

Non-verbal cognitive abilities as a predictive factor for oral language recovery (comprehension and production) in Broca's aphasia

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Abstract:

Objectives: This study aimed to investigate the nonverbal cognitive abilities that predict oral language recovery and its functions (comprehension and production). **Method:** Cognitive flexibility, planning, visuospatial memory, and oral language production and comprehension were assessed in 30 patients with Broca's aphasia, aged 33 to 70 years, according to neurological diagnostic criteria and similarity in cultural, educational, and socioeconomic background. Trail Making Test, Rey–Osterrieth complex figure Test, and The Montreal-Toulouse Algerian battery are administered to assess participants' performance. **Results:** The multiple regression model showed that cognitive flexibility, planning, and visuospatial memory strongly predicted language recovery. Specifically, cognitive flexibility predicted both production and comprehension in oral language recovery, compared to planning and visuospatial memory. **Implications:** The results show that language recovery in Broca's aphasia depends not only on linguistic indicators but also extends to cognitive functions, particularly cognitive flexibility. These findings underscore the importance of combining linguistic and cognitive training in rehabilitation programs, as retained skills can help compensate for deficits, highlighting the need for therapeutic strategies that consider nonverbal cognitive factors. The study recommends future research with larger samples and longitudinal designs to investigate the changing relationship between executive functions and language development after stroke.

Keywords: Broca's aphasia; Language recovery; Non-verbal cognitive abilities; Oral language comprehension; Oral language production.

1- Introduction

Individuals who have experienced a stroke often face a range of motor and cognitive challenges. Common symptoms among stroke survivors include impairments in cognitive functions, language abilities, and motor skills. Aphasia is a lasting consequence of brain injury, characterized by difficulties in both understanding and producing spoken and written language. Broca's aphasia, a non-fluent aphasic syndrome, is characterized by effortful speech production, reduced verbal fluency, and impairments in morphological and syntactic processing. It is frequently associated with deficits in executive functions, including planning, cognitive control, and cognitive flexibility, reflecting damage to frontal language-control networks. From this perspective, Broca's aphasia cannot be regarded solely as a disorder of speech output; rather, it involves a disruption in the interaction between language-specific mechanisms and domain-general cognitive control processes, resulting in disfluent, effortful speech and variable comprehension performance, particularly under conditions of increased cognitive demand. Broca's aphasia is explained within the cognitive-linguistic interaction model as a disorder arising from a disruption in the integration of linguistic processes and cognitive mechanisms, rather than as a purely linguistic deficit. The interactionist model posits that language production and comprehension depend on dynamic interactions among lexical access, syntactic processing, and cognitive control. This view is illustrated by the two-way interactionist model of lexical access, in which disruption of verbal and non-verbal pathways leads to the characteristic speech errors observed in Broca's aphasia (Schwartz & Dell, 2016). Linguistic symptoms such as agrammatic speech and word omissions reflect impairments in the organization of grammatical structures resulting from limited cognitive resources that support language production. Difficulties in processing complex grammatical structures have been linked to reduced cognitive flexibility and diminished capacity for cognitive shifting, thereby constraining adaptation to increased language-processing demands (Cornell et al., 1993). In parallel, models of neuroplasticity and recovery mechanisms support this interactive perspective, demonstrating that language recovery depends on the functional state of neural networks through processes such as synaptic plasticity, redistribution of domain-general cognitive resources, and the integration of neurocompensatory mechanisms with intensive therapeutic intervention (Haase & Lacerda, 2004; Berger et al., 2019). Accordingly, variability in recovery trajectories among individuals with Broca's aphasia can be understood in terms of differences in the efficiency of cognitive mechanisms, which justifies examining the role of non-verbal executive functions as key predictors of language recovery. In cases of aphasia, language difficulties are often accompanied by deficits in cognitive abilities, executive functions, information processing, and motor skills. Aphasia is caused by physical and functional damage to the brain, which can prevent language recovery and rehabilitation. Importantly, the relationship between cognitive abilities and language is interactive: cognitive functions provide critical support for language processing, while language itself represents a complex cognitive system involving attention, visual and phonological processing, as well as cognitive flexibility and planning for problem solving. This interactive perspective provides a basis for understanding Broca's aphasia through the cognitive-linguistic interaction model, which emphasizes the dynamic interaction between linguistic processes and domain-general cognitive mechanisms in the design of both speech production and comprehension.

