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The cognitive mechanisms underlying language tests in healthy adults: A principal component analysis.

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Résumé

Pour un processus d’évaluation linguistique plus précis et rapide, il est important d’identifier les mécanismes cognitifs qui soutiennent des tâches langagières couramment utilisées. Une façon de mieux comprendre ses mécanismes est d’explorer la variance partagée entre les tâches linguistiques en utilisant l’analyse factorielle exploratoire. Peu d’études ont employé cette méthode pour étudier ces mécanismes dans le fonctionnement normal du langage. Par conséquent, notre objectif principal est d’explorer comment un ensemble de tâches linguistiques se regroupent afin d’étudier les mécanismes cognitifs sous-jacents de ses tâches. Nous avons évalué 201 participants en bonne santé âgés entre 18 et 75 ans (moyenne=45,29, écart-type= 15,06) et avec une scolarité entre 5 et 23 ans (moyenne=11,10, écart-type=4,68), parmi ceux-ci, 62,87% étaient des femmes. Nous avons employé deux batteries linguistiques : le Protocole d’examen linguistique de l’aphasie Montréal-Toulouse et Protocole Montréal d’Évaluation de la Communication – version abrégé. Utilisant l’analyse en composantes principales avec une rotation Direct-oblimin, nous avons découvert quatre composantes du langage : la sémantique picturale (tâches de compréhension orale, dénomination orale et dénomination écrite), l'exécutif linguistique (tâches d’évocation lexicale - critères sémantique, orthographique et libre), le transcodage et la sémantique (tâches de lecture, dictée et de jugement sémantique) et la pragmatique (tâches d'interprétation d'actes de parole indirecte et d'interprétation de métaphores). Ces quatre composantes expliquent 59,64 % de la variance totale. Deuxièmement, nous avons vérifié l'association entre ces composantes et deux mesures des fonctions exécutives dans un sous-ensemble de 33 participants. La performance de la flexibilité cognitive a été évaluée en soustrayant le -temps A au temps B du Trail Making Test et celle de la mémoire de travail en prenant le total des réponses correctes au test du n-back. La composante exécutive linguistique était associée à une meilleure flexibilité cognitive (r=-0,355) et la composante transcodage et sémantique à une meilleure performance de mémoire de travail (r=.0,397). Nos résultats confirment l’hétérogénéité des processus sous-jacent aux tâches langagières et leur relation intrinsèque avec d'autres composantes cognitives, tels que les fonctions exécutives.

Mots-clés: tâches linguistiques; processus linguistiques; fonctions exécutives; sémantique; pragmatique; transcodage; analyse en composantes principales.

Abstract

To a more accurate and time-efficient language assessment process, it is important to identify the cognitive mechanisms that sustain commonly used language tasks. One way to do so is to explore the shared variance across language tasks using the technique of principal components analysis. Few studies applied this technique to investigate these mechanisms in normal language functioning. Therefore, our main goal is to explore how a set of language tasks are going to group to investigate the underlying cognitive mechanisms of commonly used tasks. We assessed 201 healthy participants aged between 18 and 75 years old (mean = 45.29, SD = 15.06) and with a formal education between 5 and 23 years (mean = 11.10, SD =4.68), of these 62.87% were female. We used two language batteries: the *Montreal-Toulouse language assessment battery* and the *Montreal Communication Evaluation Battery – brief version*. Using a Principal Component Analysis with a Direct-oblimin rotation, we discovered four language components: pictorial semantics (auditory comprehension, naming and writing naming tasks), language-executive (unconstrained, semantic, and phonological verbal fluency tasks), transcoding and semantics (reading, dictation, and semantic judgment tasks), and pragmatics (indirect speech acts interpretation and metaphors interpretation tasks). These four components explained 59.64% of the total variance. Secondarily, we sought to verify the association between these components with two executive measures in a subset of 33 participants. Cognitive flexibility was assessed by the time B-time A score of the Trail Making Test and working memory by the total of correct answers on the n-back test. The language-executive component was associated with a better cognitive flexibility score (r=-.355) and the transcoding and semantics one with a better working memory performance (r=.397). Our findings confirm the heterogeneity process underlying language tasks and their intrinsic relationship to other cognitive components, such as executive functions.

Keywords: language tasks; language processes; executive functions; semantics; pragmatics; transcoding; Principal Component Analysis.

Table of contents

List of tables, list of figures, or others

Tables from General Introduction

Tables from the article

List of Appendices

List of acronyms and abbreviations.

EF	Executive Functions
MAC	Montreal Communication Evaluation Battery – brief version
MMSE	Mini-Mental State Examination
MTL-BR	Montreal-Toulouse language assessment battery – Brazilian version
PCA	Principal Component Analysis
PPA	Primary Progressive Aphasia
TMT	Trail Making Test

1. Presentation

This master's thesis is presented to the *Faculté de Arts et Sciences* of the *Université de Montréal*, Psychology Department, in order for the student Ana Paula Gonçalves to obtain the master's degree in Psychology. The present thesis was supervised by Maximiliano A. Wilson, Full Professor of the Rehabilitation Department of *Université Laval*, and co-supervised by Simona M. Brambati, Associate Professor at the Psychology Department of *Université de Montréal*.

The main objective of this master's thesis is to elucidate the linguistic and cognitive mechanisms underlying commonly used language tasks in healthy adults. To achieve this goal, we conducted two studies presented as a single paper, preceded by a general introduction and followed by a general discussion.

To better guide the reading, the general introduction is divided into several sections. In the first section, we present the inherent challenges of language assessment. In the next section, we will briefly discuss the association between language and executive functions (EF). We then discuss the following language components: phonology, syntax, semantics, prosody, and pragmatics.

The article of this thesis is divided into two studies. The first study employed a factorial analyzing using a Principal Component Analysis (PCA) to explore the linguistic components underlying a set of language tasks. The second study is a correlational study that analyzes the relationship between the linguistic components found in Study 1 and two executive functions measures (i.e., cognitive flexibility and working memory). To finalize, we discuss more broadly our findings, the limitations, and the overall contributions of the present work.

As the first author of the article, I, Ana Paula Bresolin Gonçalves, actively participated in all the steps necessaries for analysing the data and writing the article included in this thesis. Under the supervision of my research directors, Maximiliano Wilson and Simona Brambati, I prepared and analysed the data, I conducted a review of the literature, and a I wrote the introduction, methodology, results, and discussion sections. The other coauthor, Rochele Paz Fonseca, provided the data employed in the article, in addition to her insights. All the coauthors of this article gave their written consent for including the article in the present thesis.

2. General Introduction

2.1 Theoretical background

2.1.1 Language assessment challenges

The detection and diagnosis of language impairments are initial key steps for clinical intervention (Turgeon & Macoir, 2008). Language processing can be affected by a wide range of neurological disorders, such as stroke (Flowers et al., 2016), right-brain damage lesions (Gajardo-Vidal et al., 2018), traumatic brain injury (Galetto et al., 2013), and neurodegenerative diseases (Klimova & Kuca, 2016), among others. These impairments can occur on different linguistic components, such as such as phonology (i.e. how phonemes form syllables and words), semantics (i.e. how language conveys meaning), syntax (i.e. sentence structure), pragmatics (i.e. meaning variations according to context) and discourse (i.e. how to form coherent sequences of sentences), and different modalities, such as oral, written, comprehension, and production.

Language is one of the most complex cognitive abilities that relies on multiple brain areas and cognitive process (Lacey et al., 2017). As such, a comprehensive language assessment should include a large number of tasks. A comprehensive speech and language assessment include formal testing, clinical observations, and gathered information provided by the patient and patient's entourage. In addition to language components in different modalities, a complete language should also include the assessment of other non-linguistic cognitive domains that might affect language performance, such as executive, mnemonical and attentional skills (Peach et al., 2017).

Standardized language tasks are commonly used to assess different language impairments (Pagliarin et al., 2014). They provide an objective measure of language abilities. Standardized language batteries seek to identify strengths and weakness in patients' language skills. This information is helpful for planning individualized and effective treatment plans. They are commonly used in clinical settings because they provide the clinician with an array of tasks to evaluate multiple components of language (Pagliarin et al., 2014). Several language batteries are commonly used in clinical and research settings, such as the Boston Diagnostic Aphasia Examination—BDAE (Goodglass et al., 2001), the Multilingual Aphasia Examination—MAE (Benton et al., 1994), Montreal Communication Evaluation Battery—brief version (MAC; Casarin et al., 2014) and the Montreal-Toulouse language assessment battery (MTL-BR; Parente et al., 2016), among many others.

One of the major challenges in language assessment is time constraints. However, useful and comprehensive, lengthy batteries are time-consuming. It is not always possible to conduct a complete language and cognitive assessment because of time and budget restrictions. Moreover, an overly long assessment can be very stressful for some patients. Considering that several tasks in a battery may contribute to the assessment of the same components, the selection of sensitive tools to assess language is of the utmost importance. In addition, the underlying linguistic and non-linguistic cognitive processes sustaining language tasks remain a matter of debate (Archibald, 2013). One way to study these processes is to explore how a large number of tasks are related. More studies exploring the joint variation across commonly used standardized language tasks are still needed (Archibald, 2013), especially in normal language functioning. Understanding these mechanisms can contribute to a more precise and time efficient language assessment. Therefore, the present thesis seeks to verify how a group of commonly used language tasks in order to investigate their underlying cognitive mechanisms.

2.1.2 Exploratory factorial analysis of language components

An exploratory factor analysis would be the best option to achieve our aim of identifying the key language components on a large set of tasks. This family of techniques has the advantage of accommodating the multifactorial aspects of language processing. The exploratory factor analysis technique summarizes the patterns of correlations among a large number of variables and identifies the variables that form coherent subsets and are relatively independent of other subsets (Tabachnick & Fidell, 2013). These subsets are known as components (principal component analysis; PCA) or factors (factor analysis). PCA and factor analysis are two similar extraction methods used in exploratory factorial analysis; however, they present important differences. In factor analysis, factors are a priori considered to be the product of a latent construct. In PCA, the components are formed by the aggregation of the correlated variables. Thus, the variables are solely responsible for the outcome of components. There is no a priori theory that explains the pattern of component formation and, as such, variables are simply empirically, but not a priori theoretically, related (Tabachnick & Fidell, 2013). Both extraction techniques have been employed to explore the structure and interrelationships among common language tasks. While some studies choose to employ PCA (Archibald, 2013; Butler et al., 2014; Crockett, 1974; Fong et al., 2019; Henry et al., 2012; Ingram et al., 2020; Marcie et al., 1993; Mirman et al., 2015), others opted to use a factorial analysis extraction method (Carroll, 1941; Clark et al., 1979; Hanson et al., 1982; Jones & Wepman, 1961; Pineda et al., 2000). For the present master's thesis, we opted for PCA because we do not have any theoretical a priori (i.e., we do not expect any given latent construct for variable groupings). We simply expect that tasks that tap the most similar underlying mechanisms will present high loadings on similar components (Henry et al., 2012).

In the next paragraphs we present the findings of articles that employ these techniques within language tasks. A more profound explanation of different language components, their definitions and their cognitive mechanisms, the associated impairments and their assessment are presented later in the general introduction. Table 1 presents the studies that used PCA or factorial analysis with language tasks. Of note, some studies included tasks assessing non-linguistic cognitive components, such as short-term memory, executive functions, praxis and reasoning. As we can observe, studies also largely vary in their sample size (between 31 and 355 participants).

Table 1.

Studies that applied exploratory factor analysis or principal component analysis to explore language underlying dimensions

Reference	Method employed	Population studied	Factors/components found
Pineda et al., 2000	factor analysis	156 healthy adults (19-60 years old)	(1) **oral reading** (word reading; sentence reading); (2) **writing** (primer-level dictation; serial writing; spelling to dictation), (3) **semantic** (confrontation naming; commands comprehension; word discrimination); (4) **semantic fluency** (animals naming); (5) **lexical graphic attention** (reading word

			recognition); (6) **repetition** (word repetition); (7) **motor** (writing mechanics)
Carrol, 1941	factor analysis	119 college students	(1) **richness of linguistic stock** (word choice; vocabulary; phrase completion; grammar; memory for homophones; rhyming; spelling; theme rating; distorted English tasks and speech attitude scale), (2) **semantic abilities** (verbal analogies; morpheme recognition; disarranged morphemes tasks), (3) **speed of association** (suffixes; form-naming; disarranged words; word-number memory; colour-naming), (4) **discourse production** (theme; grammar, similes; picture description; distorted English; anagrams tasks), (5) **facility to attach appropriate names or symbols to stimuli and speed of articulatory movements** (colour-naming; letter-star test; giving first names; form-naming; phrase completion; naming states of the Union; letter-star test—diversity tasks), and (6) **verbal memory learning** (paired associates English-Turkish; paired associates Turkish-English; and word-number memory tasks)
Hanson et al., 1982	factor analysis	118 post stroke aphasia patients	(1) **speaking** (describes function, object naming, sentence completion, imitative naming subtests) (2) **writing** (writes function in sentences, writes names of objects, writes names when heard, write name, spelling dictated subtests) (3) **spoken and written comprehension** (points to object by function, points to object by name, reads name and positions subtests) (4) **gesturing** (demonstrates function and demonstrates function ordered subtests) (5) **copying** (name copies

			and geometric forms copies subtests)
Clark et al., 1979	factor analysis	63 post brain insult aphasia	(1) **verbal competency** (name of objects; completing sentences by naming objects; providing names of objects; describing the function of an object), (2) **graphic expression** (writing sentences describing the use of objects; writing the name of objects upon visual presentation; writing names of objects to auditory dictation; writing names of objects after having them spelled), (3) **gestural verbal comprehension** (subtests requiring the subject to: point to an object on the basis of a verbal description of its function; to read a name on a card and place it near the object; to point to a named object; to read a functional description; to place it near the object described, (4) **gestural function** (demonstrating the function of each object upon tactile presentation; demonstrating the function of each object upon visual presentation), (5) **graphic-copying** (copying of geometric forms; copy an object's name)
Jones & Wepman, 1961	factor analysis	168 post acquired aphasia patients (multiple causes: cerebrovascular accident, external trauma and tumor extirpation)	(1) **visual-to-oral transmission** (principal task, reading subtests) (2) **aural-to-oral transmission** (principal task, repeating spoken words subtests) (3) **visual-to-graphic transmission** (principal task, copying printed words subtests) (4) **aural-to-graphic transmission** (principal task, writing spoken words subtests) (5) **language-symbol comprehension** (principal task, matching pictures to spoken and written words subtests)

Crocket, 1974	PCA	353 school-aged children	(1) **association of encoded and decoded materials** (oral reading names; oral reading sentences; reading sentences for meaning pointing; reading names for meaning pointing; visual - graphic naming; writing names; writing to dictation tasks), (2) **sentence repetition** (sentence repetition task), (3) **naming** (visual naming tactile naming, right and left tasks), (4) **auditory comprehension** (identification by sentence task), (5) **syntax production and fluency** (sentence construction task and visual - graphic naming tasks), (6) **working memory** (reversal of digits task), and (7) **phonological short-term memory** (repetition of the digits-forward task)
Archibald, 2013	PCA	374 schoold-aged children	(1) **working memory** (dot matrix; block recall; listening recall; couting recall; odd one out; spatial recall; concepts and FE; (2) **language processing** (recalling sentences; formulating sentences; vocabulary; similarities), (3) **phonological short-term memory** (digit recall; nonword recall; listening recall; couting recall; recalling sentences), (4) **fluid reasoning** (block design; mazes reasoning)
Marcie et al., 1993	PCA	104 mildly to moderately Alzheimer’s disease patients	(1) **operativeness factor** (antonyms; oral spelling; mental calculation; metalinguistic control; error detection; sentence generation; auditory comprehension; sentence generation; auditory comprehension; and verbal fluency tasks) (2) **transcoding factor** (reading numbers; reading; writing numbers; phonemic discrimination; writing; and naming tasks)

Hoffman et al., 2017	PCA	43 primary progressive aphasia patients	(1) **speech** (speech rate, mean unit length, phonological errors and hesitation on a semi-structure interview; speech rate, mean unit length, hesitations on a picture description task; phonological fluency), (2) **repetition and syntax** (sentence repetition; nonword repetition; word repetition; phonological verbal fluency; digit span; minimal pairs discrimination; auditory sentence comprehension; written sentence comprehension; syntactic errors, semantic errors, phonological errors on a semi-structure interview; test of reception grammar; anagram test), (3) **semantics** (picture naming; single word comprehension; semantic verbal fluency; address learning; semantic errors hesitation on a semi-structure interview); (4) **episodic** (Rey figure copy and recall; trail making task part A; cube analysis; paired associated learning)
Ramanan et al., 2020	PCA	43 logopenic progressive aphasia patients	(1) **speech production/verbal memory** (ACE-R language total; digit span forward; digit span backward; repetition; naming; ACE-R memory total; (2) **visuospatial and executive** (figure copying; semantic association; comprehension; Trail Making Test time B-time A; delayed recall; attention total)
Henry et al., 2012	PCA	15 primary progressive aphasia patients	(1) **semantics** (Pyramids and Palm Trees; Boston naming test; spoken-word to picture matching; auditory synonym judgement) (2) **phonology** (phoneme deletion; phoneme blending; minimal pair discrimination)

