

UNIVERSIDADE DE LISBOA



FACULDADE DE CIÊNCIAS  
FACULDADE DE LETRAS  
FACULDADE DE MEDICINA  
FACULDADE DE PSICOLOGIA

**Semantic Representation and Semantic Control:  
Evidence from The Camel and Cactus Test**

Maria Sara Francisco Ferreira de Almeida Ribeiro

**Mestrado Ciência Cognitiva**

Dissertação orientada por:  
Professora Doutora Ana Luísa Raposo  
Doutor José Fonseca



## Acknowledgements

To professors Ana Luísa Raposo and José Fonseca, the advisors of this dissertation, for all the support, help, availability, patience, constructive comments and, above all, the kindness with which they guided their orientation.

To my family, for supporting me in the path that I have chosen, and pushing me to always go further.

A very special thank you to all my colleagues and friends from the Cognitive Science course, for their time, care, endless nights of study and “paper club meetings” that I will take in my heart forever, and without whom these past few years would certainly not have been the same. I also wish to thank in particular Alberto Colombo, Alejandro Ruiz Rodriguez, Beatriz Lopes and Olivia Pinto for their unwavering support, friendship, and encouragement in all that has preceded this point.

Finally, I want to extend a warm note of appreciation to all the participants of this study, whose time and effort have made this dissertation possible, to the Faculty of Psychology of the University of Lisbon for the access provided to all the equipment, to Joana Almeida for her invaluable help in the data gathering portion of this study, and to the Faculty of Sciences of the University of Lisbon, my alma mater, that I leave with a twinge of sadness and many years of fond memories behind me.



## Abstract

Semantic memory and its breakdown is a fundamental field of cognitive science, merging theoretical models of semantic cognition, with its clinical implications in neural degradation and cognitive deficits, and thus bridging the areas of cognitive psychology and neuroscience. The Control Semantic Cognition framework has proposed that effective semantic cognition comprises representation and control processes (Patterson et al., 2007). This study aims to investigate the extent to which a widely used neuropsychological test of semantic impairment – the Camel and Cactus Test (CCT) – enables to differentiate between these two semantic functions. To address this issue, we collected, in a group of healthy young participants ( $n = 100$ ), a set of measures that index the representation and control demands of the CCT items. Then, we analyzed the performance of patients with stroke aphasia ( $n = 82$ ) as well as control groups ( $n = 158$ ) in light of the acquired measures. The findings confirm that the CCT items vary in representation and control requirements. Moreover, patients with stroke aphasia revealed worse performance for items with greater semantic control demands. Results argue in favour of the CSC framework by providing support for the specific impairment in semantic control in patients with stroke aphasia. They also demonstrate that the CCT is a useful tool to identify semantic control deficits. Semantic cognition is a complex cognitive process dependent on the proper interaction of the representation and control systems, the individual measure and distinction of which proves to be of paramount importance, in both clinical and investigation environments.

*Keywords:* Semantic Memory, Semantic Representation, Semantic Control, Stroke Aphasia, Camel and Cactus Test

## Resumo Alargado

Segundo a proposta de Tulving (1972), a memória humana divide-se em memória de curto e longo prazo, com esta última a subdividir-se ainda em memória explícita (ou declarativa) e implícita (ou não declarativa). A memória explícita refere-se ao tipo de recordação consciente a partir da qual se podem extrair conhecimentos específicos, seja de natureza semântica ou episódica – como saber que Paris é a capital de França – enquanto a memória implícita diz respeito ao tipo de recordação inconsciente, muitas vezes descrita como memória procedimental, contendo conhecimento de uma qualidade motora – como a habilidade física de andar de bicicleta. Como parte da memória explícita, a memória semântica coloca um mecanismo essencial de apoio à capacidade de interagir com o ambiente que nos rodeia e agir de forma propositada em relação ao significado dos conceitos e ao seu contexto geral, em vez de simplesmente as suas características superficiais (Lambon Ralph & Patterson, 2008). A memória semântica e a sua degradação são um campo fundamental da ciência cognitiva, fundindo modelos teóricos de cognição semântica, com as suas implicações clínicas na degradação neural e nos défices cognitivos, associando desta forma as áreas da psicologia cognitiva e da neurociência. Em diversas situações do dia-a-dia, estamos sujeitos ao uso do conhecimento semântico não só para produzir e compreender a linguagem, mas também para apoiar muitos outros comportamentos não-verbais baseados numa miríade de conhecimentos previamente recolhidos. Estes conhecimentos são relativos não apenas à natureza do comportamento em si, mas também à natureza dos muitos conceitos de onde deriva, e as interações entre eles.