While theoretical models emphasize the interaction between language and cognitive processes, experimental evidence investigating the prediction of nonverbal cognitive abilities for language recovery has shown inconsistent results. Although there is increasing interest in the relationship between perception and language recovery in cases of aphasia, empirical studies in this area remain theoretically inconsistent and methodologically inconclusive. While interactionist theories assume that language recovery depends on the integrity of cognitive mechanisms, experimental results have not agreed on a clear or consistent prediction. For example, Wall et al. (2017) explicitly question the clarity of the relationship between language impairment and cognitive performance in aphasia, focusing on the lack of agreement about whether cognitive impairments constitute causal limitations on recovery or merely accompanying consequences of brain damage. Several studies have reported associations between nonverbal cognitive abilities and language outcomes; however, their findings vary substantially with respect to the cognitive domains examined, the outcome measures employed, and the aphasia profiles included. Sęniow et al. (2009) associated improvements in visual memory and abstract reasoning with gains in language comprehension and production following short-term rehabilitation, suggesting a facilitative role for nonverbal cognition. Similarly, Nicholas et al. (2017) found that cognitive flexibility and visual memory were stronger predictors of quality of life than language impairment severity. Nevertheless, quality of life constitutes a broad functional outcome and does not directly elucidate the mechanisms underlying language recovery. Other studies have emphasized executive functions more generally (Gilmore et al., 2019; Simic et al., 2019), yet they often conceptualize executive control as a unitary construct rather than examining the distinct contribution of its specific components. It is important to note that existing studies exhibit notable methodological limitations that constrain theoretical interpretation. For example, Fonseca, Raposo, and Martins (2018) examined a broad range of nonverbal cognitive domains but identified matrix reasoning as the sole predictor of language recovery, raising concerns regarding construct specificity and task sensitivity. Similarly, Wall et al. (2017) demonstrated that visuospatial and attentional tasks predicted naming and auditory comprehension; however, their findings did not clarify whether these effects were driven by executive control, working memory, or more general processing efficiency. Across studies, key constructs such as cognitive flexibility, planning, and visuospatial working memory are inconsistently defined, frequently combined into composite measures, or examined indirectly, thereby limiting conclusions about their unique contribution to language recovery. Furthermore, most existing studies either examine heterogeneous aphasia profiles or focus on global language outcomes, with limited attention to differential effects on language comprehension and production, particularly in Broca's aphasia, where executive control demands are especially pronounced. This limitation is compounded by the scarcity of predictive studies conducted in non-Western and under-researched linguistic contexts, including Algeria. In such contexts, linguistic structure, rehabilitation practices, and sociocultural factors may shape language recovery trajectories in distinct ways. Collectively, previous studies underscore the relevance of nonverbal cognitive abilities in language recovery in aphasia; however, they fall short of offering a coherent account of how specific cognitive domains differentially relate to language comprehension and production, or of the conditions under which these abilities reliably predict recovery.

The present study addresses these limitations by adopting a theoretically grounded approach that examines the unique predictive contribution of cognitive flexibility,

planning, and visuospatial working memory to oral comprehension and verbal production in individuals with Broca's aphasia within an Algerian clinical context. In doing so, it seeks to refine interactive models of language recovery and to provide empirically grounded guidance for cognitively informed, evidence-based rehabilitation practices.

The importance of this study lies in its focus on aphasia—specifically Broca's aphasia—by examining the predictive role of non-verbal cognitive abilities in language recovery. It highlights the contribution of executive functions such as cognitive flexibility, planning, and visuospatial memory to the effectiveness of rehabilitation. The findings support the development of integrated language rehabilitation programs that combine both cognitive and linguistic components. Furthermore, this study addresses a research gap in the Algerian context by providing empirical data on the predictive contribution of nonverbal cognitive abilities to language recovery in individuals with Broca's aphasia. To investigate the predictive role of non-verbal cognitive tasks in the outcomes of rehabilitation and treatment in people with Broca's aphasia. This study investigated how nonverbal cognitive abilities—specifically visual memory, cognitive flexibility, and planning—contribute to the recovery of oral comprehension and production in individuals with Broca's aphasia. The study aimed to examine nonverbal cognitive factors that predict language recovery in individuals with Broca's aphasia. It also sought to explore the role of executive functions—such as cognitive flexibility, planning, and visuospatial memory—in language retrieval during both comprehension and production.