Lacey et al., 2017	PCA	38 post stroke aphasia patients	(1) **word finding/fluency** (naming; written naming; object naming; word finding; semantic verbal fluency; sentence completion; spontaneous speech content); (2) **comprehension** (word recognition; auditory word-to-picture matching); (3) **phonology/working memory** (increasing word length substest; pseudoword repetition; forward digit span); (4) **executive functions** (Cognitive Linguistic Quick Test Executive function composite score; backward digit span)
Tochadse et al., 2019	PCA	53 post stroke aphasia patients	(1) **phonology** (word repetition; nonword repetition; naming test; mean length of utterance; words per minute), (2) **semantics** (naming; spoken word-picture matching; written word-picture matching; word minimal pairs) (3) **auditory working memory** (type/toke ration; forward digit span; spoken sentence comprehension; backward digit span) (4) **executive functions** (Ravens Coloured Matrices; Camel and cactus pictures; Token)
Butler et al., 2014	PCA	31 post stroke aphasia patients	(1) **phonology** (nonword repetition; minimal pairs; picture naming; and digit span tasks), (2) **semantics** (spoken word-to-picture matching; synonym judgment; and picture naming tasks) (3) **executive-cognition** (non-word repetition; Camel and Cactus Test: Pictures; Brixton Spatial Anticipation Test; and Raven's Coloured Progressive Matrices tasks)
Halai et al., 2017	PCA	31 post stroke aphasia patients	(1) **phonology** (nonword repetition; word repetition; minimal pairs; picture naming; and digit span tasks; spoken sentence comprehension), (2) **semantics** (spoken word-to-picture matching; synonym

			judgment; and picture naming tasks; type-token ration) (3) **executive-cognition** (minimal pairs; written word-to-picture matching; Camel and Cactus Test: Pictures; Brixton Spatial Anticipation Test; and Raven’s Coloured Progressive Matrices tasks) (4) **language production** (type-token ration; number of words and words-per-minute during picture description task)
Mirman et al., 2015	PCA	99 post stroke aphasia patients	(1) **semantic recognition** (word-to-picture matching; synonym judgment; and picture association judgment; spoken sentence comprehension), (2) **speech production** (word and nonword repetition tasks and phonological errors in picture naming), and (3) **speech recognition** (auditory lexical decision; phoneme discrimination; rhyme discrimination; and word and nonword repetition tasks)
Ralph et al., 2010	PCA	33 post stroke aphasia patients	(1) **cognitive** (Pyramids and Palm Trees; Test of Everyday Attention; Wisconsin Card Sort Task; Rey Figure) (2) **phonology** (word repetition and reading tasks)
Gilmore et al., 2019	PCA	67 post stroke aphasia patients	(1) **linguistic** (personal facts; confrontation naming; story retelling; generative naming; spontaneous speech; auditory verbal comprehension; repetition; naming and word finding; reading; writing; Pyramids and Palm Trees Test; Boston Naming test) ; (2) **non-linguistic** (symbol cancellation; symbol trails; design memory; mazes; design generation; construction, visuospatial, calculation; Pyramids and Palm Trees Test)

Ingram et al., 2020	PCA	67 post stroke aphasia patients and 46 primary progressive aphasia patients	(1) **phonology** (repetition; naming; digit span; auditory comprehension; non-word minimal pairs discrimination; auditory and visual sentence comprehension); (2) **semantics** (naming; semantic verbal fluency; sentence comprehension; address call and recognition); (3) **visuo-executive** function (counting and visual imagery; Trail Making Task, Rey Complex Figure;), (4) **motor speech production** (words per minute; total number of words; mean length per utterance; digit span backwards; orobuccal and limb praxis)
Fong et al., 2019	PCA	355 people with aphasia of various types	(1) **auditory comprehension/ideomotor praxis** (word and sentence comprehension; word discrimination; word comprehension; number watching; picture-word matching; matching cases and scripts; oral commands; semantic probe; praxis; naming; reading; single word repetition); (2) **naming and reading** (word discrimination; picture-word matching; word comprehension; oral commands; semantic probes; reading; naming; repetition; praxis; complex ideational material; homophone matching); (3) **articulation-repetition** (oral commands; reading; naming; repletion); (4) **grammatical comprehension** (oral commands; complex ideational material; reading; naming; sentence repetition; auditory comprehension); (5) **phonology** (lexical decision; homophone matching; auditory comprehension

Most studies focused on post-stroke aphasic patients. These studies found between two and five language components (Butler et al., 2014; Wilson & Hula, 2019). These differences in the number of language components found may be explained by the choice of tasks used across studies and by differences in the sampling methods. These studies found components related to different language domains (e.g., phonology, semantics, syntax), and modalities (e.g., reading, writing, comprehension, production). In addition to the studies with aphasic participants, one study analyzed language performance in Alzheimer's disease and found two components, divided into transcoding and operative.

The study of both normal and impaired language processing is scientifically relevant. In patients with brain damage, the association between two tasks is not necessarily due to both tasks taping on the same language component. This association could rather be due to the spatial contiguity of brain lesions that support performance on those tasks (Goodglass & Kaplan, 1972). Therefore, studies in normal language can be more accurate to identify key language components. Additionally, the results of studies in normal language functioning can be generalized to the general population and serve as a basis of comparison for impaired language processing components. (Marcie et al., 1993).

To the best of our knowledge, only two studies focused on the components underlying language tasks in healthy adult participants (Carroll, 1941; Pineda et al., 2000). Carroll (1941) investigated the linguistic component of university students. This study found linguistic components related to richness of linguistic stock, semantic abilities, speed of association, discourse production, facility to attach appropriate names or symbols to stimuli and speed of articulatory movements, and verbal memory learning. This sample was composed of young and highly educated adults; thus, it cannot be generalized to the overall population. The second study had a sample with a larger range of age (between 19 and 60 years old) (Pineda et al., 2000). As far as we know, this was the only study to apply factor analysis to explore the underlying components of common language tasks in healthy adults with a wide range of age and education (Pineda et al., 2000). This study found the following seven language factors: oral reading (words and sentences reading), writing (dictation, serial writing, spelling to dictation), semantics (confronting naming, commands comprehension, word discrimination), semantic fluency (animals naming), lexical graphic attention (reading word recognition), repetition (word repetition), and motor (writing mechanisms). However, four factors were composed of only one variable (i.e., semantic fluency, lexical graphic, repetition, and motor). This decision can be questionable, because factors with only one variable are usually not reliable (Tabachnick & Fidell, 2013). Therefore, more studies are needed in healthy participants, especially with a wide range of age and education level. It is well known that age and education play a role in language abilities (Fonseca et al., 2015; Pagliarin et al., 2015). Thus, a more representative group of healthy adults are necessary for the results bring more generalizable to the overall population. Such findings can contribute to a better understanding of the cognitive processes underlying these tasks, leading to a more accurate and less time-consuming clinical assessment. Although two previous studies have tried to address the topic of language components in healthy adults, the conclusions are limited because of the age and education range and the use of only one variable per factor. Our study aims to overcome these limitations by including a sample with a larger range of education level and age. We hope to provide new knowledge on this relatively unexplored issue. Therefore, our study aims to investigate the underlying mechanisms of language tasks in a sample of normal individuals that greatly vary in their age (18 to 75 years old) and education level (5 to 23 years of formal education). Our study is the first one to address the issue of the main language dimensions behind two of the most widely used language tasks, the Montreal Evaluation of Communication — brief version (Casarin et al., 2014) and the Montreal-Toulouse language assessment battery for aphasia (Parente et al., 2016). In addition, this is the first study of its kind in Brazilian Portuguese.

2.1.3 Language and executive functions

Successful communication depends not only on different linguistic components but also relies on other cognitive mechanisms (Mohapatra, 2019). Language abilities allows us to organize our thoughts and to express our internal goal and desires, as well as understand other people’s ideas. To accomplish such complex tasks, we need to choose the right words, to judge if sentences make sense grammatically, to grasp the meaning of words and sentences within their context, among many other processes. Considering that language is composed of rich sources of information and many behavioral alternatives, conflicts and interferences can often happen during language processing. To handle these conflicts and interferences effectively, executive processes are engaged to monitor and regulate linguistic processing. Therefore, our ability to successfully express ourselves and understand others is not only dependent on an intact language system, but also relies on higher order control mechanisms (Mohapatra, 2019).

EF is an umbrella term that reunites complex and high-order cognitive functions responsible for goal-oriented behaviours, such as planning, problem-solving, and reasoning (Diamond, 2013; Miyake et al., 2000). These abilities are essential for mental and physical health, achieving success in school and in life, and cognitive social, and psychological development (Diamond, 2013). These sophisticated cognitive abilities are increasingly developed throughout childhood and into adulthood and they are supported by a dynamic multi-network system (Uddin et al., 2011). These abilities allow us to self-regulate and self-direct our behaviours toward a goal, to break out of our habits, to make decisions and evaluate risks, to plan for our future, to prioritize and to sequence our actions, and to cope with novel situations in our life (Snyder et al., 2015). Some core components of EF include anticipation and deployment of attention, impulse control and self-regulation, initiation of activity, working memory, cognitive flexibility, planning, and problem-solving (Gioia et al., 2000). EF are engaged when we need to inhibit behaviour, formulate strategies and monitor or performance (Anderson, 2010).

Several models of EF have been proposed. There is currently no unanimous consensus on these models (Ackerman & Friedman-Krauss, 2017; Anderson, 2010; Miyake & Shah, 1999; Rabbitt, 1999; Stelzer et al., 2014). These models provide the basis for the development of assessment tools and performance interpretation (Anderson, 2010; Chan et al., 2008; Stelzer et al., 2014). In what follows, we revise the most consensual EF models. However, this presentation is not exhaustive and many more other models can be found in the literature of EF.

Early EF models included one main executive component (i.e., unitary models), such as the central executive (Baddeley, 1986) or the supervisory activating system (Norman & Shallice, 1986). Baddeley's model focuses its attention on the role of working memory for the temporary storage and manipulation of information, whereas the supervisory activating system focuses on differentiating between automatic and deliberate actions. It classifies actions into those that can be executed automatically, known in this model as contention scheduling, and those that depend on intentional attentional resources, such as planning, decision-making, and resisting to temptations, among others. These latter are controlled by the supervisory activating system. Unitary models of EF have been criticized for being too simplistic (Stelzer et al., 2014). More recent studies suggest that executive functions are more likely composed of distinct but interrelated components (Anderson, 2010).

Barkley (1997) proposed a model of self-regulatory functions that includes multiple executive domains. In this model, self-regulation is a key element and incorporates the main elements of EF, including goal-directed behaviour, devising plans to achieve future-oriented goals, use of self-direct speech rules and plans, and impulse control ability. The four key components in this model are: (1) working memory (the temporary storage of goals and intentions, the generation of response plans, and the execution of goal-directed behaviours); (2) self-regulation of affect/motivation/arousal (the capacity to consciously self-regulate emotions; (3) internalization of speech (our private speech that can be employed to self-reflection and questioning, monitoring, and formulating rules and plans); and (4) reconstitution (the segmentation of situations or behaviours into different components, which allow the modification or reorder to construct a new approach or response set). Some important questions remain to be validated in this model. For example, whether there is a hierarchical organization between executive domains, and whether the four executive domains proposed are distinct and independent or rather represent a general executive system (Anderson, 2010; Cheung et al., 2004; Miyake & Shah, 1999).

Another well-known model, based on a confirmatory factor analysis, was proposed by Miyake and Friedman (Miyake et al., 2000). Their model proposed three main executive components: (1) updating working memory (the ability to continuously monitor and update incoming representations; (2) inhibition (the ability to deliberately suppress the dominant, automatic, or prepotent response when necessary); and (3) shifting (the ability to shift between different tasks or mental states). Their results showed that updating, inhibition, and shifting are distinct entities that are interrelated (Miyake et al., 2000). Another model was proposed by Diamond (2013). This model proposes that there are three main executive components. These three components are the building blocks for other higher-order components, such as reasoning, problem solving and planning. The three main components of this model are: (1) working (the ability to hold information in mind while manipulating it); (2) inhibition (the ability to control our attention, behaviours, thoughts, and emotions to suppress our internal dispositions or external lures when necessary); (3) cognitive flexibility (the ability to change perspective and adapt). This model makes a clear distinction between independent but interrelated components, which can be useful in clinical and research settings. However, this is a conceptual model and more studies are needed to validate it. Both Diamond's and Miyake's models present a three-component executive functions. Both models include inhibition and shifting/cognitive flexibility as main executive components. However, in Diamond's model working memory as a whole is considered an executive component, and in Miyake's model only the updating element of working memory is considered.

For the present master's thesis, we decided to focus on the two models proposing three executive components: working memory/updating, inhibition, shifting/cognitive flexibility (Diamond, 2013; Miyake et al., 2000). These two models are widely accepted in the scientific community. These models put forward distinct, yet related, executive components.

Working memory is considered an integral component of executive functioning (Anderson, 2010). Working memory can be defined as the component responsible for a limited capacity temporary storage and manipulation of information when the perceptual information is no longer present (Baddeley, 2003). Working memory allows new information to remain online while it is being related to previously learned information. Working memory differs from short memory because involves the manipulation of information. The best known working memory model was initially proposed by Baddeley (1974). It postulates that working memory has two "slave systems", one that handles verbal information (i.e. the phonological loop), and the other that process visuospatial information (i.e. the visuospatial sketchpad). These two systems respond to the central executive, an attentional limited control component. The central executive is responsible for the attentional control aspect of working memory. This model was later revised and an additional component was added to the model, the episodic buffer (Baddeley, 2000; Baddeley, 2003). This component is related to the temporary and limited storage of multimodal information. Its role is to bind together different information modalities, such as phonological, visual, spatial information, and multidimensional representations in long-term and semantic memory to form a unitary episodic representation across space and time (Baddeley, 2000; Baddeley, 2003). Updating is another executive component that is very closely related to working memory. It refers to our mental ability to monitor and update incoming representations in working memory (Miyake et al., 2000). It allows us to monitor the action being carry out, and correct or adapt our thoughts and actions if any change arises.

Working memory skills are necessary to hold short-term information in mind while accessing long-term memory. The phonological loop, one of the slave systems of the working memory, supports rehearsal and storage of verbal and acoustic information. Through working memory this new information interacts with the long-term memory via the multimodal episodic buffer allowing us to make sense of this new phonological information (Baddeley, 2003; Mohapatra, 2019). Thus, it is a crucial ability to make sense of written and spoken language (Diamond, 2013). Working memory is related to language abilities such as reading (Peng et al., 2018), writing (Capodieci et al., 2019), narrative discourse (Youse & Coelho, 2005), sentence comprehension (Fedorenko et al., 2006), among others.

Another important EF component is inhibitory control, which is the ability to suppress or inhibit the dominant or the automatic response. It allows us to control our behaviour, thought, and emotions in order to override internal predispositions or external lures. It allows us to focus our attention on the information that is more appropriate or necessary to achieve our goals (Diamond, 2013). Thanks to the inhibitory control mechanisms, we can resist the intrusions of irrelevant information from memory or external distractive information (Friedman & Miyake, 2004). Thereby, inhibitory control allows us to focus on the relevant information without overloading working memory.

During language performance, we need to inhibit distractors, while keeping relevant information online in our working memory during communication. This ability allows to choose the right word and sentence structure over other competing options and refraining us from generating the improper words or employ the improper sentence structure (Badre & Wagner, 2007). This ability is important for language abilities, such as reading (Butterfuss & Kendeou, 2018), picture naming (Sikora et al., 2016), semantic judgment (Stanley et al., 2017), sentence comprehension (Mohapatra, 2019), among others. During sentence comprehension, inhibition helps us to suppress conflicting interpretations, especially in syntactically ambiguous sentences, and it allows us to make a coherent interpretation of the sentence given its context. We also often rely on inhibitory mechanisms to suppress the most common meaning of a word or a sentence, in order to activate the most appropriate meaning within its context. This ability is essential for understanding the metaphorical meaning of words and sentences (Champagne et al., 2004).

Cognitive flexibility, also known as shift or attention switching, is considered in different models as an essential executive component. This component allows us to flexibly shift our attention between mental sets, operations, and tasks. It also allows us to change our perspectives, to adjust when the demands or priorities of a task change, and to think outside the box (Diamond, 2013). Thanks to cognitive flexibility, we can rapidly and efficiently adapt to different situations. Cognitive flexibility allows us to monitor and shift strategies, which is an important skill for reading (Butterfuss & Kendeou, 2018), sentence comprehension (Goral et al., 2011), pragmatic comprehension (Bosco et al., 2017), among other language abilities.

2.2 Language components

In what follows, we discuss the following language components: phonology, syntax, semantics, pragmatics, and discourse. These are often impaired in adults with acquired language disorders. We present their definition and their associated impairments. We also present some language tasks commonly used to assess each of these components. Only tasks included in our analysis are discussed. Finally, we discuss the role of EF in these language tasks.

2.3.1. Phonology

2.3.1.1 Definition

Phonology is the subfield of linguistics that studies the system of speech sounds. Each language (e.g. Portuguese, English, French, Spanish) has its own catalogue of sounds and rules for sound combinations which form syllables and words (Blumstein, 1998; Buckingham & Christman, 2008). Phonology studies how speech sounds can be grouped to form syllables and words. It also studies phonemes which are formed of the minimal distinctive traits of a language that expresses meaning (Wang et al., 2008). Phonology includes the encoding, representation, and retrieval of speech sounds in their prosodic dimensions (e.g. intonation, stress, and timings) and in their articulatory form (e.g. words, syllables, and phonemes) (Snow, 2000).

Sound units, also known as sound segments, can be analyzed in two representation levels, phonological (mental) and phonetic (physical). The phonological level concerns the properties of sounds and their organizational principles. These help an individual to differentiate minimal pairs. Minimal pairs happen when two words sound almost the same but they have a single different phoneme that leads to a difference in meaning (Barlow & Gierut, 2002). These differences can happen in at least one of the three traits of a phoneme: place of articulation, manner of articulation, and voice. For example, the words 'dear' and 'gear' are phonologically differentiated by the phonemes /d/ and /g/ that have different places of articulation. Both phonemes are voiced (voice) and plosives (manner of articulation). Nevertheless, they differ in their place of articulation: /g/ is velar (i.e., articulated with the back part of the tongue against the back part of the palate), whereas /d/ is alveolar (i.e., articulated with the tongue against the upper teeth). The phonetic level is responsible for the physical retrieval, acoustic transmission, and encoding of the sounds of speech. Phonetics is involved in the planning of articulatory movements for speech (Buckingham & Christman, 2008). While phonetics is responsible for the articulatory processing of sounds, phonology is responsible for translating the abstract representation of sounds stored in the brain to the actual articulation of a sound when we speak (Hayes, 2009).

2.3.2.2 Phonological Impairments

Acquired phonological deficits are common in aphasia, an acquired language disorder that often follows a stroke. Aphasic patients might present with deficits in phonological encoding and retrieval abilities (Buckingham & Christman, 2008).

Deficits in speech encoding include a decreased capacity to discriminate pairs of words and nonsense syllables, such as “pears” versus “bears” or “pa” versus “ba”. These encoding errors happen more often with consonants compared to vowels and in medial and final syllabic positions than in initial positions (Blumstein, 1998).

Phonological retrieval deficits include errors, such as phoneme substitution, simplification, addition, and environment errors (Croot et al., 2012). Phoneme substitutions occur when a phoneme is wrongfully replaced by another phoneme, for example, saying “dat” instead of “hat”. Simplification errors happen when a phoneme or a syllable is deleted, for example saying “bawn” instead of brown. Addition errors occur when an extra phoneme added to a word, for example saying “prapa” instead of “papa”. Finally, environment errors happen when the occurrence of a particular phoneme is changed by the influence of the surrounding phonetic context. Two situations may occur, the order of the segment could be changed, for example, by saying “godri” instead of “degree”, or another sound could influence the occurrence of another, for example saying “trit” instead of “Crete” (Blumstein, 1998).