O modelo teórico designado por Control Semantic Cognition (CSC framework) propõe que uma cognição semântica eficaz requer processos de representação e de controlo semânticos (Patterson et al., 2007). A representação semântica codifica o conhecimento de conceitos através da aprendizagem de relações sobre o mundo que nos rodeia. Informação sobre estas relações é recolhida através de vários tipos de fontes sensoriais, motoras e linguísticas de informação, e formam a nossa representação cognitiva interior de qualquer conceito particular. A representação semântica funciona, assim, como um armazenamento de informação associativa e enciclopédica sobre conceitos, e a sua interação com o mundo em geral, consistindo das suas qualidades e atributos abrangentes, bem como das características idiossincráticas que definem e identificam estes conceitos. O controlo semântico, por outro lado, constitui a capacidade de selecionar informação pertinente e discernir entre características relevantes e irrelevantes de um conceito, em qualquer circunstância específica, inibindo assim informações irrelevantes para qualquer tarefa específica. O seu bom funcionamento permite a seleção de associações significativas na presença de ruído representativo. Por outras palavras, permite a identificação de relações adequadas entre conceitos e ajudas anteriormente estabelecidos na formação da resposta adequada relativamente a uma determinada tarefa. Esta capacidade de recuperação flexível é fundamental para a nossa compreensão dos eventos, uma vez que um conceito particular pode assumir uma variedade de propriedades e associações dependendo das circunstâncias ou contexto em que está sendo recuperado (Jefferies et al., 2020).

O presente estudo tem como objetivo investigar se um teste neuropsicológico amplamente utilizado para testar défices semânticos – o Teste do Camelo e do Cacto (CCT) – permite diferenciar entre estas duas funções semânticas. O CCT tem como base um outro teste previamente concebido, e igualmente não verbal, frequentemente utilizado para avaliação de capacidade semântica em casos de afasia, agnosia e demência, denominado Teste das Pirâmides e Palmeiras (PPT), em que são mostradas representações minimalistas de objetos familiares, de forma a provocar demonstrações não verbais de conhecimento semântico. O teste é composto por 52 itens, cada um composto por uma imagem-alvo (e.g., uma pirâmide), juntamente com um conjunto de 2 imagens interrelacionadas (e.g., um pinheiro e uma palmeira), a partir do qual os participantes foram chamados a escolher aquele que mais intimamente associado ao alvo (Howard et al., 1992). O Teste de Camelo e Cacto foi então desenvolvido com o objetivo de aumentar o grau de dificuldade e especificidade de cada item relativamente ao PPT. O número total de itens foi alterado de 52 para 64 e o número de alternativas apresentadas para cada um dos objectos-alvo aumentou de 2 para 4. Os participantes são agora apresentados uma imagem-alvo (e.g., camelo) e convidados a escolher de um conjunto de outras 4 fotografias (e.g., cacto, árvore, girassol, rosa) a que mais estreitamente se associa com o alvo (e.g., o camelo vai com o cacto porque ambas são encontradas no deserto). Assim, para além da resposta correta, foram incluídos 3 objetos de distração para dispersar a associação automática do participante. No caso da população portuguesa em particular, foi recentemente estudada e concebida uma adaptação cultural do CCT, investigando associações ambíguas, pouco claras ou de outra forma obscuras na versão original do teste, podendo revelar-se inadequadas para esta população em particular. Da mesma forma, foi também executada uma normalização das pistas visuais utilizadas no teste, de forma a uniformizar os itens e a remover fontes adicionais de erro (Fonseca et al., 2016). Apesar da sua clara capacidade de diagnóstico de deficiências semânticas generalizadas, ainda não é claro se o Teste de Camelo e Cacto será suficientemente refinado para fazer a distinção entre perda de representação semântica ou perda de controlo semântico.