Research questions:

To what extent do non-verbal cognitive abilities (cognitive flexibility, planning, and visuospatial working memory) predict overall oral language recovery in individuals with Broca's aphasia?

To what extent do non-verbal cognitive abilities (cognitive flexibility, planning, and visuospatial working memory) predict oral language comprehension recovery in individuals with Broca's aphasia?

To what extent do non-verbal cognitive abilities (cognitive flexibility, planning, and visuospatial working memory) predict oral language production recovery in individuals with Broca's aphasia?

Research hypotheses:

Among the non-verbal cognitive abilities examined, cognitive flexibility will emerge as the strongest statistical predictor of overall oral language recovery in individuals with Broca's aphasia, compared with planning ability and visuospatial working memory.

Among the non-verbal cognitive abilities examined, cognitive flexibility will emerge as the strongest statistical predictor of oral language comprehension recovery in individuals with Broca's aphasia, compared with planning ability and visuospatial working memory.

Among the non-verbal cognitive abilities examined, cognitive flexibility will emerge as the strongest statistical predictor of oral language production recovery in individuals with Broca's aphasia, compared with planning ability and visuospatial working memory.

2- Method and Tools:

Study Design:

This study employed a quantitative correlational predictive design to investigate the extent to which nonverbal cognitive abilities (cognitive flexibility, planning, and

visuospatial working memory) predict language recovery outcomes in individuals with Broca's aphasia. Language recovery was operationally defined in terms of oral comprehension and oral production performance on the Montreal-Toulouse Algerian battery.

Patients:

Thirty participants were recruited from functional and motor rehabilitation centers in Algeria. Participants with Broca's aphasia between the ages of 33 and 70 years participate in multi-disciplinary rehabilitation programs such as motor, functional, linguistic, and cognitive using purposive sampling.

Selection criteria:

Participants were selected based on a confirmed diagnosis of Broca's aphasia established through medical and neurological evaluation, including speech-language assessment, and evidence of left-hemisphere brain damage demonstrated by CT or MRI scans. Eligible participants were native speakers of Algerian Arabic, aged between 33 and 70 years, with a stable neurological condition at the time of assessment and active participation in a multidisciplinary rehabilitation program that included speech-language and physical therapy. To minimize the influence of confounding variables, participants were selected to ensure comparable educational levels, linguistic and cultural backgrounds, and socioeconomic status. Participants were excluded if they presented with severe global cognitive impairment or neurodegenerative disorders (e.g., dementia), uncorrected visual or auditory impairments that could interfere with test performance, or a documented history of psychiatric illness or other neurological conditions unrelated to stroke.

The severity of Broca's aphasia and its post-stroke characteristics:

Broca's aphasia was diagnosed and its severity assessed using the Montreal-Toulouse Algerian Scale, a standardized, culturally adapted psycholinguistic assessment tool for the Arabic-speaking population in Algeria. Overall aphasia severity was calculated using documented performance scores from therapists across various linguistic and cognitive assessments. All participants were assessed during the chronic phase of stroke recovery (more than six months post-stroke), a period when spontaneous neurological recovery is relatively stable. This timing was chosen to ensure that observed language outcomes primarily reflected rehabilitation and cognitive factors rather than spontaneous recovery processes.

Assessments

Non-Verbal Cognitive Measures:

Cognitive flexibility :Trail Making Test (Parts A and B):

The test was originally developed as part of the Army Individual Test Battery in the 1940s, and was later used by Reitan in 1958 in the Reitan Neuropsychological Battery to assess prefrontal cortex and executive functions. It has since become a popular tool in neurocognitive assessment. A two-part test that includes visual stimuli in which the examiner traces the paths of stimuli to a threatening target to assess cognitive flexibility. The Trail Making Test is a widely used neuropsychological assessment tool designed to measure processing speed, cognitive flexibility, visual attention, and task-switching ability. It consists of two parts:

Part A: Requires the participant to draw lines sequentially connecting numbers from 1 to 25 as quickly and accurately as possible (1 → 2 → 3... etc.). This part primarily assesses visual scanning and motor speed.