Paraphasias can be defined as the unintended substitution of sounds and words. Paraphasias are classified according to their relation to the intended word. Paraphasias related to phonology can happen as phonemic or phonetic paraphasias. Phonemic paraphasias occur when the produced word is phonologically related to the target word (e.g. saying nat instead of cat) (Silagi et al., 2015). Phonemic paraphasias can happen as the substitution, omission or addition of phonemes. These paraphasias happen due to an impairment in the selection and/or the planning of the phoneme. Phonetic paraphasias occur as extreme phonetic distortion errors that happen due to an impairment on the programming or the execution of articulatory gestures (Marczy & Baqué, 2013).

Another condition that affects language abilities is primary progressive aphasia (PPA) (Bambini et al., 2016; Gorno-Tempini et al., 2011), a neurodegenerative disease that causes gradually and progressively impair language abilities. For the diagnosis of PPA, language impairment must be the most prominent difficulty and cause the most impact on daily living activities (Gorno-Tempini et al., 2011; Mesulam, 2001). Other cognitive domains can be affected by the progress of the disease; however, language still is the most impaired one (Gorno-Tempini et al., 2011). This condition is classified according to three variants: semantic, logopenic, and nonfluent/agrammatic variants (Bonner et al., 2010; Grossman, 2010). A single and isolated language impairment may be found in a minority of patients. Some patients may also present mixed features that do not fit these three classifications, which can become clearer with the progress of the disease. A clinical evaluation of different language abilities is needed to correctly classify patients into PPA subtypes (Gorno-Tempini et al., 2011).

In the logopenic variant, deficits are characterized by impaired single-word retrieval in spontaneous speech, naming and repetition. This phonological disruption occurs during phonological retrieval and encoding (Croot et al., 2012). It can be observed in the substitution, addition, or deletion of well-articulated phonemic segments. Motor speech, single-word comprehension, and syntactic abilities are usually preserved (Grossman, 2010). In the nonfluent/agrammatic variant, patients often present primary progressive apraxia of speech, characterized by an impaired planning on the speech motor control. This leads to a distorted articulation and eventually errors producing sound and syllables across words or within multisyllabic words. Phonological retrieval and encoding processes are usually spared. The other criteria diagnosis for nonfluent/agrammatic PPA and the semantic variant will be discussed later on in the syntax and semantic sections, respectively.

2.3.2.3 Phonological Tasks

Phonology is one of the key elements for successful word reading and writing abilities. Phonological abilities play a major role in reading by working as an alphabetic backup system (Wang et al., 2008). Given that phonemes are the building blocks that form words (Wang et al., 2008), explicit orthographic-phonological processes are activated to sound out individual phonemes, and then combine these into words (Veenendaal et al., 2016). This is particularly important in the context of unfamiliar or unknown words. However, when reading familiar words, both phonological and semantic processes are engaged (Cherney, 2010; Crisp & Lambon Ralph, 2006; Veenendaal et al., 2016).

Single-word reading tasks are usually employed to assess phonological abilities. They usually involve the reading of regular, irregular, foreign, and nonwords (i.e. invented words). The reading of words with regular and irregular letter-to-sound correspondences allows the assessment of phonology and semantics. Reading tasks often include words from different grammatical classes (e.g. nouns, verbs, function words) and with different frequencies (e.g. high- and low-frequency words). The reading of nonwords and foreign words assesses orthography-to-phonology mappings without semantic contribution. Clinicians can observe thought reading tasks if patients produce phonological impairments, such as phoneme omissions and substitutions, neologisms, and perseveration, besides the detection of paraphasias.

Phonology also plays a major role in spelling abilities. Spelling is actually more phonologically demanding than reading. This happens because generally there are more ways to spell a phoneme than forms to read a grapheme (Dębska et al., 2019). Spelling processes include the activation of phonological, semantics, and writing motor components.

Spelling-to-dictation tasks are often used to assess phonological impairments. These tasks usually include the spell of regular, irregular, foreign, and nonwords. Words usually vary their grammatical class (e.g. nouns, verbs, function words), length, and frequency (e.g. high- and low-frequency words).

Another task that can be used to assess phonology is the phonemic verbal fluency task, also known as letter fluency. During this task, participants must evoke words beginning with a specific sound or letter, for example, words starting with the sound /p/ or the letter p: pencil, pen, and so on). To perform this task, orthographic and phonological networks are activated. This allows us to strategic search and retrieve words following a phonemic category (Stolwyk et al., 2015). Unlike semantic categories that are often employed in everyday life (e.g. making a supermarket list), phonemic categorization is rarely used. Even if it is possible to employ semantic strategies (e.g. pen and pencil, both are school supplies), we usually need to inhibit the activation of semantically related words in order to apply novel retrieval strategies (Shao et al., 2014). For example, suppressing eraser or notebook, after pen and pencil.

Picture naming is another language task that engages phonology and semantics (Barry et al., 2001; DeLeon et al., 2007; Moayedfar et al., 2021; Morelli et al., 2011). In this task, participants must name objects or actions presented in a picture format. Naming impairments can occur as a consequence of the difficulty to access the phonological form or the semantic concept evoked by the picture (Moayedfar et al., 2021). The latter will be further discussed in the semantics section.

2.3.4.4 Phonological tasks and Executive Functions

Simultaneous information processing and storage are necessary during reading and writing; thus, engage working memory (Capodieci et al., 2019; Peng et al., 2018). Working memory plays an important role on decoding (i.e. the orthography-to-phonology mapping that allows the translation of printed words into language, and reading comprehension) (Christopher et al., 2012). For decoding, working memory helps to access and monitor speech-based information (Swanson et al., 2009). One study showed that students with poor decoding abilities had worse performance on working memory tasks when compared to adequate readers (Swanson, 1999).

Inhibitory control is also related to reading decoding (van der Sluis et al., 2007). During decoding, inhibitory control suppresses neighbouring words (i.e. orthographically similar words). These words can be incorrectly activated during reading. Their suppression helps to decrease working memory overload during reading (de Jong et al., 2009; Purvis & Tannock, 2000; Van De Voorde et al., 2010). To sum up, a poor suppression mechanism is linked to more intrusion errors that can distract from the relevant information and overload the working memory system (Butterfuss & Kendeou, 2018; De Beni & Palladino, 2000).

There is less evidence to support the role of cognitive flexibility in decoding and reading comprehension. Cognitive flexibility helps to shift between reading strategies and to monitor comprehension. Being more flexible also helps reading by allowing us to shift attention and flexibly alternate between semantic and phonological features. This flexibility is also known as graphophonological-semantic flexibility (Butterfuss & Kendeou, 2018). For decoding, one study showed that cognitive flexibility was related to better nonword reading (Colé et al., 2014). Another study found that cognitive flexibility predicts the performance of single-word reading (Ouellette & Beers, 2010). These results imply that the role of cognitive flexibility could extend beyond reading comprehension.

For spelling, working memory allows us to retrieve and maintain the phonological and orthographic sequences of words until the word is actually spelled while controlling for irrelevant concurrent information (Capodieci et al., 2019). In order to spell a familiar word, we must initially retrieve orthographic information from our orthographic lexicon (i.e. long-term memory where the orthographic representation of familiar words is stored). Whereas for unfamiliar or nonwords, we must engage phonology-to-orthography mappings. Therefore, orthographic representations can be retrieved from orthographic long-term memory or be assembled by phonology-to-orthography conversion (Rapp et al., 2016). These processes are sustained by our limited working memory capacity.

The working memory system is responsible for maintaining letter identities and their respective order online. A disruption in the working memory can lead to a decreased ability to hold items for the short period of time necessary for motor performance. This deficit can be translated into an increased probability of incorrectly producing letters in long words (Rapp et al., 2016).

2.3.2 Semantics

2.3.2.1 Definition

Semantics is the subfield of linguistics interested in how language meanings are processed (Harel & Rumpe, 2004). Semantics includes the study of meaning in words (i.e. lexical-semantics), sentences, or even larger units of discourse (Kroeger, 2019). Semantics plays a great role in several language abilities, such as naming, categorization, and comprehension.

Naming is one of the key abilities related to lexical-semantic processing. Naming ability involves several mental steps. It begins with the retrieval of a given concept. The meaning of the word is usually activated as a whole. It is then followed by lexical selection. After the activation of the target concept, the next step is to encode the morpheme-phoneme at the lemma level (i.e. abstract conceptual form of a word). The word is then phonetically encoded at the lexeme level (i.e. unit of meaning that underlies a set of words that are related through inflection), and finally, the word is articulated (Levelt et al., 1999; Moayedfar et al., 2021).

Categorization is another ability that engages semantics (Jerger & Damian, 2005). The meaning of a word is represented by its features. For example, the word “dog” can be classified in several ways using its features, such as being an animal, a mammal, domestic, besides having four legs and a tail, among other characteristics. From these features, we can categorize words using different semantic relationships (Pothos & Wills, 2011). For example, we know that words belonging to the same category (e.g. dog and cat) share more semantic features when compared to words from different categories (e.g. dog and banana).

Semantics is also key to language comprehension. Language comprehension requires the integration of different linguistic components, such as phonology, syntax, and semantics (Breese & Hillis, 2004; Gajardo-Vidal et al., 2018; Hickok et al., 2008; Simos et al., 2014). The first step to language comprehension is to convert sensory input (e.g. pictorial, spoken, or written inputs) into abstract (picture or word) forms (Booth et al., 2002). The next step involves accessing lexical information from semantic memory linked to these forms, and finally to integrate this information with the preceding context, known as the unification process (Hagoort, 2005).

In single-word comprehension, semantics contributes to word identification, and word decoding (Keenan & Betjemann, 2008). Prior knowledge that is stored in semantic memory contributes to better word identification due to word predictability (Priebe et al., 2011). For sentence comprehension, semantics helps us to decipher the words that form the sentence. In addition, it provides context that contributes to the ability to grasp the overall meaning of the sentence (Leikin et al., 2012; Priebe et al., 2011).

2.3.2.2 Semantic impairments

Semantic impairments are common in almost all types of language deficits followed by brain damage (Libben, 2008). However, not all words are equally affected. In general, abstract words (e.g. friendship or success) are more vulnerable to semantic impairments when compared to concrete words (e.g. cat or table). Moreover, some patients can have particular difficulty with certain grammatical classes of words (e.g. nouns or verbs) (Libben, 2008).

Post-left stroke patients may present impairments in how they process words. Decreased auditory and written comprehension in both word and sentences are common semantic deficits (Knollman-Porter et al., 2019; Wiener et al., 2004). This difficulty is increased with low-frequency words (DeDe, 2012) and longer and more complex sentences (Caplan et al., 2007).

Categorization deficits can be presented as a difficulty to judge if words are semantically related, or placing words in a narrow category extension. For example, when asked what mosquitoes and bees have in common, some patients may answer "animal", a large category instead of insects, a narrower category (Verheyen et al., 2019).

Given that naming involves both phonological and semantic access, naming disorders can happen as a result of a difficulty to access the phonological form of a word or to access the meaning of the word (Barry et al., 2001; DeLeon et al., 2007; Lin et al., 2014; Moayedfar et al., 2021; Morelli et al., 2011). Impairment in picture naming abilities is common in different pathologies, such as left post-stroke aphasia (DeLeon et al., 2007; Herbert et al., 2008), Alzheimer's disease (Lin et al., 2014; Moayedfar et al., 2021), and semantic PPA (Bruffaerts et al., 2020). Incorrect naming responses can take the form of semantic paraphasias (e.g. magazine instead of book), or even unrelated paraphasias (i.e. substitution of one word for another unrelated word, for example, cat instead of pencil) or as a non-response (i.e. pure anomia; absence of the name). The latter can happen as a "tip-of-the-tongue" effect, when the person knows the target concept, but cannot name it. It can also happen as circumlocution (i.e. substitution of a word for a phrase). For example, answering "It is used to call people", when asked to name a telephone. It can also involve visual substitutions that happens when the word is replaced by another that is visually similar (e.g. pyramid instead of triangle). Finally, naming errors can happen as intrusion, when the answer is actually a word that had been previously presented (Silagi et al., 2015).

Right-hemisphere damage patients can also suffer from semantic impairments. They usually present intact semantic processing when dealing with words with straightforward typical meanings (Thompson et al., 2016). Their understanding of the primary meaning of individual words and unambiguous simple sentences is usually preserved. However, they might present semantic control deficits when processing words with possible divergent meanings, especially when involving non-dominant meanings that are alternate, connotative, or less familiar (Myers, 1999; Thompson et al., 2016). They can also show impaired word retrieval skills, making more “no response” and semantic errors compared to neurotypical participants (Krishnan et al., 2015).

Patients suffering from neurodegenerative diseases can also present with semantic deficits. For example, semantic impairments in Alzheimer’s disease are characterized by difficulties in word finding and object naming (Cappa et al., 1998; Cotelli et al., 2012; Cotelli et al., 2010; Laws et al., 2007). Their most common naming errors produced are semantic paraphasias(Laws et al., 2007). These difficulties become more evident with the progress of the disease.

In the semantic variant of the primary progressive aphasia, also known as semantic dementia, semantic impairment is its core feature (Gorno-Tempini et al., 2011). This affects performance in a large number of tasks, such as confrontation naming, single-word comprehension, object and/or person knowledge, and reading. Impairment in comprehension ability is a result of progressive degradation of concept representations (Jefferies & Lambon Ralph, 2006). Poor comprehension skills are often impacted equally all input and output modalities, showing item-consistency impairments across tasks. Semantic dementia patients struggle more with less familiar items when compared to more familiar ones and they usually do not respond to phonemic cues.

2.3.2.3 Semantic Tasks

Picture naming is among the most widely used task for assessing semantics. Clinicians can observe the kind of error produced to analyze the source of the deficit.

If the errors in picture naming can be linked to semantic difficulties, but not visual problems (e.g. mirror instead of comb), this suggests a semantic deficit. Errors can also be linked to visual aspects, without involving semantic ones (e.g. knife instead of nail); thus, suggesting a deficit in object recognition. It can involve both semantic and visual aspects (e.g. horse instead of camel). In addition to the phonological errors already discussed in the phonology section.

Another task that involves semantics is the semantic categorization or judgment task, which assesses semantic processing using categorization (Obermeyer et al., 2020). In the simplest version of this task, participants must identify if a pair of words belong to the same semantic category (e.g. chair and table are both pieces of furniture). Participants must activate the semantic features of each word in order to figure out if they fit in the same semantic category (e.g. dogs and cats, for the animal category) or if the words do not belong to the same semantic category (e.g. skirt and banana). These tasks usually involve manmade (e.g. clothing, furniture, vehicles) or natural (e.g. animals, fruits, vegetables, mammals) categories.

Auditory and written comprehension tasks also involve semantics (Breese & Hillis, 2004). They assess the ability to understand spoken and written words and sentences. In the single-word version of the task, participants must identify the picture that corresponds to the spoken (i.e. auditory comprehension task) or written (i.e. written comprehension tasks) the target word (e.g. cat) among other distractors. These distractors are often visually (e.g. panther), semantically (e.g. dog), or phonologically (e.g. hat) related to the target word. Similarly, for sentence comprehension, participants must identify the image that corresponds to the written or spoken sentence. Given that sentence comprehension engages both semantics and syntax components, we will further discuss the sentence comprehension task in the syntax section.

Semantic verbal fluency tasks, also known as category fluency, is also often employed to assess semantics. During this task, participants must evoke as many words as possible following specific semantic rules, such as animals or fruits and vegetables, in a limited time range. This task assesses lexical access ability (Shao et al., 2014). Participants must activate their semantic knowledge in order to retrieve semantic associations. Strategies such as categorization or clustering help performance in this task (Gonçalves et al., 2017; Troyer, 2000). For example, when asked to name clothes, participants can subcategorize clothes by season (e.g. summer or winter clothes), occasion (e.g. parties, casual, sleeping clothes).

There is also another form of verbal fluency task known as unconstrained verbal task. During this task, participants also need to evoke as many words as possible, but none previously phonological or semantic rule is established. Thus, no clue on how to generate the words is provided. Participants that usually have a better performance are able to create clusters and to shift to new clusters when the present cluster has been exhausted (Gonçalves et al., 2017). One successful strategy is to form semantic clusters (e.g. animals, plants, food) or phonological clusters (e.g. pack, park, pace). To be able to explore this strategy, the patient needs to activate semantic and/or phonological processes. This version of the verbal fluency task has been less employed; thus, it still needs to be further explored.

2.3.2.4 Semantic Tasks and Executive Functions

EF play a role in semantics by suppressing irrelevant and distractor information, allowing information to remain online in working memory, and shifting strategies, among other functions.

Picture naming tasks engage working memory and inhibitory control. Working memory allows the patient to keep online the requirements of the tasks while the conceptual and linguistic processes are being engaged. Inhibitory control allows the suppression of irrelevant information and distractors (Sikora et al., 2016). For example, in order to successfully name a picture of a cat, many related words (e.g. dog, tail, kitten) can be activated and need to be suppressed. Inhibitory control impairment is related to response perseveration (Snowden et al., 2019). Cognitive flexibility does not seem to be related to picture naming performance (Shao et al., 2012).

Semantic judgment tasks are also related to EF (Martin & Allen, 2008; Obermeyer et al., 2020; Stanley et al., 2017). Inhibitory control helps to focus only on the relevant features and to suppress irrelevant information and distractors. Moreover, working memory helps to retain online several features while the categorization and semantic judgment processes are being conducted (Koenig et al., 2005).

EF also seem to play an important role in language comprehension. Our semantic knowledge needs to be adapted according to the requirements of the tasks or the context. EF help to direct and control semantic activation in a context-appropriate manner (Jefferies et al., 2007). EF contributes to the comprehension tasks performance because it allows us to interpret words and/or sentences according to the context of the task. Executive impairments are linked to a greater difficulty to manipulate and gate semantic information to achieve appropriated behaviours regarding context, task, and time (Thompson et al., 2018).

Verbal fluency tasks are well known for engaging both executive and linguistic components. However, there are some contradictory findings regarding the role of EF in verbal fluency tasks. For example, one study found that verbal fluency did not load in the same factor as EF measures, only on the language factor (Whiteside et al., 2016). This finding suggests that language processing be the main mechanism underlying verbal fluency tasks. On the other hand, other studies have indicated a crucial role of EF in verbal fluency (Aita et al., 2019; Amunts et al., 2020; Gustavson et al., 2019; Shao et al., 2014). During these tasks, participants have to maintain focus to only select the words that meet the criteria and to avoid repetition. The participant also needs to be flexible in order to shift strategies when the strategy employed has been exhausted. For example, when asked to name animals, one strategy is to name zoo animals, when this strategy is no longer working, a person can shift to another strategy, such as naming domestic animals. These processes are linked to inhibitory control and cognitive flexibility (Amunts et al., 2020; Fisk & Sharp, 2004; Shao et al., 2014).