A fim de proceder a uma avaliação aprofundada das capacidades do teste, o estudo seguinte centra-se numa análise item-a-item dos diferentes componentes do teste no que diz respeito a um conjunto de fatores que definem graus de dificuldade tanto para a representação semântica como para o controlo. Para isso, recolhemos, num grupo de participantes jovens e saudáveis ( $n = 100$ ). A estes participantes foi pedido que avaliassem cada item do teste de acordo com um conjunto de medidas que refletem as exigências de representação e de controlo dos itens do CCT. Seguidamente, analisámos o desempenho de pacientes com afasia por acidente vascular cerebral ( $n = 82$ ), bem como grupos de controlo ( $n = 158$ ), à luz das medidas adquiridas pelos participantes saudáveis. De forma a comparar o desempenho no CCT dos grupos de pacientes com afasia, foi realizada uma análise da variância (ANOVA), relacionando o discurso e tempo pós-início do acidente vascular cerebral, com a proporção de respostas corretas dadas pelos pacientes durante o teste. Para comparar o desempenho dos pacientes com afasia com o desempenho dos restantes grupos, outra ANOVA foi realizada relacionando todos os grupos de participantes (pacientes, idosos saudáveis e jovens saudáveis) com a proporção de respostas

corretas. Uma avaliação mais profunda sobre como o desempenho dos diferentes grupos foi afetado pelas exigências de controlo e representação, foi realizada com base num modelo linear multivariado, em que o desempenho de cada grupo por item foi relacionado com os 3 fatores (dificuldade em rejeição, dificuldade em associação, e co-ocorrência) estabelecidos previamente para cada item.

Os resultados confirmam que os itens do CCT variam em termos de requisitos de representação e controlo. Além disso, os doentes com afasia decorrente de acidente vascular cerebral revelaram um desempenho pior para itens com maior exigência de controlo semântico. Os resultados são consistentes com a CSC framework, fornecendo dados que apoiam um défice específico no controlo semântico em doentes com afasia por acidente vascular cerebral. Demonstram igualmente que o CCT é um instrumento útil para identificar défices de controlo semântico. Esta análise fornece uma base sólida de exploração sobre as características e capacidades do Teste do Camelo e Cacto, não só como uma ferramenta de diagnóstico, mas também como um dispositivo de pesquisa para a natureza da cognição semântica.

A cognição semântica é um processo cognitivo complexo dependente da interação adequada dos sistemas de representação e de controlo, sendo a medição individual e a distinção entre eles de primordial importância, tanto em ambientes clínicos como de investigação.

*Palavras-chave:* Memória Semântica, Representação Semântica, Controlo Semântico, Afasia por Acidente Vascular Cerebral, Teste do Camelo e do Cato

# Table of Contents

<b>LIST OF TABLES</b>	<b>XI</b>
<b>LIST OF FIGURES</b>	<b>XII</b>
1 INTRODUCTION	1
1.1 SEMANTIC REPRESENTATION AND ITS IMPAIRMENT IN SEMANTIC DEMENTIA	2
1.2 SEMANTIC CONTROL AND ITS DEREGULATION IN STROKE APHASIA	4
1.3 TYPES OF STROKE APHASIA	5
1.4 CONTROLLED SEMANTIC COGNITION FRAMEWORK	7
1.5 CAMEL AND CACTUS TEST	10
1.6 PRESENT STUDY	12
2 METHOD	14
2.1 PHASE 1: ITEMS' REPRESENTATION AND CONTROL DEMANDS	14
Participants	14
Materials	14
Procedure	16
2.2 PHASE 2: PERFORMANCE IN STROKE APHASIA	16
Participants	17
Materials	18
Procedure	18
Statistical Analysis	18
3 RESULTS	19
3.1 ITEMS' REPRESENTATION AND CONTROL DEMANDS	19
3.2 PERFORMANCE IN STROKE APHASIA	22
3.3 PERFORMANCE IN STROKE APHASIA AS A FUNCTION OF ITEMS' DEMANDS	23
4 DISCUSSION	25
4.1 ITEMS' REPRESENTATION AND CONTROL DEMANDS	25

4.2	PERFORMANCE IN STROKE APHASIA	26
4.3	PERFORMANCE IN STROKE APHASIA AS A FUNCTION OF ITEMS' DEMANDS	26
4.4	CAVEATS AND FUTURE DIRECTIONS	28
	<b>REFERENCES</b>	<b>31</b>
	<b>APPENDICES</b>	<b>36</b>

# List of Tables

TABLE 1.1. LOCATION AND SYMPTOMS OF THE MAIN TYPES OF APHASIA.....	6
TABLE 3.1. MEAN RESPONSES FOR EACH ITEM. THE SHADED CELLS CONCERN THE HIGHEST DEGREE OF PERCEIVED DIFFICULTY REPORTED FOR EACH QUESTION, AND THE Q1 LOWEST PERCENTAGE OF CORRECT RESPONSES. ....	19
TABLE 3.2. DESCRIPTIVE STATISTICS FOR CORRECT ANSWERS GIVEN BY EACH GROUP OF PARTICIPANTS.....	22