Part B: Involves alternating between numbers and letters in ascending order ($1 \rightarrow A \rightarrow 2 \rightarrow B \rightarrow 3 \rightarrow C \dots$ etc.). This part assesses cognitive flexibility, working memory, and set-shifting—core components of executive functioning.

Visuospatial working memory and planning: Rey–Osterrieth complex figure Test (ROCF)

The Rey–Osterrieth Complex Figure Test is a widely used neuropsychological assessment developed to evaluate visuospatial constructional ability, visual memory, and planning. It was originally designed by André Rey (1941) and later standardized and refined by Paul-Alexandre Osterrieth (1944). Complex geometric figure. The subject copies and recalls the figure through visual processing to assess planning and visuospatial memory. The test consists of a complex geometric figure that participants are asked to copy and later reproduce from memory after a delay. The procedure typically includes:

Copy phase: The participant is shown the figure and asked to reproduce it as accurately as possible.

Immediate recall phase: Shortly after, the participant is asked to redraw the figure from memory.

Oral language recovery Assessment

Language comprehension and production: The Montreal-Toulouse Algerian battery

The Montreal–Toulouse Algerian Battery is a standardized neuro-linguistic assessment tool adapted specifically for Arabic-speaking populations, particularly in Algeria. It is based on the original Montreal–Toulouse Battery developed in French, and it has been culturally and linguistically adapted to reflect the dialectal and phonological characteristics of Algerian Arabic. The language test for diagnosing aphasia includes language comprehension, production, and language functions from the phonetic to the pragmatic levels.

Domains Assessed: Oral language comprehension; Oral language production; Phonetic, lexical, morphosyntactic, and pragmatic functions; Reading and writing.

Note: Reliable tasks with significant psychometric properties were administered in the Algerian environment.

Research procedures:

The research process began with visits to rehabilitation centers and consultations with patients' families and speech-language pathologists. After obtaining informed consent, participants were selected based on predefined inclusion and exclusion criteria.

Participants then completed the study tasks individually to assess their cognitive abilities. The planning task (ROCF copy) was administered first, followed by the visuospatial working memory task (ROCF recall), the cognitive flexibility task (TMT Parts A and B), and finally the language assessments.

All tasks were conducted under controlled conditions in the speech-language pathologist's office to ensure minimal distractions. Prior to testing, participants received standardized instructions from the speech-language pathologist regarding task performance. The sessions were structured to allow sufficient time for each task, with breaks provided as needed to maintain attention and engagement. All sessions were conducted in the morning, and each task required less than 10 minutes to complete.

All participants enrolled in multidisciplinary rehabilitation programs, including speech therapy, motor rehabilitation, and physical therapy, in a structured manner and incorporating daily activities that included cognitive stimulation without a specific cognitive training protocol. At the time of assessment, participants were receiving

ongoing rehabilitation rather than intensive intervention. The rehabilitation context was considered to ensure that language recovery outcomes reflected individual cognitive characteristics and spontaneous recovery within a realistic clinical setting, rather than the effects of a specific treatment protocol.

Ethical Considerations:

Ethical approval was obtained from the university's Institutional Review Board and the Physical and Functional Rehabilitation Center. Written informed consent was obtained from the rehabilitation center management and all participants or their legal guardians prior to data collection.

Statistical analyses:

Data Analysis:

Data were analyzed using SPSS. Simple Regression Analysis:

To examine the relationship between each nonverbal cognitive ability individually and language recovery (in comprehension or production).

To demonstrate the individual effect of each independent variable on the dependent variable.

Multiple Regression Analysis:

To examine the combined predictive effect of nonverbal cognitive abilities (cognitive flexibility, planning, and visuospatial memory) on language recovery variables:

Overall language recovery

Verbal comprehension recovery

Verbal production recovery

Beta coefficients, t-values, and p-values were calculated to determine statistical significance.

The coefficient of determination (R^2) was used to determine the proportion of variance explained in the dependent variables.

