.44)	22–30	20.80 (4.70)	9–28	18.70 (4.48)	9–27	22.90 (3.89)	15–28
	Trials with low switching frequency	13.50 (1.47)	10–15	10.63 (2.36)	6–15	9.70 (2.25)	6–14	11.55 (2.14)	8–15
	Trials with high switching frequency	12.90 (1.97)	7–15	9.92 (3.02)	3–15	8.75 (3.04)	3–13	11.10 (2.57)	5–15
Reaction times (ms)	Overall	1452.84 (297.81)	846.99 – 1832.04	1954.02 (790.00)	906.21 – 5017.08	2193.57 (879.43)	1182.37 – 5017.08	1714.48 (621.98)	906.21 – 3007.28
	Non-switching stimuli	1359.64 (271.89)	817.03 – 1693.02	1822.24 (720.63)	832.57 – 4470.51	2050.96 (782.15)	1108.12 – 4470.51	1593.53 (586.58)	832.57 – 2859.37
	Switching stimuli	1580.61 (343.02)	886.18 – 2089.11	2136.82 (928.84)	941.46 – 6049.48	2400.68 (1074.63)	1279.92 – 6049.48	1872.96 (685.19)	941.46 – 3452.79

Notes: for Accuracy: Overall is out of a possible 30 correct answers, Trials with low and high switching frequencies are out of possible 15 correct answers; Reaction times are measured in milliseconds.

Table A3.

Spearman correlation analysis.

Non-fluent aphasia						
	Accuracy			**Reaction times**		
	Overall *r* (*p*)	**Trials with low switching frequency *r* (*p*)**	**Trials with high switching frequency *r* (*p*)**	**Overall *r* (*p*)**	**Non-switching stimuli *r (p)***	**Switching stimuli *r (p)***
Age	−.028 (*p* = .908)	−.050 (*p* = .835)	−.147 (*p* = .537)	.213 (*p* = .367)	.191 (*p* = .419)	.240 (*p*= .309)
Time post onset	−.134 (*p*= .573)	−.200 (*p* = .399)	−.131 (*p*= .581)	.032 (*p*= .892)	.088 (*p*= .712)	−.004 (*p*= .987)
Aphasia severity	−.205 (*p*= .386)	−.222 (*p*= .347)	−.227 (*p*= .335)	.021 (*p*= .930)	−.021 (*p*= .930)	.075 (*p*= .753)
Education levels	−.036 (*p* = .880)	−.045 (*p* = .852)	.007 (*p* = .978)	.045 (*p* = .851)	.051 (*p* = .832)	−.013 (*p* = .957)
Comprehension	−.227 (*p* = .337)	−.340 (*p* = .143)	−.134 (*p* = .574)	.113 (*p* = .636)	.069 (*p* = .772)	.145 (*p* = .541)
Production	.153 (*p* = .518)	.020 (*p* = .934)	.189 (*p* = .426)	.101 (*p* = .673)	.045 (*p* = .850)	.161 (*p* = .498)
Fluent aphasia						