2.3.3 Syntax

2.3.3.1 Definition

Syntax is the subfield of linguistics that studies the rules, principles, and processes of sentence structure. Most sentences are usually composed of at least one agent (the do*ers* of the action) and one theme (the do*ee*s of the action) (Beretta, 2008). Sentences usually contain a subject (S), a verb (V) and an object (O). Active voice sentences (e.g. she loves cakes) are less difficult to comprehend than passive voice ones (e.g. cakes are loved by her) because it is easier to identify thematic roles (who did what to whom) when they are not inverted. Sentences can also include a relative clause, which is a part of a sentence usually introduced by words such as which, that, who. Relative clauses are used to join two sentences or to give further information about the main clause (e.g. the girl likes the boy that plays on a band). The argument-verb structure also plays a role in syntax. Verbs are essential for sentence comprehension because they help to establish relations among words in a sentence (Shapiro & Levine, 1990). Arguments are expressions that contribute to complete the meaning of a predicate (i.e. the main verb and its auxiliaries). Different from adjuncts that are optional, arguments are essential for the meaning of the predicate. For example, in the phrase "The boy really likes cake", boy and cake are arguments for the verb like. The subject and object are core arguments. The word "really" in this phrase is an adjunct because it is not essential for the phrase to be meaningful. The syntactic function of the argument is essential for sentence comprehension. For example, in the phrases "John likes Mary", "Mary is liked by John", or "Mary has been liked by John", the predicate "like" has different forms, by consequent their arguments (e.g. Mary and John) also vary, whereas the thematic roles of the arguments remain the same. All these mentioned factors play a role in increasing the difficulty of producing or understanding a sentence (Caplan et al., 2007; Kudo, 1984; Leikin et al., 2012; Thompson et al., 2015).

In order to produce a sentence, we need to retrieve words from semantic memory, combining stored information, while we construct syntactic relations among the words (Vigliocco & Hartsuiker, 2002). Sentence production involves several complex processes, such as message conceptualization, accessing relevant lexical material, sentence building (i.e. sequencing of lexical material into grammatical sentences), morphophonological processes, and articulatory encoding (Thompson et al., 2015). This allows us to translate a communicative intention to overt speech.

One of the first stages is the lemma selection and retrieval. Some studies indicate that not only semantic but also syntactic information becomes accessible in this first step. Indeed, word substitution errors usually happen in the same grammatical category. Therefore, syntactic information is retrieved along with meaning and form steps during lexical access (Vigliocco & Hartsuiker, 2002). The other stage involves the access of form-related information or lexemes. Following

Levelt’s model (1999), there are two main systems responsible for sentence production. The first one involves rhetorical, semantic, and syntactic systems and it is responsible for conceptual preparation and grammatical encoding. The surface structure of the sentence is generated by the interaction of knowledge of the external and internal world and the mental lexicon (Thompson et al., 2015). The second one activates the phonological/phonetic system for morphophonological and phonetic encoding as well as articulatory processes.

Syntax is also needed to sentence comprehension. The latter can be affected by sentence complexity (e.g. number of verbs and thematic roles, sentence length, and types of syntactic construction). To understand a sentence, a person must process both the meaning of words, thus engaging semantics, and the syntactic structure, thus engaging syntax (Leikin et al., 2012). One key aspect to sentence comprehension is to understand the thematic roles (who did what to whom) (MacDonald & Hsiao, 2018). For example, we need semantics and syntax to understand the phrase “The rat was chased by the cat”. We must know the difference between a cat and a rat, thus activating semantics. Then, we must perceive that the sentence has a passive structure to interpret that the cat was the agent of the action. The knowledge of the individual words is not sufficient to comprehend a sentence. Structure cues, such as word order and verb morphology, are also necessary for assigning the correct noun for the thematic role as agent of the action (Leikin et al., 2012). In other words, syntax plays a key role in sentence comprehension (Caplan et al., 1985; Gajardo-Vidal et al., 2018; Simos et al., 2014; Sung et al., 2009; Yoon et al., 2015).

2.3.3.2 Syntactic impairments

Agrammatism is the most common sentence production deficit in post-stroke aphasia (Cho-Reyes et al., 2016). Agrammatism can be defined as a difficulty to employ basic grammar and syntactic rules. Syntactic production deficits are characterized by a decreased ability to produce a complete grammatical structure. The syntactic structure is characterized by the omission of sentence components. Sentences often contain mainly content words, such as nouns and verbs, but lack a few or even several function words, such as “the”, “and”, “what” (Adelt et al., 2018). Agrammatic patients usually produce sentences reduced in length and complexity

(Faroqi-Shah & Friedman, 2015; Lee & Thompson, 2004). Sentence deficits can also appear as a greater difficulty employing grammatical structural (e.g. difficulty employing the correct noun), and word inflections (e.g. adding "ed" or "ing" to a verb to change its tense or adding an "s" to a noun to make it plural). Hesitations during sentence production are also common. They occur as filled and unfilled pauses, false starts, repetition, and parenthetical remarks (Thompson et al., 2015).

Syntax comprehension deficits are also a common symptom of post-stroke aphasia (Caplan et al., 2007), even when presenting unimpaired single-word comprehension (Martin & Tan, 2015). This can occur as a greater difficulty to identify thematic roles in passive voices sentences (Duman et al., 2011). Aphasic patients tend to incorrectly assign verb argument structures (e.g. agent, theme, goal) (Shapiro & Levine, 1990). For example, in the phrase "The ball was thrown by the man", even though the patient can understand the semantic meanings of the nouns "ball" and "man", it can be difficult to identify the man as the role of agent (i.e. who carry out the action) and the ball as the theme (i.e. object or person being acted upon) (Martin & Tan, 2015). Another common difficulty is to understand sentences with object relative clauses, such as "the person that I saw yesterday is my new neighbour" (Caplan et al., 2007). In this kind of sentence, it can be more difficult to identify the thematic role corresponding to each noun. Likewise, sentences with reflexive pronouns, such as "my friends' father shaved himself", can be difficult to interpret for aphasic patients. For a successful interpretation, patients must understand the implication of the reflexive in this structure, while the reflexive (e.g. himself) is matched with the subject (e.g. my friend's father) (Caplan et al., 1985). Some aphasic patients may also present a greater difficulty with implausible sentences (i.e. sentences with events which never or rarely occur in our daily life) because they are less predictable. Indeed, semantic plausibility helps aphasic patients to decode their messages, contributing to sentence comprehension (Kudo, 1984). One example of a plausible sentence is "The dog has bitten the man", which is a likely event to occur, and an implausible sentence would be "The man has bitten the dog", which is an event unlikely to happen.

Other neurological conditions can also present sentence comprehension deficits, such as traumatic brain injury. Sentence comprehension deficits in traumatic brain injury can appear as a greater difficulty to comprehend more complex sentences, such as sentences containing relative clauses (e.g. who, which, that, where, etc.), passive sentences, and conjoined structures (i.e. sentences that contain two or more independent clauses united by a conjunction, such as “the girl hit the boy and the cat”) (Leikin et al., 2012).

Patients with primary progressive aphasia can also present with syntactic impairments. Indeed, the language deficits in the nonfluent/agrammatic variant of primary progressive aphasia are mainly syntactic. Deficits include grammatical simplification with errors in sentence production, impaired syntactic comprehension, and an effortful and halting speech with speech sound errors. Single-word comprehension and object knowledge are usually spared (Grossman, 2010).

2.3.3.3 Syntax Tasks

As we established in the semantic section, sentence comprehension tasks (written or auditory modalities) engage both semantic and syntax components. In these tasks, patients must indicate the picture that corresponds to the right written or spoken sentence among sentence distractors. Distractors can change the actor of the action or the action itself (i.e. agent-action mismatch). For example, in a picture depicting the sentence “The dog follows a boy”, a distractor picture could be “The boy carries the dog”. The tasks usually start with simpler sentences with fewer agents and themes and increasingly add more complex sentences with more agents, themes, and details involved. To perform well in these tasks, participants must activate phonology, syntax, and semantics in order to select the correct answer, while inhibiting the other distractors (Drummond et al., 2015).

2.3.3.4 Syntactic Tasks and Executive Functions

During language comprehension, working memory plays an essential role. The information received from the early parts of the sentence needs to remain online, so they can be integrated with the latter parts of the sentence. This allows us to grasp the overall meaning of the sentence (Martin & Tan, 2015). Studies have shown that working memory measures are able to predict performance on sentence comprehension tasks. This prediction is greater with more complex sentences or when there was an external memory load (Daneman & Carpenter, 1980; Fedorenko et al., 2006; Just & Carpenter, 1992). Other studies showed that an overall decreased working memory capacity is linked to a worsen performance on sentence comprehension. However, these two deficits can be dissociated (Caplan et al., 1999; Hanten & Martin, 2000; Waters et al., 1991).

Inhibitory control also contributes to sentence comprehension by suppressing competing sentence representations, allowing for a coherent sentence representation (Mohapatra, 2019). In addition, inhibition also helps to suppress irrelevant information in semantically ambiguous sentences (Yoon et al., 2015). Cognitive flexibility also plays a role in sentence comprehension. Each new sentence must be integrated and interpreted independently from the previous ones. Cognitive flexibility supports sentence comprehension by allowing us to flexible shift from one sentence structure to another (Goral et al., 2011).

2.3.4 Pragmatics

2.3.4.1 Definition

Meaning is not only dependent on structural and linguistic knowledge, it also relies on background contextual information, such as manners, place, time, culture, and identity of the speaker (Ariel, 2010). Pragmatics is the subfield of linguistics that studies how utterances have meanings according to the situation (Bosco et al., 2018). It can be defined as the study of how language is used in communication or the principles of language use (Wearing, 2015).

While semantics studies the meaning of conventional language, pragmatics is interested in how context and the inferred intent of the speaker interfere with the transmission of meaning. Pragmatics helps to connect the abstract linguistic knowledge of rules and the actual realization of linguistic form and interpretation within its context (Ariel, 2010). Pragmatics includes different linguistic aspects, such as context-dependent utterances, metaphorical interpretations, and indirect speech acts.

Context cues are often necessary for conveying meaning. If an utterance depends on context support or any reference to extra-grammatical factors, it can be considered as pragmatically determined (Ariel, 2010). Understanding that the semantic interpretation could differ from its pragmatics interpretation is a key aspect of pragmatics. While semantic meanings are mostly constant, context insensitive and context invariant, pragmatics meaning are context-sensitive (Ariel, 2010).

Communicating by recognizing and expressing intention also involves pragmatics (Scott-Phillips, 2017; Wearing, 2015). The standing meaning could not be enough to understand what a speaker actually means by their utterance. We often need to understand their intentions in order to determine the actual meaning. It is the task of the addressee to identify the intention behind the utterance and the effect the speaker wanted to produce (Wearing, 2015). This also includes the understanding that a message can be implied even when it is not explicitly expressed (Ariel, 2010). For example, if a person says, "could you close the window? It's very cold outside," what the person actually means is that closing the window will prevent the cold outside from entering the room. The actual intended meaning is implied. Pragmatic meanings must be inferred by the addressee; thus, they are often implicit and secondary (Ariel, 2010; Wearing, 2015). Inference can be defined as information that we have to interpret even if it is not explicitly stated.

Pragmatics also allows us to understand the implied meaning of speech acts. According to Austin (1962), speech acts are verbal acts that carry out an act rather than describing an event. This includes acts such as requesting, promising, apologizing, answering, warning, inviting, ordering, among others (Ariel, 2010). Speech acts can be performed as indirect speech acts. This happens when the speech act is not explicitly stated. For example, if a person asks, "Can you pass me the salt?" the direct meaning of the question is the ability to carry out the action of passing the salt; however, there is also the implied request to the salt to be passed (Asher & Lascarides, 2001). In everyday life, it is common to employ indirect speech acts for rejecting proposals or to make requests. For example, if a person makes an invitation such as "would you like to go on a date Friday night?" and the answer to this question is "I have to study", the addressed person employed an indirect speech act to rejecting the initial proposal.

Metaphors also engage pragmatics, because their interpretation is not direct; instead, they depend on figurative interpretation. Figurative interpretation happens when the meaning of a word or a sentence is modified from its literal meaning to a non-literal meaning. Other than metaphorical interpretation, a few examples of figurative language include irony, understatement, deliberate exaggeration (Baum & Dwivedi, 2003; Davis, 2007). Context plays an essential role to determine if a statement should be interpreted in its literal or non-literal meaning. For example, "*fan the flame of the campfire*" can be understood in its literal meaning, while "*fan the flame of the relationship*" has a non-literal meaning interpretation (i.e. intensify or stir up feelings on a relationship) (Davis, 2007). How a person will interpret the pragmatic message also depends on the listener's recognition and interpretation. For example, how a person interprets the metaphor "Lawyers are sharks" may depend on the listener's previous view of lawyers (Gibbs & Colston, 2020). Given that metaphors have an implied meaning and they are context-dependent, we can conclude that pragmatics plays an important role on metaphorical interpretation.

2.3.4.2 Pragmatic Impairments

Pragmatic skills can be affected by neuropsychiatric disorders, such as right brain damage, traumatic brain injury, Alzheimer's disease, and schizophrenia. People with impaired pragmatic skills have trouble communicating in a socially appropriate manner. These patients can present with difficulty understanding the non-literal language messages, such as sarcasm/irony, indirect speech acts, figurative expressions, such as metaphors, or social cues, such as facial expressions, besides deficits in narrative production, and conversational skills (Parola et al., 2020; Weed, 2011)

Both pragmatic production and comprehension can be impaired. It can also affect different communicative modalities, such as linguistic, extralinguistic (e.g. gestures and facial expressions), and paralinguistic (e.g. prosody) (Parola et al., 2020). Common comprehension deficits in pragmatics include difficulties understanding the non-literal meaning of utterances, such as unconventional requests, new metaphors, speech acts, inferences, and humour (Brownell et al., 1986; Champagne-Lavau & Stip, 2010; Lundgren & Brownell, 2016; Yang et al., 2010). Pragmatic deficits may appear as a difficulty to interpret other people's intentions during conversations or watching television (Lehman Blake, 2006).

Pragmatic production deficits may occur as insufficient shared knowledge for their communication partner, making their discourse confuse and less informative (Chantraine et al., 1998). They may have difficulty respecting their turn to talk, maintaining the conversational topic, and making eye contact (Barnes & Armstrong, 2010; Dardier et al., 2011; Lehman Blake, 2006). Some patients can also have trouble comprehending the context and the moral of stories (Champagne et al., 2004; Zimmermann et al., 2011) and conversational joking (Bogart et al., 2012).

2.3.4.3 Pragmatics Assessment Tasks

One task that relies on pragmatic skills is the interpretation of speech acts (Bosco et al., 2018). For this task, participants have to identify when a speech has been indirect or direct. In other words, when the speaker meant exactly what he/she said (direct) or when the speaker's intention is conveyed by its context (indirect). For example, a direct speech act would be to ask a salesperson to sell you coconut water and an indirect one if they have coconut water. In the first one, it is clear the client's intention, but in the second one, his intention to buy coconut water is implied.

Another task associated with pragmatic skills is the metaphors interpretation. For this task, participants must explain the non-literal meaning of metaphorical sentences. For example, the non-literal message of the metaphor "He is a walking dictionary" is that a person has a lot of knowledge. The participant needs to initially process the literal meaning, thus activating semantic processing (Holyoak & Stamenković, 2018). Then, he/she must decide if the utterance is compatible with the context. If it is not compatible, further processes are needed to establish utterance meaning (Pawełczyk et al., 2017).

2.3.4.3 Pragmatics Assessment Tasks and Executive Functions

The literature on the relationship between pragmatics and EF is conflicting and non-conclusive (Parola et al., 2020). On the one hand, several studies have shown the role of EF in metaphor interpretation, speech acts, and pragmatic comprehension in ambiguous speech. On the other hand, other studies were not able to find any relationship between EF and pragmatic abilities (Champagne-Lavau & Stip, 2010; McDonald, 2000; Parola et al., 2018). This may be explained by the heterogeneity of tasks used to assess pragmatic skills, and even heterogeneity in patients presenting impaired pragmatic abilities (Parola et al., 2020).

One meta-analysis with traumatic brain injury found an association between executive functions and pragmatic. The latter was assessed by the ability to make inferences about implied messages in ambiguous speech, such as sarcasm, humour, and other figurative language forms (Rowley et al., 2017). Another recent study with traumatic brain injury patients also showed that executive measures (i.e. working memory, cognitive flexibility, and planning) can predict pragmatic production and comprehension abilities assessed by indirect, deceitful, and ironic communicative acts (Bosco et al., 2017).

Working memory is thought to play a role in pragmatics by allowing contextual information to remain online while inferences are being processed during ambiguous speech interpretation (Wilson, 2005). Inhibition also seems to play a role in pragmatics. Inhibition processes are activated to suppress multiple meanings in non-literal language comprehension. This seems to play a major role in the selection of the most appropriate meaning. However, one study did not find an association between inhibition and an indirect request comprehension task (Champagne et al., 2004). The same study found a significant correlation between cognitive flexibility and the indirect request comprehension task.

Metaphor interpretation is also related to EF. Proverbs interpretation is associated with problem-solving, cognitive flexibility, and planning skills (Sponheim et al., 2003). Inhibition help to suppress the prepotent but irrelevant and distracting information of key elements during metaphor comprehension. For example, in the metaphor "Rumours are weeds", the fact that weeds are plants is not necessarily relevant for the metaphor. However, the aspect that weeds are undesirable and spread quickly is needed for interpreting the metaphor. In other words, more common features often need to be suppressed during metaphor interpretation, while less common or secondary features need to be activated (Chiappe & Chiappe, 2007). An impaired ability to inhibit irrelevant features can lead to competition, resulting in an increased difficulty to understand the metaphorical meaning. Cognitive flexibility helps to shift between the literal and the metaphorical meaning of sentences (Champagne et al., 2004).

Working memory also seems to play a role in metaphor interpretation by supporting inhibitory mechanisms. In addition, working memory is linked to better activation of large semantic neighbourhoods and a wide range of representations. People with low working memory abilities are more likely to not engage pertinent properties during metaphors interpretation (Chiappe & Chiappe, 2007).

2.3.5 Discourse

2.3.5.1 Definition and Cognitive Mechanisms Underlying Discourse

Discourse can be defined as any connected speech or writing that is longer than a sentence and that embodies a coherent sequence of sentences, propositions, speech acts or conversation turns (Sobhani Rad, 2014). Discourse is a high-order linguistic component that relies on different language components. The comprehension of individual words and sentences are key elements for discourse comprehension, thus engaging phonological, semantic, and syntax components. However, the comprehension of single words and sentences are not sufficient for discourse comprehension. Indeed, we need to integrate all sentences to form a coherent discourse as a whole (Perfetti & Frishkoff, 2008). Therefore, another essential feature of discourse is cohesion. Cohesion can be defined as the organization necessary to mark meaningful relationships within and across sentences (Lê et al., 2011).