# List of Figures

FIGURE 1.1. SCHEMATIC DEPICTION OF THE CSC FRAMEWORK AND ITS NEURAL COMPONENTS. THE CSC FRAMEWORK PROPOSES THAT THE ATL PLAYS AN IMPORTANT ROLE IN THE STORAGE OF CONCEPTUAL INFORMATION, AND THAT PMTG WORKS IN CONCERT WITH OTHER REGIONS SUCH AS IFG TO SUPPORT SEMANTIC CONTROL PROCESSES. ADAPTED FROM JEFFERIES ET AL. (2020).	9
FIGURE 2.1. EXAMPLE OF AN ITEM PLATE IN THE ORIGINAL FORMAT OF THE CAMEL AND CACTUS TEST, BASED ON THE PORTUGUESE VERSION BY FONSECA ET AL. (2016). THE CAMEL IS THE TARGET OBJECT AND THE FOUR OBJECTS BELOW CORRESPOND TO THE FOUR OPTIONS CONTAINING THE CORRECT RESPONSE AND THREE DISTRACTOR OBJECTS.	15
FIGURE 2.2. EXAMPLE OF AN ITEM PLATE IN THE MODIFIED FORMAT OF THE CAMEL AND CACTUS TEST, BASED ON THE PORTUGUESE VERSION BY FONSECA ET AL., 2016. THE CAMEL AND THE CACTUS ARE PRESENTED. THE NATURE OF THE RELATIONSHIP BETWEEN THE TWO OBJECTS IS LEFT UNDETERMINED.	15
FIGURE 3.1. SCATTERPLOT GRAPHS OF THE REJECTION FACTOR BY PERFORMANCE OF EACH OF THE PATIENT GROUPS	24

# 1 Introduction

Semantic memory is a fundamental cognitive function that refers to our general knowledge about the world, including information about words, objects, facts, and norms, without a required connection to a particular memory of a time and place. Semantic memory poses an essential mechanism supporting the capacity to interact with our environment and act in a purposeful manner relating to the meaning of concepts and their overall context rather than simply their superficial characteristics (Lambon Ralph & Patterson, 2008).

In the course of our life, the use of semantic knowledge is pervasive, not only to produce and understand language but also to support many non-verbal behaviours – an action which at first may seem like a trivial behaviour, is often based on a myriad of previously gathered knowledge pertaining not simply to the nature of the behaviour, but also to the nature of the many concepts from which it derives, and the interactions between them. A textbook example is the action of making a sandwich, which draws on a variety of previously gathered semantic concepts pertaining to the attributes of all of the elements involved in the process (e.g., knowing that a sandwich is a food, that a baguette is a type of bread or how to use a knife to spread butter). Without these previously ascertained concepts, the action is likely to fail, as is often the case with coded algorithms in which these concepts are missing.

Semantic representation refers to the knowledge of concepts through the learning of relationships between worldly data. These relationships are gathered by way of input across various types of sensory, motor, and linguistic sources of information, and form our inner cognitive representation of any particular concept. The notion of concepts plays an essential role in semantic cognition since they prevent the individual to perpetually rediscover or relearn an object's properties with each encounter, and rather generalize its features into an abstract representation of said object (Yee et al., 2018). Identifying an object as a hammer, for example, allows us to deduce its characteristics without a need to relearn the entirety of its conceptual nature. The generalization of this concept would allow an individual to learn its identifying characteristics – namely, that this is an object that is typically made of a hard substance such as metal or wood, that is grasped with one hand in a downwards motion, that it is a tool used to pound nails, and so forth – and extrapolate these characteristics into any other object fitting the “hammer” definition. Any further encounter with a hammer-like object, from this point forward, would return a hammer concept in the brain (Martin, 2016).

Semantic representation, thus, functions as a depository of associative and encyclopaedic information on concepts, and on the world at large as one interacts with it, consisting of the features and attributes, as well as the idiosyncratic characteristics that define and identify these

concepts. Unlike other types of memory, conceptual knowledge is largely shared across individuals in a given culture, even if its extent is dependent on individual experience, that is to say, individuals are likely to have the same representations of concepts even if the scope of knowledge pertaining to any individual concept may vary (Lambon Ralph et al., 2017).