3- Results and Discussion

3.1 Results

Cognitive flexibility, planning, and visual spatial memory predict language recovery

After analysing the data with multiple regression analysis, the analysis showed that cognitive flexibility, planning, and visual spatial memory predict language recovery. The Value P is equal to 0.000, which is less than the significant level of 0.01, and a relationship between variables of non-verbal cognitive abilities and language recovery. The non-verbal cognitive ability variables combined explain 96.6% of the variance in language recovery. However, considering the relationship of visual spatial memory to linguistic recovery, the beta value does not exceed 0.23, which is not statistically significant, and we find that the P.Value is equal to 0.13, which is greater than the significance level (0.05). This indicates that visual space memory does not predict language recovery. Regarding planning skill, the beta value of 0.06 is not statistically significant through the t value (-0.23) and the P.Value of 0.718, which is greater than the significance level of 0.05. This explains why the planning coefficient in the regression model is not significant and does not prove that it can predict language recovery. As for cognitive flexibility, the beta coefficient is (-0.87), which is statistically significant through the t-value (16.80). This means that the better the cognitive flexibility, the better the language and value recovery. We find that the P.Value is equal to (0.000), which is less than the significant level. (0,01) This proves that cognitive flexibility predicts language recovery.

Table 1: Regression model for predicting nonverbal cognitive abilities for language recovery

		Regression coefficient R	Coefficient R	F value	Significance f	Beta	T value	Significance T	Contrast inflation factor
language recover	visual spatial memory	0,967	0.966	126,818	0,000	,23	1,463	,135	8,090
	Planning					-,06	-,231	,718	8,641
	Cognitive flexibility					-,87	16,80	,000	1,281

Table 1 presents the results of the multiple regression analysis predicting overall oral language recovery from non-verbal cognitive abilities (cognitive flexibility, planning, and visuospatial working memory). As shown, cognitive flexibility emerged as the strongest and only significant predictor of overall recovery, explaining a substantial proportion of the variance in post-stroke language outcomes. In contrast, planning and visuospatial working memory did not reach statistical significance.

Cognitive flexibility, planning, and visual spatial memory predict oral language production recovery

After analysing the data of the non-verbal cognitive abilities tasks and the language production sub-task with multiple regression analysis, the P.Value is equal to zero (0.000), which is less than the 0.01 level of significance. The regression is statistically significant, and this explains the existence of a relationship between the non-verbal cognitive abilities and the language production sub-task. The results showed the significance of the regression model through the value of F (69.234) in terms of (0.000), which is smaller than the level of significance (0.01). From the results obtained, non-verbal cognitive abilities explain 88.9% of the variance occurring in oral language production, given the R coefficient. Regarding visual-spatial memory and language recovery, the beta value, which shows the relationship between oral language production and visual-spatial memory, was (0.34) statistically significant from the t value (2.332). The P.Value is equal to (0.28), which is smaller than the significance level (0.05), and this indicates that visual-spatial memory predicts oral language production recovery. In planning skill, the beta value for the variable is (-0.27), which is not statistically significant, through the T-value (-1.452) and the P.Value (0.159), which is greater than the significance level (0.05). This explains that the coefficient of the planning variable in the regression model is not significant; planning skill cannot predict oral language production recovery. In cognitive flexibility, the beta value is (0.87), which is statistically significant through the t-value (-11,869). This means that as cognitive flexibility improves, the level of oral language production improves. The P.Value is (0.000), less than the significant level (0.01). This proves the significance of the regression model at a significance level of less than (0.01), this explains that cognitive flexibility can predict oral language production recovery.

Table 2: Regression model for predicting nonverbal cognitive abilities for oral language production recovery

		Regression coefficient R	Coefficient R	F value	significance f	Beta	T value	significance T	Contrast inflation factor
language production recovery	visual spatial memory	,943	,889	69,234	,000	,434	2,332	,028	8,090
	planning					-,279	-1,452	,159	8,641
	Cognitive					-,879	-11,869	,000	1,281

flexibility

Table 2 presents the regression outcomes for oral language comprehension recovery. Cognitive flexibility was the only variable that showed a statistically significant predictive association with comprehension performance, whereas planning and visuospatial working memory contributed minimally to the model.