Discourse is also dependent on the context in which they are produced. For example, a person can use a pronoun, such as “he”, “she”, “it”, as a way to link previously presented information. For these cues to work effectively, the person must consider the knowledge and intention states of their conversational partner, besides the propositional information to be encoded (Perfetti & Frishkoff, 2008).

2.3.5.2 Discourse Impairments

Discourse abilities are an essential feature of the pragmatics-communication component that allows us to express and comprehend ideas, thoughts, questions, etc. Discourse plays a key role in everyday communication; therefore discourse impairments can lead to restricted participation in society (Lê et al., 2011). Discourse impairments can occur even in the absence of aphasia symptoms. For example, traumatic brain injury and right brain damage patients are known for being “good talkers” but “poor communicators”.

Discourse deficits can present as a difficulty to identify the discourse theme, the main point, and the connections among textual propositions, besides distinguishing important from trivial aspects (Ariel, 2010). The production of discourse of right-hemisphere damage and traumatic brain injury is often characterized as being incoherent, tangential, and self-oriented (Lehman Blake, 2006), besides being ambiguous and vague (Douglas, 2010). It might also present verbosity, disorganized thoughts, and focus on irrelevant details (Galetto et al., 2013; Minga, 2016). Some patients will monopolize conversations and make off-topic comments, whereas others will hesitate to talk at all because of their difficulties (Barnes & Armstrong, 2010). Some patients can present a flat and monotone discourse (Baum & Dwivedi, 2003; Lehman Blake et al., 2013; Pell, 2006).

Coherence discourse impairments, such as disorganized topic coherence and management, are also common (Johns et al., 2008). The topic of discourse is often changed abruptly and new topics are poorly related to previous ones (Pompili et al., 2020). Even when individual sentences are syntactically well structured and semantically congruent, a disruption in comprehension can occur if there are inconsistencies across sentences impairing the overall meaning of the discourse (Johns et al., 2008).

Coherence impairment can occur as an increased difficulty to employ macrostructures. This can be observed as an increased difficulty to arrange sentences into coherent paragraphs. This difficulty can also appear when retelling a story as a whole (Titone et al., 2001). Stories often do not have sentences that are tight appropriately together, besides lacking cohesion and coherence and being less informative (Minga, 2016).

Pragmatic impairments can also occur in discourse. These impairments include misattributions (i.e. when erroneous information is conveyed), the inclusion of irrelevant details, inconstant reference (i.e. characters are referred in different ways to the story leading to confusion), vagueness, and non-narrator speech (i.e. when patients step out of their role as narrator) (Klin, 2000; Norbury et al., 2014). Discourse impairment can also appear as a difficulty to identify the thematic role and the main ideas and to grasp the overall meaning of the story and the implied message (Johns et al., 2008).

Alzheimer's disease patients also often present impaired discourse abilities. Their discourse is often fluent but non-informative. Their discourse is characterized by incomplete and short sentences and lacking organization, cohesion, and coherence. They present difficulty managing and maintaining conversational topics. They also often change topic abruptly and relate poorly new topics to old ones (Pompili et al., 2020).

2.3.5.3 Discourse Tasks

Discourse can be assessed by a wide range of tasks, such as picture or object description, narrative, and procedural discourse tasks, besides conversational discourse. In the descriptive discourse task, patients must attribute features and concepts of a given stimulus, such as an object or a picture. In the procedure one, patients must explain the action sequences necessary to perform a given task, such as putting on pants or cooking an egg. Narrative discourse task is the most often used discourse task. It employs a story creation or a story retelling technique (Lê et al., 2011). In the first, participants create a story from a figure or a sequence of figures (Andreetta et al., 2012; Coelho et al., 2005; Marini et al., 2014). In the latter, participants must retell a story with as much information as possible (AbdulSabur et al., 2014; Coelho, 2002; Lindsey et al., 2018).

Narrative discourse engages various language components, both microstructures (phonological, semantical, and syntactic) and macrostructures (pragmatics and cohesion) (Andreetta et al., 2012; Coelho et al., 2005; Lindsey et al., 2018; Youse & Coelho, 2005). Microstructure features that can be analyzed in narrative discourse tasks include sentential complexity and verbal output errors (e.g. mazes, lexical errors, verbal paraphasias) (Lê et al., 2011). For the macrostructure, we can analyze pragmatics and coherence components. For instance, an inferred moral message can be present in the story for assessing if the patient is capable to identify and interpret inferences. In order to understand the underlying meaning of the story, patients need to engage pragmatic comprehension (Prado et al., 2015). We can also analyze two levels of discourse coherence: local and global. Local coherence refers to the ability to thematically link two sentences and global coherences refers to the ability to link each sentence to the overall discourse theme (Lê et al., 2011). Narrative discourse also uses temporal-causal organization.

Participants must organize the temporal order of the event and infer a causal relationship between the event components, as well as being able to construct a theme (i.e. creating a point in the story) (Ulatowska & Olness, 2007).

2.3.5.3 Discourse Tasks and Executive Functions

Discourse is a high-order linguistic component that relies on different language components, such as phonology, semantics, syntax, pragmatics, coherence, in addition to other non-linguistic domains, such as EF. EF are needed for categorization, organization, and management of large-scale information units, such as retelling a cohesive story (Cannizzaro & Coelho, 2013). Discourse impairments are often a reflection of deficits in both executive and linguistic organization processes (Ylvisaker, 2001). Indeed, discourse impairments were found to be significantly correlated with EF (Coelho, 2002; Mozeiko et al., 2011). A decreased performance in EF is associated with the production of irrelevant utterances, word-finding problems, and increased difficulty to sequence words and prepositions (Youse & Coelho, 2005).

Working memory helps to form a cohesive and organized story. To elaborate a cohesive story, a person must integrate prior episodes or episodic moments to what is being told (Mozeiko et al., 2011). Indeed, studies found that a significant correlation between working memory and discourse measures in narrative discourse tasks (Cahana-Amitay & Jenkins, 2018; Hartley & Jensen, 1991; Henderson et al., 2017; Youse & Coelho, 2005). Working memory allows the integration of information from different sources and the temporal store of complex information. Therefore, a deficit in working memory can potentially impair the integration of different episodic narrative information during discourse (Cahana-Amitay & Jenkins, 2018). Deficits in working memory can appear as a decreased ability to establish a consistent connection between sentences and the general topic of discourse, leading to a breakdown of hierarchical discourse organization and disrupted sequential processing (Cahana-Amitay & Jenkins, 2018). Working memory is also linked to micro-level components of discourse, such as lexical access and syntactic process (Henderson et al., 2017).

Inhibition also contributes to discourse by monitoring the production of off-topic comments during storytelling, helping to avoid a tangential discourse (Lundin et al., 2020; Mozeiko et al., 2011). Deficits in inhibition are also linked to a decreased ability to use clues and hints during discourse (McDonald & Pearce, 1996). The narrative discourse task was also found to be associated with cognitive flexibility (Zimmermann et al., 2011). Cognitive flexibility contributes to the recall and integration of content during story narrative (Mozeiko et al., 2011).

The linguistic and cognitive mechanisms underlying language tasks in healthy adults: A Principal Component Analysis.

Running head: The linguistic and cognitive mechanisms underlying language tasks in healthy adults

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Abstract

We explored how a set of language tasks would group in 201 healthy participants to investigate their underlying cognitive mechanisms. Using a Principal Component Analysis, we discovered four language components that explained 59.64% of the total variance: pictorial semantics (auditory comprehension, naming and writing naming tasks), language-executive (unconstrained, semantic, and phonological verbal fluency tasks), transcoding and semantics (reading, dictation, and semantic judgment tasks), and pragmatics (indirect speech acts interpretation and metaphors interpretation tasks). Secondarily, we verified the association between these components with two executive measures in a subset of 33 participants. Cognitive flexibility performance was assessed using the Trail Making Test and working memory using the n-back test. The language-executive component was associated with a better cognitive flexibility score (r=-.355) and the transcoding and semantics one with a better working memory performance (r=.397). Our findings confirm the heterogeneity process underlying language tasks and their relationship to executive functions.

Key-words: language tasks; language processes; executive functions; semantics; pragmatics; transcoding; Principal Component Analysis.

Introduction

A key step during language assessment is to understand the cognitive mechanisms underlying commonly used language tasks. This leads for a more precise and time-efficient language assessment. Language tasks usually engage different language components, such as phonology (i.e. how phonemes form syllables and words), semantics (i.e. how language conveys meaning), syntax (i.e. sentence structure), pragmatics (i.e. meaning variations according to context) and discourse (i.e. how to form coherent sequences of sentences). Which key linguistic and cognitive mechanisms are involved in commonly used tasks remains a matter of debate (Lacey et al., 2017). Therefore, more studies that aim to investigate these underlying components, especially in normal language performance, are needed.

A comprehensive language assessment should include a large number of tasks that assess these different language components in different modalities (e.g. oral, written, expressive and receptive language). Standardized language batteries are commonly used in clinical settings because they provide the clinician with an array of tasks to evaluate multiple components of language (Pagliarin et al., 2014). Several language batteries are commonly used, such as the Boston Diagnostic Aphasia Examination—BDAE (Goodglass et al., 2001) and the Multilingual Aphasia Examination—MAE (Benton et al., 1994), among many others. In the present study, we focus on two batteries extensively used in Brazilian Portuguese, the language studied here: the *Montreal Communication Evaluation Battery—brief version* (MAC; Casarin et al., 2014) and the *Montreal-Toulouse language assessment battery* (MTL-BR; Parente et al., 2016). The MAC battery assesses communicative skills that are commonly associated with the right hemisphere lesions (Casarin et al., 2014). It contains tasks assessing different linguistic-communicative components, such as semantics, prosody, pragmatics, and discourse. The MTL-BR battery assesses language components typically impaired in post-stroke aphasia, such as phonology, syntax, semantic, and pragmatics. It includes tasks that involve different input and output modalities, such as auditory, verbal, visual, and written, and different levels of complexity, such as word, sentence, and discourse (Parente et al., 2016).

One major challenge in language assessment is time. However, useful and comprehensive, lengthy batteries are time-consuming. It is not always possible to conduct a complete language and cognitive assessment because of time restrictions. In addition, an overly long assessment can be very stressful for some patients. Therefore, the selection of sensitive tools to assess language is of the utmost importance. Additionally, several tasks in a battery may contribute to the assessment of the same components. Knowing which language components underlie a task may inform clinical decisions on which task to use to target a specific language component and save valuable time.

Performance on language tasks depends not only on language skills but rather one the combination of linguistic and non-linguistic components (Butler et al., 2014). One of the non-linguistic components that have a major impact on language tasks is executive functions (EF). EF can be defined as the complex and high-order cognitive functions responsible for goal-oriented behaviours, including shifting, updating, inhibiting, planning, problem-solving, and reasoning (Diamond, 2013; Miyake et al., 2000). Several studies highlight the crucial role of executive abilities in language (Gonçalves et al., 2018; Martin & Allen, 2008; Obermeyer et al., 2020). EF are needed to monitor and regulate linguistic processes, such as acting on the selection among competing representations and suppression of irrelevant ones, besides monitoring ongoing behaviour (Mohapatra, 2019). Considering the relationship between different language components to EF could lead to a more accurate language assessment.

The aim of the present study is to explore the underlying linguistic and cognitive mechanisms of language tests. To do so, we conducted two studies. In Study 1, we explore the cognitive mechanisms of language tasks through Principal Component Analysis (PCA). In Study 2, we verify the association between language components and executive functions using correlations.

Study 1: The cognitive mechanisms underlying language tasks

1.1 Introduction

Most language tasks rely on heterogeneous linguistic and non-linguistic processes. As such, language tasks are not a pure measure of a single language component. The underlying cognitive mechanisms of commonly used language tasks still need to be further explored. The elucidation of these could contribute to a more accurate and time-wise language assessment. Multivariate statistical approaches, such as PCA or a factorial analysis, help us to explore language multidimensionality. By employing these techniques in Study 1, we can identify the underlying linguistic components that are represented by an optimal combination of scores across several language tasks (Butler et al., 2014).

Most studies with PCA and factorial analysis focused on post-stroke aphasic patients (Butler et al., 2014; Fong et al., 2019; Gilmore et al., 2019; Halai et al., 2017; Hanson et al., 1982; Ingram et al., 2020; Jones & Wepman, 1961; Lacey et al., 2017; Mirman et al., 2015; Ralph et al., 2010; Tochadse et al., 2018) and primary progressive aphasia patients (Henry et al., 2012; Hoffman et al., 2017; Ingram et al., 2020; Ramanan et al., 2020). These studies highlight the multidimensionality of language founding between two and four language components (Butler et al., 2014; Wilson & Hula, 2019). These differences in the number of language components found may be explained by the choice of tasks used across studies in addition to differences in sampling methods. These studies found components related to different language domains (e.g., phonology, semantics, syntax), and modalities (e.g., reading, writing, comprehension, production). In addition to the studies with aphasic participants, one study used PCA to analyze language performance in Alzheimer's Disease (Marcie et al., 1993). This study found two components. The first component grouped tasks that required transformations of verbal stimulus into output with new information, thus interpreted as an "operativeness factor" and the second component grouped tasks requiring transformation between input and output formats. To summarize, in patients, the components that usually appear are related to phonology, speech production and recognition, semantics, and syntax, besides executive-cognition. Correlations between subtests performance in these patients might happen for two reasons. The first one because they share common underlying cognitive mechanisms. The second one because they may also happen due to the spatial contiguity of lesions to brain regions that support those cognitive functions (Goodglass & Kaplan, 1972). Therefore, studies of normal language functioning can be more accurate to identify key language components in a large set of language tasks. Studying both the key language components of disordered and normal language functioning can be clinically relevant. One limitation when exploring the language components in a specific language impairment is that the results are generalizable only to this clinical population. Studies with normal language functioning can serve as a basis to be compared to the language processing in different clinical populations.

Studies in healthy adult participants found components involving the association of encoded and decoded materials, syntax production and comprehension, semantics, and discourse production. Fist study was composed of only university students (Carroll, 1941). The second study had a sample with a larger range of range (between 19 and 60 years old) factors with only one variable (Pineda et al., 2000). This decision can be questionable, because factors with only one variable are usually not reliable.

It is well known that age and education play a role in language abilities (Fonseca et al., 2015; Pagliarin et al., 2015). Thus, it is important to have a more representative group of healthy adults so the results are more generalizable for the overall population. Thus, the aim of Study 1 is to explore how language tasks group according to their underlying cognitive mechanisms in normal adult language processing. As far as we know, the present study is the first one to apply a multivariate approach to study the underlying cognitive-linguistic mechanisms of the MAC and MTL-BR batteries, and the first one to explore factorially language components in Brazilian Portuguese.

1.2 Methodology

1..2.1 Participants

A total of 349 people, aged between 18 and 75 years old, participated in the study. For Study 1, we included the 201 neurologically healthy adults who completed both language batteries entirely. Participants were recruited in universities and coexistence groups. Their sociodemographic data are presented in table 1. They did not receive any financial compensation for their participation, and all signed an informed consent form. The assessment was conducted by properly trained and qualified healthcare professionals who had completed or were in the process of completing additional training in language and neuropsychological assessments.

Participants met the following inclusion criteria: (1) they had Brazilian Portuguese as their first language; (2) they had normal or corrected-to-normal vision and hearing; (3) they had no current and/or previous neurological or psychiatric conditions, as self-reported; (4) they had no depression as assessed by the Beck Depression Inventory (BDI-II) (Beck et al., 2011); (5) they had no history of alcoholism and/or current or previous abuse of illicit drugs or benzodiazepines and antipsychotics; and (6) they had normal general cognition, as assessed by the clock-drawing test (Agrell & Dehlin, 2012) and the Mini-Mental State Examination (MMSE) (Folstein et al., 1975; Kochhann et al., 2010).

In order to test the possible impact of depression symptoms on the performance of our task, we ran a regression analysis between the selected language tasks and depressive symptoms assessed by the Beck Depression Inventory (BDI-II). None of the correlations were significant. Therefore, we believe that these results were not enough valuable to be present as a table in this article. However, other variables having an effect on cognition, such as sleep and anxiety or other psychological variables, could have been explored. Unfortunately, they were not available in our database. Future studies should be performed to better explore the role of these variables in language processing.

Table 1

Sociodemographic data of the participants of Study 1

Female Sex N (%)	Years of formal education M (SD)	Age M (SD)	MMSE M (SD)
127 (62.87)	11.10 (4.68)	45.29 (15.06)	27.79 (2.08)

Note. MMSE = Mini Mental State Examination.

1.2.2 Ethics Procedures

The sample used for the present study was collected as part of a previous study. This larger study had as objective to adapt to Brazilian Portuguese two language batteries, the brief version of MAC battery and the MTL-BR language assessment battery. This previous study was evaluated and approved by the Research Ethics Committee of the Pontifical Catholic University of Rio Grande do Sul (PUCRS), Brazil (number 04908/09). We will conduct a secondary analysis of these data. The present study was approved by the Aging-Neuroimaging Research Ethics Committee of the Research Center of the Institut Universitaire de Gériatrie de Montréal (CER VN 20-21-17).

1.2.3 Materials

The following two language batteries were used in our analysis:

The *Montreal Communication Evaluation Battery—brief version* (Ferré et al., 2011), adapted to Brazilian Portuguese (Casarin et al., 2014), is composed of nine tasks that assess discursive, pragmatic inferential, lexical semantic, and prosodic abilities. The following tasks were included in our analysis: metaphors interpretation, unconstrained verbal fluency, narrative discourse, and indirect speech acts interpretation. For a more detailed description of each task, see appendix A.

1. Metaphors interpretation: participants must explain the meaning of six metaphorical sentences (three new or unconventional metaphors and three idiomatic expressions). This task assesses the ability to understand metaphorical language.

2. Unconstrained verbal fluency: participants must evoke as many words as possible without a priori criteria, over 150 seconds. This task the ability to explore the lexical-semantic memory with no category restriction.

3. Narrative discourse: participants must listen to a history and then retell the story with the maxim of information. Participants must also answer questions about the story to verify if they understood the implicit meaning of the story.

4. Indirect speech acts interpretation: participants must identify and explain when a speech is indirect (the speaker's intention is not clear) or when it is direct (speaker literally means what is said). This task assesses the ability to understand speech acts according to the situational context.

5. Semantic judgement: participants must indicate if a pair of words are semantically related (ex. chair and table). If there is a semantic relation, the participant must justify its answer. This task assesses the ability to identify semantic relationships between words.