One of the vital purposes of research in the field of semantic cognition is to understand the interaction between the structure of *semantic representation*, i.e., the information we possess about concepts and *semantic control*, that is, the processes that operate on it in order to flexibly retrieve the information required for the task at hand (Grossman & Irwin, 2018). If we want to eat an apple, for example, features such as “is sweet” and “it has seeds” are relevant. However, if we need to hold an apple, those features are less critical and instead we must retrieve information about its weight and shape, which would require semantic control. In the following sections, I will first address semantic representation and semantic control processes, before discussing how they can be tested and disentangled in patients with semantic processing impairments. I will then focus on a widely used neuropsychological test to assess semantic processing in brain-damaged patients – the Camel and Cactus Test – and explore its ability to detect semantic representation vs. semantic control deficits.

## **1.1 Semantic representation and its impairment in Semantic**

### **Dementia**

The classical outlook on semantics proposes an “embodied” view of semantic cognition, drawing conceptual knowledge from a distributed array of sensory input (Barsalou, 1999; Martin, 2007; Pulvermüller, 2005). According to this “distribution-only” view, the meaning of a concept is obtained through links between neural networks representing the idiosyncratic fragmented details of said concept (e.g., shape, colour, sound, linguistic properties, etc), allowing then for all the information about the concept as a whole to be activated and retrieved from the access point of a single modality. The concept “dog”, for example, once retrieved would return all the information stored on the particular concept, such as the general dog-like shape, the barking sound a dog makes, the smell of a dog, the texture of fur, and so forth. These distributed regions, along with the diverse links between them, would constitute the whole semantic network. This idea submits that particular information about different object features may be stored in different regions of the cortex, with studies indicating that the ventral and lateral regions of posterior temporal cortex can be differently engaged depending on the type of information retrieved (Martin et al., 1995).

This view incurs in several obstacles, such as the difficulty found in processing abstract concepts such as “justice” or “truth” with regards to sensory and motor correlates from which to derive a neural link. Furthermore, neuroimaging studies have not yet been able to conclusively

show that sensory and motor activation is essential for computing meaning, since this could instead reflect spreading activation from amodal semantic regions (Jefferies, 2013).

Alternative theoretical accounts of semantic cognition propose that flexible semantic cognition is derived from the interaction of multiple neurocognitive components. There is, however, still some controversy in regard to the functional organization of these components and their interaction in the brain. In response to this, investigators have suggested the existence of so called “convergence zones”, binding the fragmented representations of a concept in multiple regions that are linked together through activation zones. These activation zones would then combine these different, fragmented, types of input into a more abstract, multimodal semantic representation of said concept. The convergence of different types of information could be further linked to several regions distributed across the cerebral hemispheres, such as sounds to language or vision to language (Damasio, 1989; Damasio et al., 1990). These zones would be located along the telencephalon, at varied neural levels, associating cortices of different orders. The location of convergence zones for different entities would show variation between individuals but they would not be placed in a random fashion, with zones that bind features into entities located earlier in the processing streams, and convergence zones that bind entities into progressively more complex events gradually placed more anteriorly in the processing streams. These latter anteriorly placed convergence zones would perform the more extensive integration, while zones in the more posterior cortical brain regions would be more immediately related to the conscious experience (Damasio, 1989).

Evidence for this model is based on data from experimental neuropsychology in patients with focal cerebral lesions, resulting in the loss of semantic information. Notably, deficits in semantic representation often occur as a result of atrophy of the anterior temporal lobe (ATL) (Jefferies & Lambon Ralph, 2006; Patterson et al., 2007; Rogers et al., 2004). Specifically, Semantic Dementia (SD) patients showcase atrophy and progressive degradation of grey matter in the anterior portion of the temporal cortices, most severely affecting the inferior portion of the lateral temporal lobe, typically bilaterally but often asymmetrically (Jackson, 2021; Mummery et al., 2000), associated with a gradual loss of semantic representations. This results in a diminished capacity for evoking the representation of abstract concepts when compared to concrete ones, specific relative to general concepts, as well as less familiar relative to more familiar concepts (Jefferies & Lambon Ralph, 2006). These impairments are observed in every modality, thereby resulting in poor comprehension and lacking production of information across all verbal and nonverbal domains, including spoken and written words, pictures, environmental sounds, smells, and touch (Grossman & Irwin, 2018).