Non-fluent aphasia						
	Accuracy			**Reaction times**		
	Overall *r* (*p*)	**Trials with low switching frequency *r* (*p*)**	**Trials with high switching frequency *r* (*p*)**	**Overall *r* (*p*)**	**Non-switching stimuli *r* (*p*)**	**Switching stimuli *r* (*p*)**
	Accuracy			**Reaction times**		
	Overall *r* (*p*)	Trials with low switching frequency *r* (*p*)	Trials with high switching frequency *r* (*p*)	Overall *r* (*p*)	Non-switching stimuli *r* (*p*)	Switching stimuli *r* (*p*)
Age	−.094 (p = .693)	−.021 (p = .931)	−.111 (p = .641)	.036 (p = .879)	.035 (p = .884)	−.045 (p = .852)
Time post onset	−.089 (p = .710)	−.314 (p = .178)	.038 (p = .875)	−.084 (p = .726)	−.124 (p = .601)	−.039 (p = .870)
Aphasia severity	.361 (p = .118)	.411 (p = .072)	.225 (p = .340)	−.239 (p = .310)	−.214 (p = .366)	−.217 (p = .359)
Education levels	−.035 (p = .883)	.212 (p = .369)	−.080 (p = .738)	.305 (p = .191)	.270 (p = .249)	.270 (p = .249)
Comprehension	.372 (p = .106)	.324 (p = .164)	.188 (p = .427)	−.150 (p = .527)	−.124 (p = .602)	−.129 (p = .589)
Production	.284 (p = .226)	.309 (p = .185)	.227 (p = .337)	−.152 (p = .523)	−.130 (p = .585)	−.129 (p = .587)
Aphasia (combined)						
	Accuracy			**Reaction times**		
	Overall *r* (*p*)	Trials with low switching frequency *r* (*p*)	Trials with high switching frequency *r* (*p*)	Overall *r* (*p*)	Non-switching stimuli *r* (*p*)	Switching stimuli *r* (*p*)
Age	−.026 (p = .873)	−.020 (p = .904)	−.048 (p = .768)	.134 (p = .418)	.107 (p = .511)	−.154 (p = .342)
Time post onset	−.126 (p = .438)	−.263 (p = .102)	−.067 (p = .682)	−.074 (p = .648)	−.079 (p = .630)	−.063 (p = .699)
Aphasia severity	−.087 (p = .593)	−.054 (p = .742)	−.124 (p = .446)	−.015 (p = .926)	−.001 (p = .996)	.026 (p = .875)
Education levels	.079 (p = .629)	.190 (p = .241)	.035 (p = .828)	.115 (p = .481)	.097 (p = .550)	.078 (p = .634)
Comprehension	−.184 (p = .255)	−.228 (p = .156)	−.169 (p = .298)	.138 (p = .395)	.137 (p = .399)	.172 (p = .289)
Production	.061 (p = .710)	.045 (p = .781)	.097 (p = .553)	.024 (p = .885)	.023 (p = .889)	.068 (p = .677)

Notes: r – correlation coefficient.

Table A4.

Results of between group comparison using the Mann–Whitney U-test.

Performance measure		**Controls vs. Aphasia (combined)**	**Controls vs. non-fluent aphasia**	**Controls vs. fluent aphasia**	**Non-fluent vs. fluent aphasia**
Accuracy (number of correct answers)	Overall Z (p)	−4.374* (p = .000)	−4.720* (p = .000)	−2.832* (p = .005)	−2.796* (p = .005)
	Trials with low switching frequency Z (p)	−4.298* (p = .000)	−4.531* (p = .000)	−2.905* (p = .004)	−2.457* (p = .014)

Performance measure		Controls vs. Aphasia (combined)	Controls vs. non-fluent aphasia	Controls vs. fluent aphasia	Non-fluent vs. fluent aphasia
	Trials with high switching frequency Z (p)	−3.831 * (p = .000)	−4.139 * (p = .000)	−2.480 * (p = .013)	−2.494 * (p = .013)
Reaction times (ms)	Overall Z (p)	−2.838 * (p = .005)	−3.571 * (p = .000)	−1.325 (p = .185)	−1.948 (p = .051)
	Non-switching stimuli Z (p)	−2.823 * (p = .005)	−3.733 * (p = .000)	−1.136 (p = .256)	−2.083 (p = .037)
	Switching stimuli Z (p)	−2.776 * (p = .006)	−3.327 * (p = .001)	−1.461 (p = .144)	−1.758 (p = .079)

Note.

* $p < .017$

Table A5.

Results of the Confidence Interval (CI) analysis, demonstrating how many PWA within each group performed below the CI for the control group.

Performance measure		Mean	Confidence Interval (95%)	Participants with non-fluent aphasia preforming below the CI	Participants with fluent aphasia performing below the CI
Accuracy (number of correct answers)	Overall	26.40	25.33–27.47	19	13
	Trials with low switching frequency	13.50	12.85–14.14	18	13
	Trials with high switching frequency	12.90	12.04–13.76	18	13
Reaction times (ms)	Overall	1452.84	1322.321–1583.36	15	11
	Non-switching stimuli	1359.64	1240.48–1478.79	15	11
	Switching stimuli	1580.61	1430.28–1730.94	15	12