The *Montreal-Toulouse language assessment battery* (Nespoulous et al., 1992), adapted to Brazilian Portuguese (Parente et al., 2016), contains 22 tasks used to evaluate oral and written expression and comprehension, in addition to praxis and arithmetical abilities. The following tasks were included in our analysis: automatic speech, auditory comprehension, written comprehension, dictation, reading, semantic verbal fluency, phonological verbal fluency, naming, and written naming. For a more detailed description of each task, see appendix B.

1. Automatic speech: participants must evoke automatisms such as numbers, days of the week, and the birthday song. This task assesses the ability to evoke automatisms.

2. Auditory comprehension: participants must identify images that represent words and phrases from auditory input. This task assesses spoken word and sentence comprehension.

3. Written comprehension: participants must identify images corresponding to words and phrases from visual input.

4. Dictation: participants must listen to an auditory stimulus and then search for the corresponding written representation, including regular, irregular, foreign words and non-words and one sentence. This task assesses the ability to understand auditory stimulus and identify the correct spelling of words.

5. Reading: participants must read out loud 12 words (among regular, irregular, foreign words and non-words) and three sentences. This task assesses the ability to recognize letters and produce the appropriate phonological sounds.

6. Semantic verbal fluency: participants must evoke as many animals as possible, over 90 seconds. This task assesses the ability to produce spontaneous words within a semantic category.

7. Phonological verbal fluency: participants must evoke as many words beginning with the letter M as possible, over 90 seconds. This task assesses the ability to produce spontaneous words within a phonological category.

8. Naming: the participant must identify and name pictures of 12 nouns and 3 actions (verbs). This task assesses the ability to name images corresponding to nouns and verbs.

9. Written naming: participants must identify and indicate the right figure of 12 nouns and three actions (verbs). The ability to identify and indicate figures referring to nouns and three actions.

We only included tasks assessing single-word and phrase levels. We decided not to include tasks at the narrative and discoursive levels because they involve multiple language components simultaneously. For example, text comprehension can simultaneously engage phonological and semantic abilities for word decoding (Cherney, 2010), phonological, semantic and syntactic ones for sentence comprehension (Gajardo-Vidal et al., 2018), as well as discursive abilities for capturing the overall meaning of the text (Chesneau & Ska, 2015). Narrative discourse tasks can also engage multiple language components simultaneously, both in the micro (e.g., phonology, semantics, syntax) and macro (e.g., cohesion, coherence) levels (Andreetta et al., 2012; Lindsey et al., 2018). For this reason, it would be very difficult to clearly disentangle which are the cognitive mechanisms that support different aspects of these tasks. Therefore, we excluded the conversational discourse task from the MAC battery, as well as the oral and written text comprehension tasks and the written and oral narrative discourse tasks from MTL-BR.

Both the MAC and the MTL-BR batteries have reading tasks. The reading task from the MTL-BR battery employs single words and phrases, whereas the reading task from the MAC battery assesses reading text comprehension. Since we used single-word and phrase-level tasks, we chose the reading tasks of the MTL-BR battery. Also, both batteries include narrative discourse tasks. In our analysis, we decided to include pragmatic abilities only. During the MAC narrative discourse, participants have to make inferences about the story that they just heard. Inferences are considered to be a pragmatic ability (Ariel, 2010; Wearing, 2015). During the written and oral narrative discourse tasks from MTL-BR battery, participants have to tell (oral narrative discourse) or to write (written narrative discourse) a story from a picture. While the narrative discourse tasks from MTL-BR battery assess the micro- and macro-structures of the discourse, the narrative discourse from MAC assesses the ability to synthesize and infer information. Unlike the MAC battery, the narrative discourse task from MTL-BR does not include pragmatic interpretations. Therefore, we decided to include the narrative discourse task from MAC for its assessment of pragmatics.

The emotional prosody task from the MAC battery and the nonverbal praxis, object manipulation, body part recognition, and left-right orientation, number dictation, reading of numbers, and calculation tasks from the MTL-BR were not used in the present analyses because they do not assess language *per se*. We also excluded the repetition task from the MTL-BR battery, because it presented a restricted variability with 95% (191 of 201 participants) presenting only two scores (32 or 33). Considering that a low variability can affect the analysis, we opted for excluding this variable.

1.3 Procedures et data analysis

The data were analyzed using SPSS 25.0. As in previous similar studies (Archibald, 2013; Butler et al., 2014; Crockett, 1974; Henry et al., 2012; Ingram et al., 2020; Lacey et al., 2017), we used a factorial analysis with a PCA extraction method. This approach seeks to condense a large number of variables into smaller sets of interrelated variables regrouped by their underlying dimensions with a minimal loss of information (Hair et al., 2009). We conducted an exploratory factorial analysing using a PCA method to explore how the chosen language tasks would group (Fabrigar et al., 1999). We expect that tasks that tap the most similar underlying mechanisms will have loading on similar components (Henry et al., 2012). Given that all tasks share a common linguistic feature, we expected an inter-relatedness between components. Thus, we choose to apply the Direct-oblimin rotation, which is an orthogonal rotation (Lambert et al., 2018). We used the criterion of eigenvalues greater than one to establish the number of components, (Bourque et al., 2006; Kaiser, 1960).

After all these decisions are taken, the analysis can be conducted. An adequate PCA/factor analysis has to make sense and to be easily interpretable (Tabachnick & Fidell, 2013). An a priori established loading cutoff point is used to define which variables have a meaningful contribution to the components/factors' formation. The choice of the loading cutoff size depends on the researchers' preference. Choosing to include only variables with high loading reduces the risk of components formed by variables that contribute too unequally, as well as, the inclusion of variables that contributed only slightly in the components/factors' formation. The found factors/components are then given a label accordingly to the neurolinguistic interpretation based on the variables that contributed to their formation (Wilson & Hula, 2019). We used a loading criterion of .500 or higher, which is considered a strong load (Costello & Osborne, 2005; Marcotte et al., 2017).

Given the influence of age and education on language skills, these two measures were studied for each variable by means of regression analyses. Regression analyses of age and education are presented in table 2. Aged explained variance in seven of 14 variables (auditory comprehension, written comprehension, semantic judgment, semantic verbal fluency, naming, phonological verbal fluency, and written naming). Education explained variance in all variables. We regressed age and/or education into each variable for which one or both regressor variables affected performance. The standardized residuals obtained from this regression were then used as the new variable entered in the PCA analyses. In such a way, the newly calculated variable also considered the effect of age and education on performance. To limit the impact of extreme scores, we replaced the 26 outliers identified (out of 3,015 observations) with a score equivalent to 3.29 standard deviations from the mean of a given task (Field, 2018).

Table 2

Regression analyses for each language task with age and education as regressors

	Age			Education		
	beta	t	p*	beta	t	p
Auditory comprehension (MTL-BR)	-0.200	-3.001	.003**	0.272	4.08	<.001***
Written comprehension (MTL-BR)	-0.220	-3.419	.001*	0.349	5.416	<.001***
Dictation (MTL-BR)	-0.005	-0.080	ns.	0.496	8.051	<.001***
Reading (MTL-BR)	-0.04	-0.618	ns.	0.422	6.561	<.001***
Metaphors interpretation (MAC)	0.035	0.529	ns.	0.374	5.679	<.001***
Unconstrained verbal fluency (MAC)	0.083	1.468	ns.	0.598	10.529	<.001***
Narrative discourse (MAC)	-0.041	-0.697	ns.	0.556	9.374	<.001***
Indirect speech acts (MAC)	-0.029	-0.422	ns.	0.197	2.826	.005**

Semantic judgment (MAC)	-0.077	-1.161	ns.	0.357	5.408	<.001***
Semantic verbal fluency (MTL-BR)	-0.143	-2.361	.019*	0.495	8.188	<.001***
Naming (MTL-BR)	-0.251	-3.796	<.001***	0.256	3.88	<.001***
Phonological verbal fluency (MTL-BR)	0.127	2.079	.039	0.500	8.173	<.001***
Written naming (MTL-BR)	-0.255	-4.124	<.001***	0.409	6.631	<.001***
Automatic speech (MTL-BR)	0.065	0.949	ns.	0.271	3.965	<.001***

Note. significance level at **p*<.05, ***p*<.01 ***at *p*<.001; MTL-BR = *Montreal-Toulouse language assessment battery (MTL-BR)*; MAC = *Montreal Communication Evaluation Battery – brief version* (MAC); ns = not significant.

1.4 Results

Table 3 presents the descriptive analyses (mean and standard deviation) of the language tasks used in the present study. We considered for normalcy a skewness value between -2 and 2 and a kurtosis value between -7 and 7 (Curran et al., 1996). All language tasks are normally distributed.

Table 3.
Descriptive analysis of each language task

	Raw scores	Standardized Residuals	
	m (sd)	Skewness	Kurtosis

Auditory comprehension (MTL-BR)	18.18 (1.19)	-1.26	1.29
Written comprehension (MTL-BR)	12.72 (0.61)	-1.53	2.39
Dictation (MTL-BR)	20,36 (2.18)	-1.82	5.26
Reading (MTL-BR)	32,49 (0.80)	-1.25	1.55
Metaphors interpretation (MAC)	8.47 (2.31)	-0.56	0.09
Unconstrained verbal fluency (MAC)	46.28 (17.94)	0.4	0.3
Narrative discourse (MAC)	34.04 (11.91)	.55	-.263
Indirect speech acts (MAC)	10.1 (1.74)	-0.84	0.48
Semantic judgment (MAC)	5.35 (1.26)	-1.72	2.73
Semantic verbal fluency (MTL-BR)	22.35 (0.80)	0.32	-0.07
Naming (MTL-BR)	29.49 (1.00)	-1.55	2.48
Phonological verbal fluency (MTL-BR)	16.74 (6.24)	0.31	0.13
Written naming (MTL-BR)	28.34 (2.49)	-1.16	1.81

Automatic speech (MTL-BR)	11.74 (0.54)	-1.58	2.19

Note. MTL-BR = Montreal-Toulouse language assessment battery (MTL-BR); MAC = Montreal Communication Evaluation Battery – brief version (MAC)

We performed a Kaiser-Meyer-Olkin test (KMO) to verify sampling adequacy. Values must be over .600 in all variables. All the variables presented values over .600, except the automatic speech task, which had a value of .472. We thus decided to not include this variable in our analysis. Another test performed was the Barlett's test of sphericity. For adequacy, this test should be statistically significant, which was the case for our analysis. Only variables with loadings higher than 0.500 were retained (Costello & Osborne, 2005; Marcotte et al., 2017). For this reason, the narrative discourse task (highest load of 0.43) and the writing comprehension task (highest load of 0.458) were not included in our final PCA solution presented in table 4.

Table 4

Oblimin-rotated pattern matrix for the principal component solution with language tasks

	Component 1: Pictorial Semantic	Component 2: Language-Executive	Component 3: Transcoding and Semantics	Component 4: Pragmatics
Auditory comprehension*	0.694			
Naming*	0.663			
Written naming*	0.613			
Unconstrained verbal fluency**		0.781		

Semantic verbal fluency*		0.730		
Phonological verbal fluency*		0.726		
Reading*			-0.740	
Semantic Judgment**			-0.732	
Dictation*			-0.584	
Indirect speech acts interpretation**				0.776
Metaphors interpretation**				0.652
Percentage variance				
Total variance = 53.16%	24.35%	12.16%	8.86%	7.77%

Note. The values on this table represent the loadings which are the correlations between the variables and their component. *tasks from the *Montreal-Toulouse language assessment battery (MTL-BR)*; **tasks from the *Montreal Communication Evaluation Battery – brief version* (MAC).

1.5 Discussion

The goal of Study 1 was to explore how a set of language tasks would group to investigate their underlying cognitive mechanisms. We used a PCA that produced four components. These components accounted for around 53% of the total variance in language tasks. In what follows, we present an interpretation of these components based on the variables that contributed to their formation (Wilson & Hula, 2019). We decided to label the components to facilitate the interpretation of results. The interpretation and naming of components depend on which of the observed variables correlated highly with each factor (Tabachnick & Fidell, 2013). The labelling process depends on how the researcher interprets the reasons behind variables loading high in each component and not on others. Therefore, the label processing is subject to interpretation.

Our first component is composed of naming, written naming, and auditory comprehension tasks. In the naming task, participants must identify and name pictures from a visual input. In the written naming task, participants must match an image with its corresponding written name. In the auditory comprehension, participants are asked to identify which picture represents the word that they just heard. Naming and comprehension tasks are known for engaging semantic processes (Almeida et al., 2007; DeLeon et al., 2007; Gajardo-Vidal et al., 2018; Moayedfar et al., 2021; Simos et al., 2014; Yoon et al., 2015). Semantics enables us to understand the meaning of a given information, whether this information is presented by an auditory, pictured object or a visual input (Bonin et al., 2015). Given that all three tasks involve pictures and access to semantics, we decided to name this component *pictorial semantics*.

For the second component, all three verbal fluency tasks grouped. In these tasks, participants must recall as many words as possible in a given time frame. In the phonological verbal fluency task, participants must evoke words starting with the letter M. In the semantic verbal fluency, participants must evoke as many animals as possible. In the unconstrained verbal fluency, participants must evoke as many words as possible without a priori criteria. During verbal fluency tasks, patients must explore their semantic memory. During the task, participants often need to shift between strategies. For example, shifting from animals in the zoo to animals starting with the letter b during the semantic verbal fluency or to shift from words starting with “m” to words starting with “f”. In addition, the person needs to avoid repetition and words that do not meet the established criteria. The capacity to switch between strategies or to inhibit inappropriate words engage executive functions (Amunts et al., 2020; Gustavson et al., 2019; Shao et al., 2014). Verbal fluency tasks are well established and often-used tasks for assessing language and executive abilities (Shao et al., 2014). This is why we decided to label this component *language-executive*.

The third component is composed of reading, dictation, and semantic judgment tasks. Dictation and reading tasks involve the capacity of transcoding print-to-sound (reading) and sound-to-print (dictation). In the reading task, participants must read out loud words and sentences. In the dictation task, participants must listen to words and sentences and then produce their written representation. Both processes are related to our ability to transcode a written input to an oral output and an auditory stimulus to a written output, respectively. In the semantic judgment task, participants must indicate if a pair of words is semantically related and then justify their answer. Consequently, we named this component *transcoding and semantics*. Unlike semantic tasks, reading and spelling to dictation tasks are also associated with encoding and decoding abilities. That is why it was surprising to find that the semantic judgment task loaded in the same component as reading and dictation tasks. The reading and spelling of regular words engage semantic mechanisms. This may explain the reason that reading, dictation, and semantic judgment tasks have loaded in the same component. We will further discuss this hypothesis later on in the overall discussion section of the article.

The fourth component is composed of indirect speech acts interpretation and metaphors interpretation tasks. Indirect speech acts interpretation involves the ability to identify and explain when a speech is direct (speaker literally means what is said) or indirect (the speaker's intention is not clear). Metaphors interpretation involves the capacity to understand metaphorical sentences. Both tasks demand the interpretation of a non-literal or figurative message. In other words, participants have to figure out what the information actually meant given its context (Pawełczyk et al., 2017). Both tasks involve the pragmatic aspects of language (Asher & Lascarides, 2001; Pawełczyk et al., 2017). Thus, we decided to label this component as *pragmatics*."

To summarize our results, the PCA analysis yielded four language components. The first one relies both on semantics and transcoding abilities. The second one is defined by their language-executive ability. The third one grouped by their common narrative abilities. The fourth one is related to comprehension aspects of language. For Study 2, we verify if the language components described in Study 1 are associated with EF.

Study two: Language components and their association with executive functions

2.1 Introduction

In our first study, we found the following four components underlying language tasks processing: pictorial semantics, language-executive, transcoding and semantics, and pragmatics. In Study Two, we focus on the relationship between these four language components and EF.

As already mentioned, performance on language tasks depends on a combination of linguistic and non-linguistic components (Butler et al., 2014). One largely studied theme in neuropsychology is the relation between language and EF (Mohapatra, 2019). EF are responsible for the capacity to organize our thoughts, reflecting in our language expression and comprehension (Diamond, 2013). EF help us to choose the target word among the competing and irrelevant options while avoiding us to produce wrongful words during speech (Badre & Wagner, 2007). EF can also play a role in sentence comprehension. It helps to monitors and selects the most appropriate response according to context while suppressing competing sentence representations (Mohapatra, 2019).

One comprehensive literature review sought to investigate the influence of EF on language processing in adult language disorders (Mohapatra, 2019). They found that EF components such as switching, cognitive flexibility, inhibitory control, sequencing, working memory, and processing speed were strong associated with the following language aspects: narration, story retelling, conversational discourse, metaphor interpretation, phonological processing, and indirect speech acts (Mohapatra, 2019). Deficits in EF are linked to the production of irrelevant utterances, word-finding problems, and difficulty ordering words and sentences, among other deficits (McDonald et al., 2013).

Recent theoretical models postulate that there are three main executive components: working memory updating, inhibitory control, and cognitive flexibility (Miyake et al., 2000). Working memory can be defined as the temporary storage and manipulation of information when the perceptual information is no longer present (Baddeley, 2003). Updating allow us to continuous monitor and update incoming representations in working memory (Miyake et al., 2000). Inhibitory control can be defined as the ability to deliberately suppress or inhibit the dominant or the automatic response (Diamond, 2013; Miyake et al., 2000). Cognitive flexibility, also known as shifting, can be defined as the cognitive component that allows us to flexibly shift our attention between mental sets, operations, and tasks (Diamond, 2013; Miyake et al., 2000).

In the present study, we focus on two of these main EF: working memory updating and cognitive flexibility. Working memory is a crucial ability to make sense of written and spoken language (Diamond, 2013). For instance, working memory allows us to store and manipulate words and phrases while we identify and interpret phrase structure (e.g. identify the thematic roles on active/passive voice sentences); thus, helping during sentence production and comprehension (Mohapatra, 2019). Working memory is also related to language abilities such as reading (Peng et al., 2018), writing (Capodieci et al., 2019), narrative discourse (Youse & Coelho, 2005), sentence comprehension (Fedorenko et al., 2006), among others. A poor working memory capacity is related to worse decoding ability (i.e. orthography-to-phonology mapping) during reading (Christopher et al., 2012). During spelling, working memory impaired is associated with a higher risk of incorrectly producing a letter in long words (Rapp et al., 2016). It is also related to a longer reaction time during picture naming (Shao et al., 2012), to an increased difficulty to understand and produce more complex sentences (Daneman & Carpenter, 1980; Fedorenko et al., 2006; Just & Carpenter, 1992) and to correctly interpret metaphors (Chiappe & Chiappe, 2007). In addition, it is associated with a decreased ability to establish a consistent connection between sentences and the general topic of discourse, leading to a breakdown of hierarchical discourse organization and disrupted sequential processing (Cahana-Amitay & Jenkins, 2018), among other language impairments.