From a research perspective, the specificity of the semantic decline observed with this disorder means that SD offers a neurological model of semantic representation impairment and its effect on cognition without major complications from co-occurring deficits pertaining to other non-semantic function. This provides a unique opportunity for researchers to argue for amodal

semantic representations, as SD seems to challenge the assumption that semantic memory is based on a widely distributed system of modality specific representations (Lambon Ralph & Patterson, 2008).

## **1.2 Semantic control and its deregulation in Stroke Aphasia**

Conceptual representations are thought to interact with control processes in order to focus ongoing retrieval on currently relevant aspects of knowledge. Semantic control portrays the ability to select pertinent information and discern between relevant and irrelevant characteristics of a concept, in any specific circumstance, thus inhibiting irrelevant information for any particular task. Its proper functioning allows for the selection of significant associations in the presence of representational noise. In other words, it allows for the identification of appropriate relationships between previously established concepts and aids in the formation of the appropriate response to a particular task. This capacity for flexible retrieval is shared across both words and objects and is critical to our comprehension of events, as a particular concept can take on a variety of properties and associations depending on the context in which it is being retrieved (Jefferies et al., 2020).

While research on patients with SD has been critical in advancing our knowledge on the role of the ATL in semantic memory, deficits in semantic cognition are more frequently seen following left-hemisphere stroke which results in Stroke Aphasia (SA) (Noonan et al., 2010). Aphasia is an impairment of comprehension or formulation of language, resulting from a breakdown of the two-way translation that establishes a correspondence between thoughts and language (Damasio, 1992). It can be caused by a variety of brain aetiologies; however, the most common precursor of aphasia is cerebrovascular accident or stroke targeting the cortical centre for language (Laska et al., 2001) . The lesions that cause aphasia are usually located in the left cerebral hemisphere, given its dominance for language in both right-handed and left-handed people (Damasio, 1992). The symptoms of aphasia can range from a mild impairment to a complete loss of any fundamental components of language such as semantic, grammatical, phonologic, morphologic, and syntax.

Critically, aphasia is characterized by a lowered ability in the association of connected concepts when presented with distractive information, without impairment in the semantic representation of the concepts themselves (Jefferies & Lambon Ralph, 2006). Patients may have difficulty identifying meaningful relationships between words where they do not share a strong automatic association as well as when required to ignore strong semantic associations that are irrelevant to the task at hand (Jefferies et al., 2020). For instance, in a synonym-matching task, aphasia patients may incorrectly select “major-minor” rather than the correct association “major-important”.

Comprehension impairments are also frequently observed in SA typically alongside other language deficits; in particular, they can be observed in Wernicke's aphasia, transcortical sensory aphasia and global and mixed transcortical aphasia, often associated with prefrontal and temporoparietal damage in the left hemisphere (Berthier, 2001; Chertkow et al., 1997) Patients with damage to the left prefrontal cortex often have difficulty retrieving words in response to specific cues, suggesting that this region plays a crucial role in retrieving lexical and semantic information (Martin & Chao, 2001).

### **1.3 Types of Stroke Aphasia**

Aphasia is typically divided into two distinct subgroups: receptive or fluent aphasia and expressive or non-fluent aphasia (Peristeri et al., 2021). In fluent aphasia, the patient can produce sentences that sound like normal speech, but some of the words are either entirely made-up or have sounds that are not correct. Patients are unable to understand words or recognize auditory, visual, or tactile symbols, caused by a disturbance in Wernicke's area (located at the posterior end of the superior temporal gyrus) whose function is to process visual and auditory information, and it is the centre for comprehension and planning of words. Fluent aphasia disorders include Wernicke's, transcortical sensory, conduction, and anomic aphasias (Le & Lui, 2022).

Patients with Wernicke's aphasia are unable to repeat words and sentences correctly, to assemble phonemes correctly, or otherwise name things properly. The speech, however, is fluent, effortless, and produced at normal or even faster than normal rates. The content of the speech is often unintelligible because of the frequent errors in phoneme and word choice and absence of content words. These patients also present difficulties comprehending the sentences produced by other people (Kertesz, 1993). Unlike Wernicke's aphasia, patients with conduction aphasia seem able to comprehend basic sentences as well as produce intelligible speech. Hinderances are instead observed in their ability to repeat sentences verbatim or even assemble phonemes effectively, as well as their ability to evoke words in a task of confrontation naming, which is also impaired. Conduction aphasia, furthermore, shares with Wernicke's aphasia the inability to repeat, defective assembly of phonemes, and impaired naming ability, but it is distinguished by relatively preserved speech production and auditory comprehension (Acharya & Maani, 2022).