Cognitive flexibility, planning, and visual spatial memory predict oral language comprehension recovery

After analyzing the data of the non-verbal cognitive abilities tasks and the sub-task of understanding oral language with a multiple regression analysis, the P.Value is equal to (0.000), which is less than the significance level of 0.01. This indicates that the regression is significant and non-verbal cognitive abilities can predict oral language comprehension recovery. It explains the relationship between visual-spatial memory, planning, cognitive flexibility, and oral language comprehension recovery. The results showed the significance of the regression model through the value of F (72.615) in terms of (0.000), that is, smaller than the level of significance (0.01). Visual-spatial memory, planning, and cognitive flexibility explain 89.3% of the variance in oral language comprehension recovery given the R coefficient. Regarding visual spatial memory and oral language comprehension recovery, the beta value (0.19), which shows the relationship between them, is not statistically significant, and the P.Value is equal to (0.91), which is greater than the significance level (0.05). Visual-spatial memory in the regression model is not statistically significant, and visual-spatial memory cannot predict oral language comprehension recovery. In addition, the beta value for planning skill is (0.14), which is not statistically significant through the T value (0.79) and the P.Value (0.437), which is greater than the significance level (0.05). Planning skill in the regression model is not significant and cannot predict oral language comprehension recovery. Regarding cognitive flexibility, the beta value is (0.85), which is statistically significant through the t value (-11.830). This means that the better the cognitive flexibility, the better the oral language comprehension recovery. P.Value (0.000) which is less than the significance level (0.01). This explains that cognitive flexibility is statistically significant in the regression model, and cognitive flexibility can predict oral language comprehension recovery.

Table 3: Regression model for predicting nonverbal cognitive abilities for oral language comprehension recovery

		Regression coefficient R	Coefficient R	F value	significance f	Beta	T value	significance T	Contrast inflation factor
language comprehe nsion recover	Visual spatial memory	,945	,893	72,615	,000	,019	,107	,916	8,090
	planning					,149	,790	,437	8,641
	Cognitive flexibility					,857	-11,830	,000	1,281

Table 3 presents the regression analysis predicting oral language production recovery. Both cognitive flexibility and visuospatial working memory were significantly associated with production outcomes, whereas planning remained non-significant.

Discussion:

The present study examined the factors predicting oral language recovery both comprehension and production in individuals with non-fluent aphasia. Specifically, it investigated whether non-verbal cognitive abilities contribute to language recovery outcomes in Broca's aphasia. Using multiple regression analyses, the results demonstrated that non-verbal cognitive abilities significantly predicted overall oral

language recovery, as well as comprehension and production when examined separately. At the level of individual predictors, cognitive flexibility emerged as the only significant predictor of overall language recovery and oral language comprehension. In contrast, planning ability and visuospatial memory did not reach statistical significance in these models. For oral language production, however, both cognitive flexibility and visuospatial memory were significant predictors, whereas planning ability again showed no significant contribution. These findings indicate that non-verbal cognitive abilities do not contribute uniformly to different language domains, and that distinct cognitive mechanisms may support comprehension and production during recovery.

Differential Predictors of Oral Language Comprehension and Production Recovery:

The results highlight the prominent association between cognitive flexibility and language recovery, while also underscoring the heterogeneity of cognitive functioning in aphasia. Importantly, the findings indicate that aphasia is not necessarily accompanied by a generalized cognitive deficit. Rather, certain non-verbal cognitive abilities, particularly cognitive flexibility, may remain relatively preserved and appear to be associated with more favorable recovery profiles. From a clinical standpoint, these results question approaches that restrict rehabilitation to language-focused training alone, such as naming or comprehension exercises in isolation. Instead, they suggest that incorporating non-verbal cognitive abilities that support language processing may be beneficial. When linguistic processes are compromised, preserved cognitive resources, especially cognitive flexibility, may support the use of compensatory strategies, including repetition, imitation, and contextual cueing. Moreover, individuals with relatively higher cognitive proficiency tend to demonstrate greater responsiveness to rehabilitation and a stronger capacity to generalize learned skills to everyday communicative situations. The consistent association of cognitive flexibility with both comprehension and production outcomes emphasizes its functional relevance in Broca's aphasia and points to the need for further investigation of the cognitive and neural mechanisms that may underlie this relationship.