Cognitive flexibility allows us to monitor and shift strategies, which is an important skill for reading (Butterfuss & Kendeou, 2018), sentence (Goral et al., 2011), pragmatic (Bosco et al., 2017) comprehension, among other language abilities. A poor cognitive flexibility skill is related to lower performance on verbal fluency tasks (Amunts et al., 2020; Fisk & Sharp, 2004; Shao et al., 2014) and sentence comprehension tasks (Goral et al., 2011). Reduced flexibility can lead to an increased difficulty for conceiving alternate meanings during non-literal language interpretation (Champagne et al., 2004). Impaired cognitive flexibility can also impact the recall and integration of content during story narrative (Mozeiko et al., 2011).

As we discussed, language seems to have an intrinsic relationship with EF. Therefore, a better understanding of the interaction between executive and linguistic skills could provide a better understanding of the cognitive processes underlying language tasks (Obermeyer et al., 2020) and could potentially help guide the clinician's choice of tasks. Therefore, the goal of Study 2 is to explore the association between the language groups formed after the PCA in Study 1 and two EF measures, working memory and cognitive flexibility, using a correlation analysis. Previous studies have found an association between cognitive flexibility and verbal fluency tasks and pragmatic tasks. Cognitive flexibility is related to the ability to shift between strategies during verbal fluency tasks (Amunts et al., 2020; Fisk & Sharp, 2004; Shao et al., 2014) and to shift to the non-conventional meaning of utterances during pragmatic interpretation (Bosco et al., 2017; Champagne et al., 2004). There is also strong evidence of a link between working memory and reading (Christopher et al., 2012; Peng et al., 2018; Swanson et al., 2009) and writing performance (Capodieci et al., 2019; Rapp et al., 2016). Working memory is related to the access and monitor of speech-based information during reading (Swanson et al., 2009). During decoding, working memory is responsible for retrieving and maintaining the phonological and orthographic sequences of words, while controlling for irrelevant concurrent information (Capodieci et al., 2019). Working memory is also related to semantic judgment task performance (Martin & Allen, 2008; Obermeyer et al., 2020; Stanley et al., 2017). During semantic judgment tasks, working memory can help to retain online several features while the categorization and semantic judgment processes are being conducted (Koenig et al., 2005). Considering these previous studies, we predict that the cognitive flexibility score will be associated with the language-executive and pragmatic components. We also expect that working memory will be associated with the transcoding and semantics component. We hope that the results of Study 2 will provide further insight into which language tasks are more sensitive to executive processes.

2.2 Methodology

2.2.1 Participants

We include in Study 2 a subset from Study 1, composed of 33 participants, who were administered the Trail Making Task (TMT) and the N-back test, in addition to both language batteries. Only a subset of participants had performed both language battery tasks and the executive tasks. It would be interesting to verify if the language components remain the same in this subset. Unfortunately, this verification is not possible because PCA is not recommended for small samples such as we have for study 2 (Hair et al., 2009; Ho, 2013; Tabachnick & Fidell, 2013). It would have been relevant to include an inhibition measure in our analysis. However, given that this was a retrospective study, we were constrained by the cognitive measures available to us.

Table 5 presents the sociodemographic data of this subset of participants.

Table 5

Sociodemographic data of the participants of Study 2

N	Female Sex N (%)	Years of formal education M (SD)	Age M (SD)	MMSE M (SD)
33	20 (60.6)	14.97 (3.67)	41 (16.25)	28.81 (1.45)

Note. MMSE = Mini-Mental State Examination.

2.2.2 Materials

In addition to the language tasks of Study 1, we also included the following EF measures for the correlation analysis:

The Trail Making Test (TMT) (Reitan, 1992), adapted to Brazilian Portuguese (Zimmermann et al., 2017), is a visuospatial test that assesses cognitive flexibility and processing speed. It has two parts. In part A, participants must draw lines following the increasing order of numbers as fast as possible. In part B, he/she must alternate between numbers and letters, following the increasing order of numbers and alphabetical order. Following Sanchez-Cubillo et al. (2009), we calculated a cognitive flexibility score that minimizes the visuoperceptual and working memory demands of the execution of the TMT task. The score is calculated by subtracting the time (in seconds) of part A from the time (in seconds) from part B. Here is the mathematical formula for the calculation of the score:

$$Cognitive\ flexibility\ core\ =\ Time\ B\ (in\ seconds)\ -\ Time\ A\ (in\ seconds)$$

In this score, a smaller difference in time between parts B and A is associated with better cognitive flexibility. TMT part A is a more automatized process and TMT part B a more controlled one (Sánchez-Cubillo et al., 2009). The cognitive flexibility score allows us to clear the more automated process (part A) from the more controlled process (part B). Thus, if a person takes much longer to execute part B when compared to part A, this difference will not be attributed to a decreased motor or processing speed, but rather to a worsen cognitive flexibility ability.

The N-back Task (Dobbs & Rule, 1989; Nebes et al., 2000) is a test used to measure working memory employing an updating paradigm (Rac-Lubashevsky & Kessler, 2016; Schmiedek et al., 2009). We used the version of the test adapted to Brazilian Portuguese (De Nardi et al., 2013). The test is divided into four conditions, the 0-back, which is the control condition, the 1-back, the 2-back, and the 3-back. In the first condition, participants must repeat the number that they just heard (0-back). In the 1-back condition, participants must repeat the number enunciated one presentation before the current number. For the 2-back condition, participants have to say the number presented two numbers from the present one, and in the 3-back condition, three numbers before the present number. For example, in the 2-back condition, the instructor could say a sequence like "3, 2, 9, 4, 2….", and participants must immediately after the first two numbers answer "none", and right after hearing "9", they should say "3", when hearing "4", answer "2", and so on. For a more detailed explanation of the task see De Nardi et al. (2013).

A trial has a maximum of 10 correct answers and it ends when the participant makes an error. Each condition has two trials, totalizing a maximum of 80 correct answers for the entire task. For working memory performance, we will use the total number of correct responses. This score has been shown to be a good proxy of working memory (Nebes et al., 2000).

It should be noted that we only included a single task to assess each executive component. No single task can measure the integrity of a function, especially complex functions such as EF. However, this is a retrospective study; thus, our analysis is limited to the cognitive measures that are available to us. We believe this analysis is still relevant because it presents a first exploration of the relationship between language components and executive functions. Our findings need to be validated in future studies.

2.3 Procedure and data analysis.

We created one composite score for each PCA component (i.e. pictorial semantics, language-executive, transcoding and semantics, and pragmatics) obtained from Study 1. To that end, we multiplied the scores of the tasks that formed each component. We chose a multiplicative score approach for the computation of composite scores. Multiplicative scores better retain the dimensionality of the scores, present a better test/retest reliability and are more sensitive than the addition of scores (Armstrong et al., 2007; Tofallis, 2014). We used the Pearson's correlation analyses to explore the association between the PCA component composite and the EF scores. We considered a significance level of p <.05.

2.4 Results

Table 6 presents the descriptive analysis of TMT and N-back test. We considered for normalcy a skewness value between -2 and 2 and a kurtosis value between -7 and 7 (Curran et al., 1996). Following this criterion, both tasks are normally distributed.

Table 6.
Descriptive analysis of the executive tasks

	m (dp)	Skewness	Kurtosis
Trail-Making Test	43.05 (9.08)	-0.72	0.51
N-back Test	68.40 (56.25)	1.72	2.87

Table 7 presents the correlation matrix between the language components composite score extracted from Study 1 and the executive scores. The language executive component correlated significantly and negatively with the TMT score (r = -.355, *p* = .043). Higher scores in the language executive component were associated with better cognitive flexibility. The transcoding and semantics composite score correlated significantly and positively with the N-back score (r=.397, *p*=.022). Higher scores in transcoding and semantics were associated with better working memory performance. Both correlations had a medium-size effect (Cohen, 1992). Neither the pictorial semantic nor the pragmatics components were significantly correlated to any measures of executive functions.

Table 7.
Correlations between the language components composite score extracted from Study 1 and the executive scores.

	Pictorial Semantic		Language-Executive		Transcoding and semantics		Pragmatics	
	r	p	r	p	r	p	r	p
Trail Making Test								
Time B-Time A	.045	.48	-.355*	.31	.083	.02	.134	.47
N-back								
Total of correct answers	-.126	.80	.182	.04	.397*	.64	-.129	.46

Note. *Significance level at p<.05

2.5 Discussion

The aim of Study 2 was to verify the association between the language components identified in Study 1 and executive measures. As we predicted, the language-executive component was associated with cognitive flexibility and working memory with the transcoding and semantics component. However, pragmatics was not associated with cognitive flexibility, as we previously predicted.

Better performance on the language-executive component was associated with better cognitive flexibility. As already mentioned, the verbal fluency tasks that composed the language-executive component are well known for assessing executive abilities, especially for their cognitive flexibility demands (Shao et al., 2014). During the task, participants need to focus to select only words meeting the selected criteria, while avoiding repetitions, thus activating cognitive flexibility processes (Fisk & Sharp, 2004; Shao et al., 2014).

Our second finding is the association between the transcoding and semantics component with the working memory score. Better performance on the transcoding and semantics component was associated with better working memory capacity. In the semantic judgment task, participants must keep in mind two words while verifying the existence of a semantic relation (ex. chair and table), thus activating both working memory and semantic processes (Stanley et al., 2017). Regarding the transcoding tasks (dictation and reading tasks), several studies have shown the role of working memory for transcoding a print-to-sound (reading task) and sound-to-print (dictation task) (Peng et al., 2018). A reader must sustain attention and keep the information in working memory to transcode a sequence of printed letters into their corresponding sounds (reading) or a sequence of sounds into their corresponding sequence of letters (spelling to dictation); thus, activating working memory abilities. There are also studies in individuals with dyslexia that show that working memory is a predictor of reading abilities (Berninger et al., 2006; Fostick & Revah, 2018; Knoop-van Campen et al., 2018).

The other two language components (pictorial-semantic and pragmatics) were not associated with EF. This result could indicate that pictorial semantic and pragmatic tasks may be less executive demanding. The pictorial-semantic component was composed of two naming tasks and one auditory comprehension task. Like our study, Shao and colleagues (2012) failed to find an association between picture naming and cognitive flexibility. However, they did find an association between picture naming and working memory, which differs from our results. This difference may be explained by the fact that their study used reaction times and ours the number of correct answers. This study suggests that participants with better working memory abilities were able to answer more quickly because they were able to keep online the specific task demands (Shao et al., 2012).

The relationship between pragmatics and EF is controversial. The lack of association between pragmatics and EF, like the one we found here, is in line with previous studies (Champagne-Lavau & Stip, 2010; McDonald, 2000; Parola et al., 2018). However, other studies found that pragmatics and executive measures, namely working memory, cognitive flexibility, and planning, were associated (Bosco et al., 2017; Champagne et al., 2004; Sponheim et al., 2003). Further studies are needed to establish the role of EF in different pragmatic skills.

To summarize, our findings indicate that the language-executive component was associated with better cognitive flexibility ability and the transcoding and semantics component with better working memory ability. The other two components (pictorial semantics and pragmatics) were not associated with either cognitive flexibility or working memory scores.

3. Overall Discussion

The present study sought to explore how a set of language tasks would group to investigate their underlying cognitive mechanisms. We used a PCA approach. This first analysis revealed four language components: pictorial semantics, language-executive, transcoding and semantics, and pragmatics. These four components accounted for around 53% of the total variance of language performance. Secondarily, we verified the association between these four language components and EF. We found that the language-executive component was associated with cognitive flexibility. As language-executive increased, so did the cognitive flexibility score. Also, the transcoding and semantics component was associated with the working memory score. A higher score on the transcoding and semantics component was associated with better working memory abilities.

Language processing involves many linguistic and non-linguistic cognitive processes and, as such, it is inherently multifactorial. How we interpret language complexity depends on how conceptual and statistical approaches incorporate this multidimensionality. A multivariate approach, such as PCA, presents many advantages (Butler et al., 2014). PCA allows us to identify components that represent the optimal combination of language scores. A combined score reduces measurement noise when compared to individual scores. Therefore, combining test scores can result in statistically improved scores and more reliable measures. Besides, PCA enables us to decompose data tests into their primary underlying components. Multiple abilities are necessary to complete most language tasks. Thus, most language tasks are not a pure measure of a single underlying linguistic ability. The fact that we found four components even using a limited number of tasks highlights the heterogeneity and complexity of language processing.

Previous studies applied multivariate approaches to study language grouping in children (Archibald, 2013; Crockett, 1974), college students (Carroll, 1941), healthy adults (Pineda et al., 2000), post-stroke aphasia (Butler et al., 2014; Fong et al., 2019; Gilmore et al., 2019; Halai et al., 2017; Hanson et al., 1982; Ingram et al., 2020; Jones & Wepman, 1961; Lacey et al., 2017; Mirman et al., 2015; Ralph et al., 2010; Tochadse et al., 2018) primary progressive aphasia (Henry et al., 2012; Hoffman et al., 2017; Ingram et al., 2020; Ramanan et al., 2020) and Alzheimer's disease patients (Marcie et al., 1993). We found some similar language components to these studies, but also some differences.

Our first component (pictorial semantics) is semantic in nature. Another study also found a semantic component similar to ours (Butler et al., 2014). Their component included an auditory comprehension task (i.e. spoken word-to-picture matching) and a naming task. Unlike ours, a synonym task has also loaded in their component. Another study also found a semantics component composed of spoken word-to-picture matching and synonym judgment tasks, besides a non-verbal comprehension picture association judgment task (Mirman et al., 2015). Other study found a component composed of picture naming and single-word comprehension, in addition to semantic verbal fluency (Hoffman et al., 2017). In the case of our analysis, the semantic verbal fluency did not present a high loading in this component. The naming task also appears in a semantics component of another study along with spoken word-picture matching, written word-picture matching and word minimal pairs tasks (Tochadse et al., 2018). In another study, the naming and written naming tasks loaded with object naming, word finding, semantic verbal fluency, sentence completion tasks (Lacey et al., 2017). This component was labelled as word finding/fluency. Through a connected speech task, Marcotte and colleagues (2017) also found a semantics component composed of noun frequency, noun imageability, noun familiarity, noun age of acquisition, besides familiarity and age of acquisition of all words. Other study found semantic components composed of confrontation naming, commands comprehension, word discrimination tasks

(Pineda et al., 2000). These tasks are not part of our study. The results mentioned above show that semantics is one of the most important components for language processing. Therefore, a complete language assessment should include one or more semantic tasks, such as comprehension and picture naming tasks.

Regarding the relationship between pictorial semantics and EF, we did not find an association between this component and EF (working memory and cognitive flexibility measures). Different from our result, other studies found that picture naming tasks were related to working memory (Shao et al., 2012; Sikora et al., 2016; Snowden et al., 2019). However, their study used reaction time as their measure, and ours used the total of correct answers. Working memory was also found to be related to auditory comprehension in post-stroke aphasia patients (Choinski et al., 2020). Like our result, other studies did not find an association between picture-naming and cognitive flexibility (Shao et al., 2012; Sikora et al., 2016)

Our second component, language-executive, is composed of three verbal fluency tasks. Other studies also found an executive component, as we found in our analysis (Butler et al., 2014; Ingram et al., 2020; Ramanan et al., 2020; Tochadse et al., 2018). However, these components were formed of non-linguistic executive tasks, unlike our study that only include language tasks in our PCA analysis. Another study that included verbal fluency tasks found that verbal fluency loaded in an operativeness factor along with the following other variables, such as antonyms, oral spelling, mental calculation, metalinguistic control, error detection, sentence generation, auditory comprehension, and sentence generation (Marcie et al., 1993). Semantic verbal fluency loaded with semantics components (Hoffman et al., 2017; Ingram et al., 2020) and word finding fluency (Lacey et al., 2017).

As expected, we found that the executive component was associated with better cognitive flexibility. Verbal fluency tasks are well known for engaging both linguistic and executive components. To complete these tasks, the participant must maintain focus to only select words that meet the criteria and to avoid repetition. In addition, it is also necessary to flexible shift strategies when the current strategy is no longer fruitful. These processes are linked to inhibitory control, and cognitive flexibility (Amunts et al., 2020; Fisk & Sharp, 2004; Shao et al., 2014). Considering that assessment times are often limited, using tasks that are sensitive to both linguistic and executive skills can be a useful tool for clinical assessment.

Transcoding and semantics, our third component, is composed of reading, dictation, and semantic judgment tasks. Other studies also found a language component linked to transcoding (Crockett, 1974; Marcie et al., 1993), referring to the ability to associate encoded and decoded materials. This component is usually assessed by oral reading and decoding tasks. Different from our results, another study found two separate components for oral reading (word reading; sentence reading) and writing (primer-level dictation; serial writing; spelling to dictation) (Pineda et al., 2000). Reading, dictation, and semantic judgment tasks all engage semantic mechanisms. Indeed, it is well established that the reading and spelling of regular and irregular words uses a lexical route, engaging both phonological and semantic processing (Bergeron et al., 2014; Chapleau et al., 2017; Cherney, 2010; Johansson-Malmeling et al., 2021; Matías-Guiu et al., 2017; Provost et al., 2016; Shim et al., 2012). In the reading and dictation tasks employed in our study, there are regular and irregular words, in addition to nonwords that do not engage semantics. In future studies, it could be interesting to separate these two categories into two different variables (e.g. regular and irregular words from nonwords).

Regarding the relationship of EF, we found that better score on transcoding and semantics components is associated with better working memory capacity. Working memory helps to access and monitor speech-based information during decoding (Swanson et al., 2009). For spelling, working memory is responsible for retrieving and maintaining the phonological and orthographic sequences of words until the word is actually spelled while controlling for irrelevant concurrent information (Capodieci et al., 2019). Working memory also contributes to semantic judgment task performance. It allows us to retain online several features while the categorization and semantic processes are happening (Koenig et al., 2005). As expected, our study found a significant correlation between this component and working memory.

Our fourth component, pragmatics, is composed of indirect speech acts interpretation and metaphors interpretation tasks. No other multifactorial study included pragmatic tasks. Indeed, most language studies chose not to include pragmatic measures, because differences between pragmatics and semantics and grammar are not straightforward (Ariel, 2010).

We did not find that the pragmatics component was associated with working memory and cognitive flexibility. There are conflicting findings regarding the role of EF in pragmatics. Like our study, some studies did not find a link between pragmatics and EF (Champagne-Lavau & Stip, 2010; McDonald, 2000; Parola et al., 2018). However, other studies found that indirect pragmatic utterances were associated with executive measures, such as working memory, cognitive flexibility, and planning (Bosco et al., 2018; Champagne et al., 2004).