People with non-fluent aphasia, on the other hand, struggle to produce speech, omit function words, and speak in very short sentences. The ability to convey words is impaired, but the understanding and ability to form a concept are relatively preserved. This type of aphasia stems from a disturbance in the left frontal dominant part or frontoparietal area, including Broca's area, located in the inferior frontal region and considered to be the centre for motor execution of speech and sentence formation. Non-fluent aphasia syndromes include Broca, transcortical motor, mixed transcortical, and global aphasia (Le & Lui, 2022).

In Broca's aphasia, there is extensive damage involving not only Broca's area (in the inferior left frontal gyrus) but also the surrounding frontal fields and the underlying white matter and basal ganglia (Damasio, 1992). Patients with global aphasia lose the ability to comprehend and formulate language, with speech reduced to a few words or sentences, without recognition of grammatical words or grammatically elaborate sentences. This type of aphasia displays features of both Broca's and Wernicke's aphasia, with a particularly wide area of injury and severe fluency impairment. Auditory comprehension, much like speech, is restricted to a small number of nouns, verbs, and idiomatic expressions (Damasio, 1992). Unlike all the other types of aphasia, transcortical aphasias preserve in the patient the ability for repeating words. The motor variant usually occurs after damage is sustained in the left frontal cortices above and anteriorly to Broca's area, with a possibility of substantial damage to Broca's area itself being one of the precursors to this type of non-fluent aphasia. The sensory variant, alternatively, is caused by lesions sustained in the temporal or parietal cortices, neighbouring Wernicke's area (Wilkins & Brody, 1970). Mixed transcortical aphasia results from lesions in the association cortex that isolate but spare the left hemisphere perisylvian region including Wernicke's area, Broca's area, and the connections between them. This type of aphasia is characterized by severely diminished quantity of spontaneously generated verbal output, very poor auditory comprehension, and relative sparing of repetition (Kertesz, 1993).

A summary of the main types of aphasia, along with areas of injury and fluency of speech can be found in Table 1.1.

Table 1.1. Location and symptoms of the main types of aphasia.

<b>Type of Aphasia</b>	<b>Discourse</b>	<b>Comprehension</b>	<b>Location of Damage</b>
Wernicke's	Fluent	Impaired	Left temporal (posterior and superior)
Transcortical Sensory	Fluent	Intact or largely preserved	Posterior or inferior to Wernicke's area
Conduction	Fluent	Intact or largely preserved	Left supramarginal gyrus or left auditory cortex
Anomic	Fluent	Intact or largely preserved	Left angular or temporal gyrus
Broca's	Non-fluent	Intact or largely preserved	Left frontal (lower, posterior)
Global	Non-fluent	Impaired	Left perisylvian lesion, or separate frontal and temporoparietal damage
Transcortical Motor	Non-fluent	Intact or largely preserved	Anterior or superior to Broca's area
Transcortical Mixed	Non-fluent	Impaired	Association cortex between Wernicke's and

Type of Aphasia	Discourse	Comprehension	Location of Damage
			Broca's area

The distinct types of aphasia can further present themselves as either acute or chronic aphasias, depending on the time post onset of the event that originated them.

Acute aphasic patients are individuals that have been diagnosed with the condition following a recent stroke and have yet to regain their language abilities (Msigwa & Cheng, 2020). The Stroke Recovery and Rehabilitation Roundtable (Bernhardt et al., 2017) proposed an outline definition for critical timepoints post-stroke, with the acute post-stroke phase spanning from the 1st day to the 6th following months. Acute phases can be further subdivided into hyper-acute, encompassing the first 24 hours post-stroke (a period defined by cell death and hematoma expansion), acute, spanning from 1 to 7 days post-stroke, early subacute, from 7 to 3 months after the stroke, and finally, late subacute, from 3 to 6 months post-stroke. A critical phase of increased endogenous neural plasticity takes place during the early subacute phase, extending in particular over first week until the first month, leading to a greater chance of recovery during this period. A significant improvement in function is also observed past the early and late subacute phases, way into the chronic stages, with chronic and late acute stroke patients regaining more function and reporting less dramatic impairment than patients earlier in the process of recovery.