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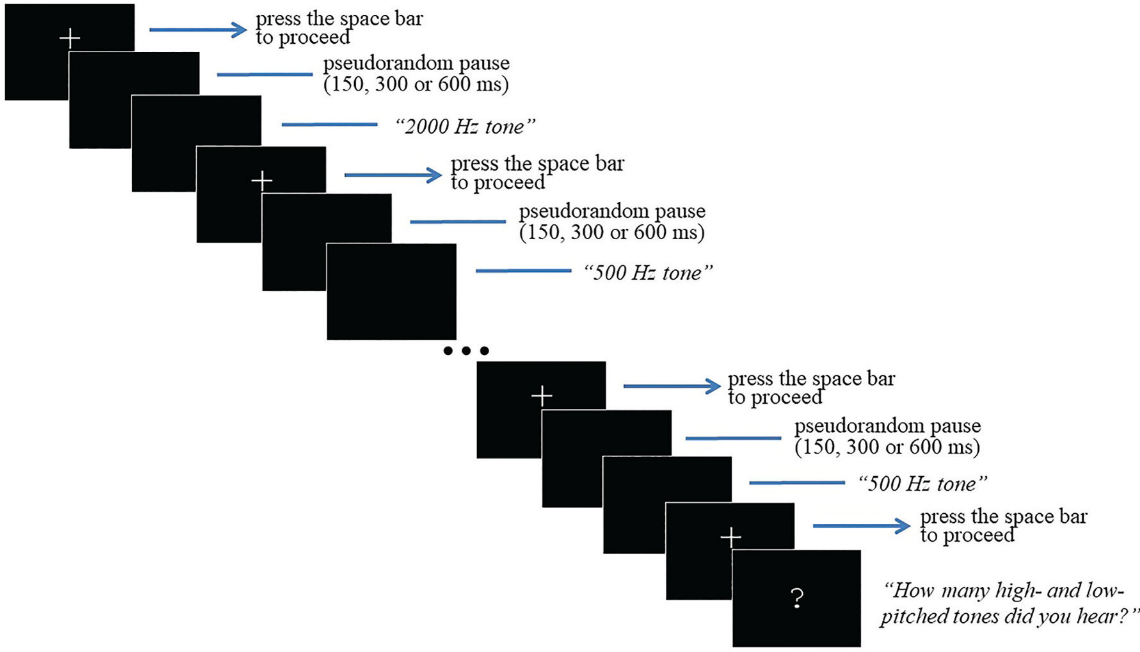

Figure 1.
Schematic representation of the experimental switching attention task.

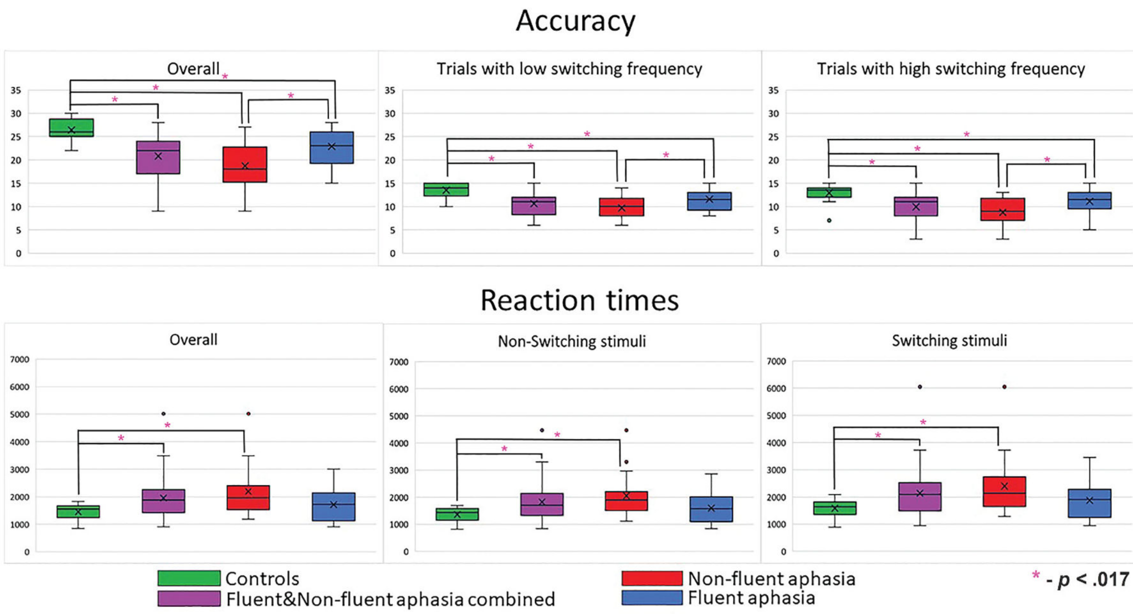

Figure 2.