Neurocognitive and Neuroplasticity-Based Interpretation of the Findings:

From a neurocognitive perspective, cognitive flexibility has been consistently associated with activity in prefrontal regions, particularly the dorsolateral prefrontal cortex, which supports cognitive control, response selection, and the ability to shift strategies according to contextual demands. Neuroimaging evidence has demonstrated functional connectivity between Broca's area and prefrontal executive regions within the left frontal network, suggesting an interaction between language-specific systems and domain-general control mechanisms. Within this framework, cognitive flexibility may support compensatory processes when core language structures are compromised by enabling the engagement of alternative neural pathways. In line with neuroplasticity models, recovery following stroke is understood as a dynamic process involving functional reorganization rather than the simple restoration of damaged language modules. Undamaged or partially preserved brain regions may contribute to language performance through adaptive reallocation of processing resources. The present findings are compatible with this view, insofar as executive functions, particularly cognitive flexibility, appear to be associated with more favorable language outcomes. Importantly, this association should be interpreted as reflecting a supportive role of executive control in recovery, rather than a direct causal mechanism. The limited resource framework provides an additional interpretive lens, suggesting that language

processing draws on shared cognitive resources such as attention and control. From this perspective, reduced language performance may reflect inefficiencies in cognitive regulation rather than a complete loss of linguistic knowledge. Cognitive flexibility, by enabling strategy shifting and adaptive regulation, may help individuals manage increased processing demands during language tasks. At the cognitive level, cognitive flexibility may allow individuals with aphasia to adjust communicative strategies, activate alternative lexical retrieval routes, and make use of contextual or feedback-based cues. Such processes are particularly relevant in tasks involving picture naming or sentence comprehension, where patients must navigate linguistic difficulty under constrained processing conditions. Consistent with executive control models of language, higher-order processes such as inhibition, updating, and task switching are core components of non-verbal executive functioning that support effective language use across communicative contexts. Taken together, these considerations suggest that the association between executive functions and language recovery reflects complex and interconnected neurocognitive processes. The findings support the view that aphasia does not necessarily entail a global impairment of cognitive abilities, but rather a heterogeneous cognitive profile in which certain executive functions may remain relatively preserved. This underscores the importance of comprehensive cognitive assessment and suggests that rehabilitation approaches may benefit from capitalizing on preserved executive resources to support language recovery, while acknowledging the need for further experimental and longitudinal research to clarify underlying mechanisms.

Comparison with Previous Empirical Studies:

The present findings indicate that cognitive flexibility emerged as the most consistent predictor of oral language recovery, particularly for comprehension, whereas visuospatial memory showed a more specific association with oral language production. Planning, in contrast, did not demonstrate a significant predictive contribution in the regression models. This differentiated pattern aligns partially with earlier work while also highlighting important points of divergence. For instance, Sęniow et al. (2009) reported that visuospatial working memory predicted overall improvement in language function following rehabilitation. However, when comprehension and production were examined separately, the predictive patterns observed in the present study were not fully replicated, suggesting that the contribution of non-verbal cognitive abilities may vary depending on the specific language domain assessed. Similarly, Fonseca, Raposo, and Martins (2018) examined a broad range of non-verbal cognitive functions and identified matrix reasoning as the primary predictor of language recovery in aphasia. While their findings underscore the relevance of executive functioning, the present results refine this conclusion by suggesting that not all executive components contribute equally to this effect. In particular, cognitive flexibility appears to be more closely associated with language outcomes than planning, supporting the view that executive functions should not be treated as a unitary construct in aphasia research. The prominent role of cognitive flexibility observed in this study is also consistent with the systematic review by Simic et al. (2019), which reported a reliable association between executive control and language recovery outcomes. In a similar vein, Wall et al. (2017) demonstrated that performance on non-verbal cognitive tasks was related to naming and auditory comprehension in individuals with aphasia; however, their study did not clarify which specific cognitive mechanisms underpinned these associations. The present findings contribute to this literature by suggesting that cognitive flexibility may be a particularly relevant

executive component underlying these effects. Moreover, Gilmore et al. (2019) demonstrated that visuospatial memory and executive functions, including cognitive flexibility and planning, predicted the maintenance of learning and the acquisition of new skills following naming therapy. The current results converge with these findings by confirming the involvement of non-verbal cognitive abilities in language recovery, while also indicating that cognitive flexibility shows a more robust and consistent association across language domains. Taken together, these findings support the view that non-verbal cognitive abilities are meaningfully associated with language recovery in aphasia, with cognitive flexibility emerging as a central predictive factor. Importantly, this association should be interpreted in relational rather than causal terms, reflecting the interaction between executive control processes, neural reorganization, and language performance within the context of post-stroke recovery and rehabilitation.