Differences in findings across studies may be explained by the choice of tasks employed in each study. For instance, contrary to our findings, other studies also found components linked to syntax (Crockett, 1974; Marcotte et al., 2017). Our analysis included tasks that assessed sentences (e.g. written comprehension, auditory comprehension, dictation, and reading tasks). However, sentences were included together with words. We could not separate the stimuli between words and sentences because they did not have enough score variability when separated. It would be interesting in future studies to study the processing of words and sentences separately to verify if a syntax component would be formed.

It is difficulty to establish if differences in the findings of our Study 1 are due to differences in populations (normal versus clinical) or because the choice of tasks varies considerably among studies. Future studies need to further explore the factorial solution of the MAC and the MTL-BR batteries in pathological language functioning. Future studies could verify if the components we found in Study 1 with normal participants remain the same with people with language difficulties. Regarding the difference in findings in Study 2, one possible hypothesis that may explain the different findings is that the pictorial semantics and pragmatics tasks might be less executive demanding in normal participants when compared to patients with acquired language disorders. In opposition, transcoding (reading, semantic judgment, and dictation tasks) and language-executive (verbal fluency tasks) seem to be executive demanding even in normal subjects. However, this hypothesis needs to be further explored in future studies.

4. Limitations and Future studies

Language is a complex and multidimensional cognitive domain; thus, a large range of tasks are used to assess different aspects of it. Only a limited number of tasks were included in our study. Factor solutions will depend on the tasks that researchers decided to include in their analysis (Halai et al., 2017). We can only speculate what the results would be if a more comprehensive battery of language and cognitive functioning tests were included (Crockett, 1974). Whilst we included a variety of tasks from two of the most widely used language batteries in Brazil, future studies should widen their assessment in order to capture more key linguistic features.

It is also important to consider that both batteries (MAC and MTL-BR) were created to assess patients facing language impairments after suffering a brain injury, such as traumatic brain injury and stroke. These impairments are not usually observed in healthy individuals. Therefore, the difficulty level of each test may not be the most suitable for assessing language performance in healthy adults. This could lead to a ceiling effect problem, thus decreasing task variability and limiting our analysis. Another limitation is the smaller sample size employed for the second objective, which can limit our statistical power (Hackshaw, 2008). It is also important to consider that we only used two executive measures, cognitive flexibility, and working memory. It is possible that if we had included other executive measures, such as inhibitory control, we could have detected additional findings. In addition, we only used one task for each executive measure. Even though the TMT is widely used to assess cognitive flexibility and N-back for working memory, we cannot generalize the performance obtained from a single task to characterize the integrity of these complex functions. We recommend that future studies include a larger number and variety of tasks assessing EF.

Considering that this was an exploratory study, additional work needs to be done to confirm our findings. Moreover, it would be interesting if future studies explore the relationship between the components found in our study and other cognitive components, such as semantic memory and attention.

5. Conclusions

As mentioned earlier, assessment time is often limited; thus, understanding the linguistic and executive mechanisms underlying commonly used language tasks is of the utmost importance. By employing a PCA analysis to explore the key components of commonly used language tasks, our results revealed four core underlying linguistic components. Considering these underlying components can potentially contribute to a more precise language assessment. Clinicians can also use the combined score of components. This method has important advantages when compared if the of single test measures, such as (1) the combination of test scores usually leads to statistically improved and more reliable measures; (2) using PCA, we can decompose the test data into their primary underlying component; (3) we can position individuals' performance within a grad or a multidimensional space (Butler et al., 2014).

In addition, our study shows how working memory and cognitive flexibility play an important role in sustaining the execution of clinical tasks commonly used in the clinical setting. Considering the impact of age and age-related diseases on this function, our discovery suggests that the performance of EF in language tasks should be considered as a factor. Tasks assessing EF should be systematically included in language batteries. We hope that our results can help clinicians to make more informed decisions regarding their choice of language tasks leading to a more time-wise assessment

6. General discussion and final conclusions

Our goal was to explore the linguistic and cognitive mechanisms underlying language tasks. For our first goal, we used a data reduction method, PCA, which allowed us to extract the key language components that best explain the variation found in the data (Butler et al., 2014). This method presents some important advantages that can be useful in research and clinical settings. For example, we can use PCA to identify which tasks tap the same underlying abilities (Butler et al., 2014), as we did in the present study using different language tasks. We can then interpret the underlying mechanisms that are behind different tasks. Understanding the underlying mechanisms of different tasks can lead to a more accurate assessment. Moreover, we can observe the size of the loadings to see to what extent the observed variable is related to each factor (Tabachnick & Fidell, 2013). The higher the loading, the more the observed variable has contributed to forming the component. Thus, we can employ PCA to identify the purest measure of a specific function, which could potentially lead to less data collection required during clinical studies, because clinicians can choose the task that better represents a given underlying construct (Butler et al., 2014).

Our PCA analysis revealed the following four language components: pictorial semantics (e.g. auditory comprehension, naming and written naming tasks) language-executive (unconstrained, semantic and phonological verbal fluency tasks), transcoding and semantics (reading, dictation, and semantic judgment tasks), and pragmatics (indirect speech acts interpretation and metaphors interpretation tasks). These four components accounted for around 53% of the total variance. In addition, we verified if these language components were associated with two executive measures. A higher score on the language-executive component was associated with better cognitive flexibility. Likewise, a higher score on the transcoding and semantics component was associated with better working memory ability.

Our first component, which we named pictorial semantics, was composed of auditory comprehension, naming and written naming tasks. Picture naming tasks are useful tools to assess semantic and phonological access in different pathologies such as post-stroke aphasia, semantic dementia, and Alzheimer's disease. Picture naming impairments are a typical symptom of post-stroke aphasia (Herbert et al., 2008; Semenza et al., 2011; Walker et al., 2018). These patients often have a decreased lexical retrieval ability, even when their semantic knowledge is preserved (Walker et al., 2018). Patients with Alzheimer's disease present with an increased difficulty to access the phonological form of words and their meaning due to their progressive loss in semantic knowledge (Moayedfar et al., 2021; Silagi et al., 2015). Alzheimer's Disease patients present more no-responses and errors compared to healthy elders during picture naming tasks (Moayedfar et al., 2021; Silagi et al., 2015). Likewise, patients with the semantic variant of PPA present with a decreased performance during picture naming tasks due to the progressive loss of semantic knowledge (van Scherpenberg et al., 2019). Decreased auditory comprehension of both word and sentences are also common after semantic deficits in patients with post-stroke aphasia (Knollman-Porter et al., 2019; Wiener et al., 2004), especially with low-frequency words (DeDe, 2012) and longer and more complex sentences (Caplan et al., 2007). If we observe the loadings from the PCA, we can observe that the auditory comprehension task had the most contribution to form the pictorial semantics component, followed by naming and written naming tasks. Both naming and auditory comprehension tasks are very much used by clinicians to assess language. However, if for some reason, such as time constraints, clinicians need to choose between these three tasks, auditory comprehension tasks should be privileged for assessing pictorial semantics. Future studies should investigate which of these pictorial semantics tasks is the most discriminatory to differentiate normal and pathological performance in different language disorders, especially post-stroke aphasia.

Our second component, which we named language-executive, was composed of unconstrained, semantic and phonological verbal fluency tasks. This component was also associated with higher cognitive flexibility. Cognitive flexibility allows us to flexibly shift our attention between mental sets, operations, and tasks (Diamond, 2013). Verbal fluency tasks are commonly used to access the phonological and semantic retrieval. Similar to other studies, our results show that verbal fluency also requires cognitive flexibility, which is associated with the ability to shift to another cluster when the employed strategy has been exhausted (i.e. changing from domestic animals to wild animals) (Amunts et al., 2020; Fisk & Sharp, 2004; Shao et al., 2014). It can be used to assess a large set of language disorders in several neurological populations, such as post-stroke aphasia (Bose et al., 2017), Alzheimer's Disease (Henry et al., 2004) and traumatic brain injury (Henry et al., 2004), among others. These patients usually produce fewer words when compared to normal subjects. Given the role of EF in verbal fluency tasks, if a patient presents executive difficulties, this kind of task may not be the most appropriated to assess language performance. All three verbal fluency tasks had similar loadings. Unconstrained verbal fluency had the highest contribution, followed by semantic verbal fluency, and phonological verbal fluency. This indicates that unconstrained verbal fluency should be privileged to assess language-executive performance. Semantic verbal fluency and phonological verbal fluency are widely used tools; however, more studies need to be conducted using unconstrained verbal fluency. Future studies should investigate each of the verbal fluency tasks is the most discriminatory to identify executive dysfunction in different pathologies. Several studies were already conducted comparing the semantic and phonological fluency; however, no study compared unconstrained verbal fluency to other verbal fluency tasks. One study found that semantic fluency was the better discriminant between Alzheimer's Disease patients and normal control subjects when compared to phonological and supermarket verbal fluency tasks (Monsch et al., 1992). Another study also found that semantic verbal fluency was the best for discriminating patients with post-stroke aphasia and normal control subjects when compared to action and phonological verbal fluency tasks (Faroqi-Shah & Milman, 2018). One more study found that semantic verbal fluency was the better discriminant between traumatic brain injury patients and normal control subjects when compared to phonological verbal fluency task (Kavé et al., 2011).

Our third component, which we named transcoding and semantics, was composed of reading, dictation, and semantic judgment tasks. Higher scores in this component were associated with higher working memory scores. Reading difficulties is a common symptom of post-stroke aphasia. These patients can present an increased difficulty to read words accurately and fast. This difficulty usually varies with the severity of the disease and it is often worse with nonwords when compared to real words (Brookshire et al., 2014). Spelling impairments are also commonly reported in patients with post-stroke aphasia. Common spelling errors include omissions, substitutions, and additions of letters (Johansson-Malmeling et al., 2021). Most comprehensive aphasia batteries include reading and spelling tasks (Friedman & Lott, 2015). The third task that composed this component was the semantic judgment task. Traumatic brain injury (Brown et al., 2015) and Alzheimer's Disease patients (Hornberger et al., 2009) show lower performance in this kind of task when compared to normal subjects. The task that had the largest contribution to form the transcoding and semantics component was the reading task, followed by semantic judgment and the dictation task. Therefore, reading tasks should be privileged for assessing transcoding, and its relationship to semantics should also be taken into consideration. As our results demonstrate, semantic judgment, reading and writing tasks are associated with working memory. Other studies have shown the role of working memory in reading and writing (Capodieci et al., 2019; Peng et al., 2018; Stanley et al., 2017; Swanson et al., 2009), besides the relationship of working memory and semantic judgment task (Stanley et al., 2017). Working memory helps the decoding of words during reading by accessing and monitoring speech-based information (Swanson et al., 2009). During spelling, working memory helps by retrieving and maintaining the phonological and orthographic sentences of words while the word is being spelled (Capodieci et al., 2019). For the semantic judgment task, working memory allows the two words to remain online while the participant activates semantic processes to analyze if there is a similarity between both words (Stanley et al., 2017). Knowing these associations can be useful when planning an assessment. For example, it can be important to add a working memory task when assessing patients with reading or writing impairments, or semantic disorders. This can also be useful when preparing a treatment plan. For example, clinicians could plan a treatment that targets working memory, in order to improve working memory performance, but also to transfer this improvement to reading and writing performance as a consequence (Majerus, 2018). If the goal is to investigate only reading and spelling skills, it can be interesting to apply nonwords that do not depend on semantics. Our reading and dictation tasks included both real and nonwords. We decided to include both together in our analysis because they did not have enough variability when separated. Future studies should consider separating real and nonwords into two different variables.

Our fourth component, which we named pragmatics, was composed of indirect speech acts interpretation and interpretation of tasks. Pragmatic impairments are a common symptom of traumatic brain injury and right-hemisphere damaged patients. These patients present an increased difficulty to interpret nonliteral messages, such as indirect speech acts and metaphors. Pragmatic deficits can appear as a difficulty to interpret other people's intentions during conversations or watching television or to convey to others one's own intentions (Lehman Blake et al., 2013). Right hemisphere patients are also more likely to interpret the metaphor using their literal meaning rather than the conventional metaphorical interpretation (Lundgren & Brownell, 2016). Both indirect speech acts interpretation and metaphors interpretation can be used to assess pragmatic performance. Indirect speech acts interpretation had the largest contribution to form the pragmatics components. Therefore, if the main goal is to assess pragmatics, the indirect speech acts task should be privileged.

A study using a different kind of multicomponent analysis, a hierarchical cluster analysis, and the MAC language battery (Joanette et al., 2004) found four language clusters after a right hemisphere stroke (Ferré et al., 2012). The first cluster is characterized for global and massive impairments in most of the tasks (conversational discourse, metaphors interpretation, unconstrained verbal fluency, linguistic prosody comprehension and repetition, emotional prosody repetition and production, semantic judgment). The second cluster presents mixed deficits (conversation, linguistic prosody, repetition, narrative discourse, retelling, semantic judgment). The third cluster presenting only conversational discourse disorders and emotional prosody production. Finally, the fourth cluster showing no communication impairments. Given the differences in analyses and population, our components were not similar to the clusters found in this study. It could be interesting if future studies test if the same components would be found in different language pathologies, such as post-stroke aphasia, traumatic brain injury, Alzheimer's Disease, primary progressive aphasia, among others.

In the present study, we found that language involves many linguistic-cognitive processes. As such, language is inherently multifactorial. Currently, there is an increased number of tasks developed and adapted to assess a variety of language abilities. The fact that we found four components even using a limited number of tasks highlights the heterogeneity and complexity of language processing. A comprehensive language assessment provides information on what mechanisms are impaired or spared. This information guides clinicians to formulate a treatment plan. However, as already mentioned, length assessments are not always possible due to time and cost, besides being stressful to patients. Therefore, identifying the most sensible tasks is of utmost importance.

Language tasks rely not only on heterogeneous language processing but they rely also on other cognitive processes, such as cognitive flexibility and working memory, as shown by our results in Study 2. If clinicians want to assess a given language component, they should know the implication of other cognitive functions in the array of tasks available to assess that language component is able to target the main deficits. For example, it is important to consider that reading and dictation tasks involve mainly transcoding mechanisms but it is also associated with working memory or that cognitive flexibility is necessary to perform verbal fluency tasks.

Some limitations need to be considered when analyzing our results. We only included a limited number of tasks in our study. Many other language tasks exist to assess different components of language. It is only possible to speculate what the results would be if we had included other language and cognitive functioning tasks (Crockett, 1974). Another factor to consider is the fact that both batteries employed in our study (MAC and MTL-BR) were created to assess patients facing language impairments after suffering brain damage, such as traumatic brain injury and stroke. However, the participants in our studies were healthy individuals. It is thus possible that the difficulty level of each task may not be the most suitable for assessing language performance in healthy adults. This could lead to ceiling effects, thus decreasing task variability and limiting our analysis. For Study 2, a small sample size was employed, which could limit our statistical power (Hackshaw, 2008). In addition, our analyses only employed two executive measures, cognitive flexibility, and working memory. Future studies with larger samples should further investigate the association between language components and EF of Study 2. If other executive measures, such as inhibitory control, had been included, we might have detected additional associations between language components and EF.

Furthermore, we only used one task for each executive component. One single task is not capable to assess the integrity of such complex cognitive functions. Therefore, future studies should include a larger number of tasks assessing cognitive flexibility and working memory.

Considering that this was an exploratory study, additional work needs to be done to confirm our findings. Future studies could include even a larger number of tasks assessing other language components. In addition, it can be useful to test which task of each component is the most discriminatory to different language pathologies. Moreover, it would be interesting if future studies explore the relationship between the components found in our study and other cognitive components such as attention and semantic memory. We hope our findings help to further elucidate the linguistic and executive mechanisms of commonly used language tasks, contributing to a more precise language diagnosis.

7. References

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Appendices

Appendix A.

Description of the selected language tasks from the MAC battery.

Task	What is assessed	How it is assessed	Maximal punctuation
Metaphors interpretation	The ability to understand metaphorical language	Participant must explain the meaning of six metaphorical sentences (three new or unconventional metaphors and three idiomatic expressions).	12 points for explanation (0, 1 or 2 points each)
Unconstrained Verbal Fluency	The ability to explore the lexical-semantic memory with no category restriction	Participants must evoke as many words as possible, without a priori criteria, over 150 seconds.	Does not apply

Semantic Judgment	The ability to identify semantic relationships between words	Participants must indicate if a pair of words are semantically related (ex. chair and table). If there is a semantic relation, the participant must justify its answer.	6 points for identification (1 point for) each and 3 points for each explanation (0, 1, or 2 points each)
Narrative Discourse	The ability to synthesize and infer information, in addition to the capacity to understand a story	Participant must recall after each paragraph as much as information as possible from a three-part history.	11 points for the recall of main ideas; 17 points for recall information; 12 points for text comprehension
Indirect speech acts interpretation	The ability to understand speech acts according to the situational context	Participants must identify and explain when a speech is indirect (the speaker's intention is not clear) or when it is direct (speaker literally means what is said).	12 points for an explanation (0, 1, or 2 points for each)

Appendix B.

Description of the selected language tasks from the Montreal-Toulouse battery.

Task	What is assessed	How it is assessed	Maximal punctuation
Automatic speech	The ability to evoke automatisms	Participant must evoke automatisms such as numbers, days of the week, and the birthday song	6 points for phonemic errors; 6 points for omissions
Auditory comprehension	Spoken word and sentence comprehension	Participants must identify images that represent words and phrases (both simple and complex) from auditory input.	5 points for words (1 for each) 14 points for phrases (1 for each)

Written comprehension	The ability to identify images corresponding to words and written sentences	Participants must identify images corresponding to words and phrases (both simple and complex) from visual input.	6 points for words (1 for each) 8 points for phrases (1 for each)
Dictation	The ability to understand auditory stimulus and search the corresponding written representation	Participants must listen to an auditory stimulus and then search for the corresponding written representation, including regular, irregular, foreign words and non-words and 1 sentence	9 points for words (1 each); 13 points for sentences (1 point for each word written correctly)
Reading	The ability to recognize letters and produce the appropriate phonological sounds	Participants must read out loud 12 words (among regular, irregular, foreign words and non-words) and 3 sentences.	12 points for words (1 point for each) 21 points for sentences

			(1 point for word)
Semantic verbal fluency	The ability to produce spontaneous words within a sematic category	Participants must evoke as many animals as possible, over 90 seconds.	Does not apply
Naming	The ability to name images corresponding to nouns and verbs	The participant must identify and name pictures of 12 nouns and 3 actions (verbs).	30 points (0, 1, or 2 for each answer)
Phonological verbal fluency	The ability to produce spontaneous words within a phonological category	Participants must evoke as many words beginning with the letter M as possible, over 90 seconds.	Does not apply

Written naming	The ability to identify and indicate figures referring to nouns and three actions	Participant must identify and indicate the right figure of 12 nouns and three actions (verbs).	30 points (0, 1, or 2 for each answer)