Boxplots for correct responses and reaction times. The box represents the interquartile range, with the central line marking the median, and the cross representing mean. The whiskers denote the largest/smallest values within 1.5 times the interquartile range above/below the 75th/25th percentile. Values falling outside of that range are shown as points. The asterisk marks significant differences between groups according to the Mann–Whitney U-test with controlled familywise error. Reaction times are measured in milliseconds, and accuracy is the number of correct responses.

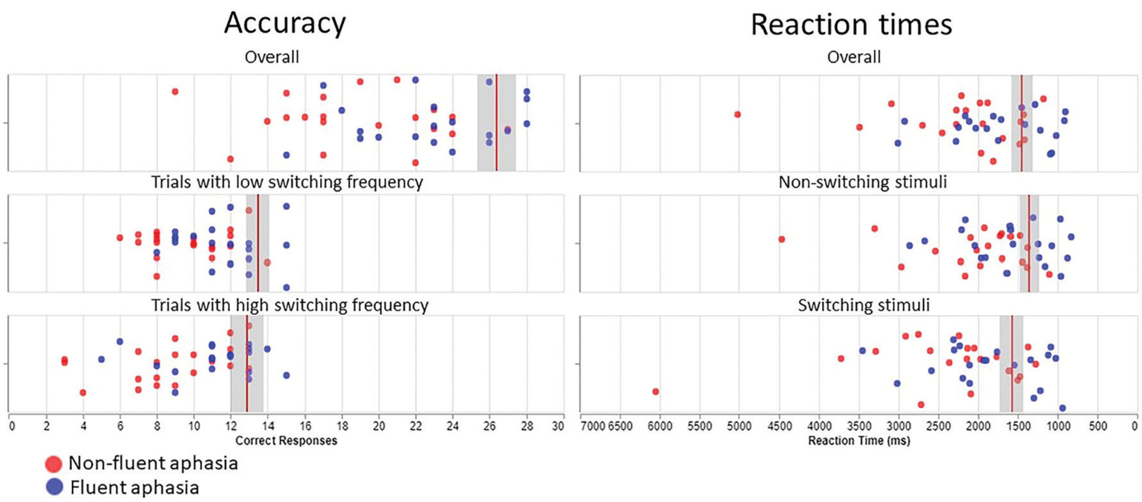

Figure 3.

Confidence Interval analysis for accuracy and reaction times. The gray bar represents a 95% Confidence Interval around the mean of the control group, with the red central line marking the mean. The red dots represent participants with non-fluent aphasia and blue dots represent participants with fluent aphasia. Accordingly, dots to the left of the confidence interval (gray bar) represent performance below the mean of the control group (less accurate and slower). Note, that the x-axis is reversed for the reaction times.

Table 1.

Demographic data of participants.

Groups	Number of participants	Age (years) *M*± *SD* (min-max)	Stroke time post-onset (months) *M*± *SD* (min-max)	Aphasia severity *M*± *SD* (min-max) according to ASA
Controls	20	51.25 ± 7.83 (38–68)	-	-
PWA	40	53.45 ± 8.12 (34–68)	22.43 ± 26.04 (2–120)	213.33 ± 41.91 (113–271)
Non-fluent	20	53.30 ± 7.89 (38–67)	20.40 ± 26.02 (2–120)	226.32 ± 34.32 (139–271)
Fluent	20	53.60 ± 8.54 (34–68)	24.45 ± 26.56 (2–95)	200.35 ± 45.52 (113–265.5)

Notes: ASA – the Assessment of Speech in Aphasia; PWA – participants with aphasia.