Despite the importance of the current study's findings, methodological limitations must be considered. The small sample size may limit the statistical significance and generalizability of the results. The rehabilitation context may have influenced language recovery among participants, introducing variability that could not be fully controlled. Although standardized, reliable, and approved tools were used in the Algerian context, the complexity of cognitive functions and their psychological and mental nature make them difficult to control and isolate without interference. The study did not control for demographic variables that could have influenced the statistical prediction model and the language recovery trajectories of the study participants.

3. Conclusion:

The study's results indicate the role of executive functions and cognitive processing capacity in recovering language function abilities. The results of this study confirm the crucial role of cognitive functions—particularly cognitive flexibility—in supporting oral language recovery in individuals with Broca's aphasia. These findings underscore the importance of rehabilitation programs that integrate nonverbal cognitive skills alongside language training, potentially enhancing treatment outcomes and patients' quality of life. While the study helps fill a knowledge gap within the Algerian context, it is limited by its small sample size and cross-sectional design, as well as the absence of functional neuroimaging. Future research should adopt longitudinal designs, include comparison groups, and utilize neuroanalytical tools to better understand the dynamic interaction between cognitive and linguistic networks during language recovery. Incorporating nonverbal cognitive assessments into language diagnosis and therapy could signal a paradigm shift in aphasia treatment, encouraging stronger collaboration among neurologists, neuropsychologists, and speech-language pathologists. However, the study needs further investigation due to the limitations of the study, such as the sample size and the use of computerized task tools to measure executive function, taking into account the treatment factor and the stage of injury.

Limitations:

Small sample size: The study included only 30 participants, which limits the generalizability of the results. Larger samples are needed to validate the results and ensure greater statistical accuracy.

Cross-sectional design: The study adopted a cross-sectional approach, which prevented conclusions about causality or changes in language recovery and cognitive performance over time, and calls for a longitudinal study.

Lack of a control group: The lack of a comparison group (e.g., stroke patients without aphasia, fluent aphasia, or normal aphasia) limits the ability to assign a specific predictive value to Broca's aphasia.

Reliance on behavioral measures only: The study relied solely on behavioral tasks. Including neuroimaging or electrophysiological data (such as functional magnetic resonance imaging or activity-related electroencephalography) could provide more precise insights into the neural mechanisms underlying language recovery.

Recommendations:

Based on the results of this study and the identified methodological limitations, we recommend future research that takes the following considerations into account:

Design longitudinal studies: To understand temporal changes in the relationship between executive functions and language retrieval, particularly cognitive flexibility, while tracking the development of language and cognitive performance over different stages of recovery.

Incorporate functional neuroimaging techniques (such as fMRI or EEG): To investigate neural activity associated with language retrieval and the activation of areas responsible for executive functions, providing objective evidence about the underlying neural mechanisms.

Expand sample sizes and compare across different types of aphasia: For example, compare Broca's aphasia with lobar or global aphasia, to determine whether the relationship between cognitive abilities and language retrieval differs depending on the clinical pattern.

Develop dual (linguistic-cognitive) therapeutic interventions: Design treatment protocols that integrate cognitive flexibility, planning, and attention training with language rehabilitation, and measure their empirical impact on language recovery.

Studying individual differences in executive and language performance: To identify personal factors (such as age, duration of injury, educational background) that may influence the effectiveness of language recovery associated with cognitive functions.

Focusing on local cultural and linguistic contexts: By conducting similar studies in different Arab environments, we are enhancing our understanding of the relationship between language and cognition within diverse linguistic and cultural contexts.

Conflict of interest:

The authors declare that they have no conflict of interest.

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