Patients diagnosed with acute aphasia may either regain semantic capabilities or remain impaired after this period, at which point they are considered to have chronic aphasia. Patients with chronic impairment have gone past the main recovery of function stages, but may still present residual recovery from compensatory mechanisms marked in particular by compensatory reorganization of cognition, even in the absence of further neural recovery (Gerstenecker & Lazar, 2019).

## 1.4 Controlled Semantic Cognition framework

In order to better understand the issue of generalized semantic impairment, the “dual hub” account was originally put forward to explain different types of picture naming errors in patients with aphasia, following damage to different cortical regions, as well as difficulty with object recognition in patients with damage to the temporal lobes.

It suggests that semantic knowledge is represented in two complementary systems, consisting of different hub regions that store taxonomic knowledge of concepts (similarity relations based on shared features, e.g., dog-bear), and thematic information (contiguity relations based on co-occurrence in events or scenarios, e.g., dog-leash) separately (Mirman et al., 2017).

As is the case with the convergence-zone theories, it proposes that distinct areas of the brain capture different combinations of characteristics, relevant to the representation of different kinds of conceptual information, but unlike the previous model, it suggests two main hubs supporting distinct processes required to acquire or retrieve particular aspects of knowledge. The anterior temporal lobes (ATLs) are thought to underpin taxonomic knowledge about objects, extracting perceptual concept features for the purpose of general object processing, while temporoparietal regions such as the angular gyrus (AG) and the posterior middle temporal gyrus (pMTG) support knowledge of thematic associations and events (Schwartz et al., 2011).

According to the dual-hub theory, the ATL system is the dominant one in naming, explaining then why taxonomic errors are predominant over thematic errors in patients sustaining injury to this area. The portrayal of the ATL as the representational hub for object identification is consistent with the location of this area at the end of the ventral visual stream – a neural pathway supporting the transformation of visual perception to conceptual representation – an acutely appropriate location for acquiring information about patterns and physical features, consistent with taxonomical tasks. The pMTG has likewise been demonstrably shown to have a stronger response in thematic decisions when compared to taxonomic ones, as well as with regard to the processing of verbs as compared to nouns, an expected outcome considering the functional nature of the system (Jefferies et al., 2020; Teige et al., 2019). This model fails nevertheless to account for the role of the LPC in the retrieval deficits following stroke aphasia, particularly as it regards the function of the inferior frontal gyrus (IFG), which, in conjunction with the AG and pMTG, seems to carry out a relevant role when it comes to certain types of aphasia (Noonan, 2010).

The Controlled Semantic Cognition (CSC) framework, also known as the “hub-and-spokes” theory (Patterson et al., 2007), is a central theory of semantic processing that accounts for a wide range of evidence, including loss of semantic information in SD and deregulation of semantic control in SA (Teige et al., 2019). For an illustration of the CSC framework and its neural components, see Figure 1.1.

The CSC keeps with previous theories of cognition, by maintaining the notion that multimodal verbal and non-verbal experiences provide the input fragments for constructing concepts, and that these information sources are encoded in modality-specific areas, the “spokes”, which are distributed across the brain. It contrasts the dual hub theory in that it proposes a single transmodal “hub”, situated bilaterally in the ATLs, which mediates the cross-modal interactions for all modality-specific sources of information, meaning it mediates all representations or processes that operate across different kinds of sensory, motor, and linguistic input. The proposed location of this single convergence-zone is key for the cross-modal nature of the hub, since the ATLs have been consistently regarded as the ideal location for forming amodal semantic representations as they have extensive connections with cortical areas that represent modality-specific information (Damasio, 1989; Damasio et al., 2004; Guérit, 2000). In this semantic

central station, associations between different modal attributes (such as shape and name, shape and action, or shape and colour) are processed by a common set of neurons and synapses, regardless of task.

In accordance with the hub-and-spokes theory, we can then anticipate that that damage to the location of the hub (the ATLs) should produce an impairment in semantic representations, independent of the modality of both the input (objects, pictures, words, sounds, etc) and the output (naming an object, drawing from memory, etc). As reported above, this prediction is sustained by what is observed in patients suffering from SD, whose damage to the ATLs results in the projected impact restricted to the representation of conceptual knowledge. Furthermore, SD patients show very high parallels between their scores on different semantic tasks and strong item-specific consistency across modalities, suggesting the loss of the concept as a whole rather than a modality specific deficit (Bozeat et al., 2000; Rogers et al., 2004).

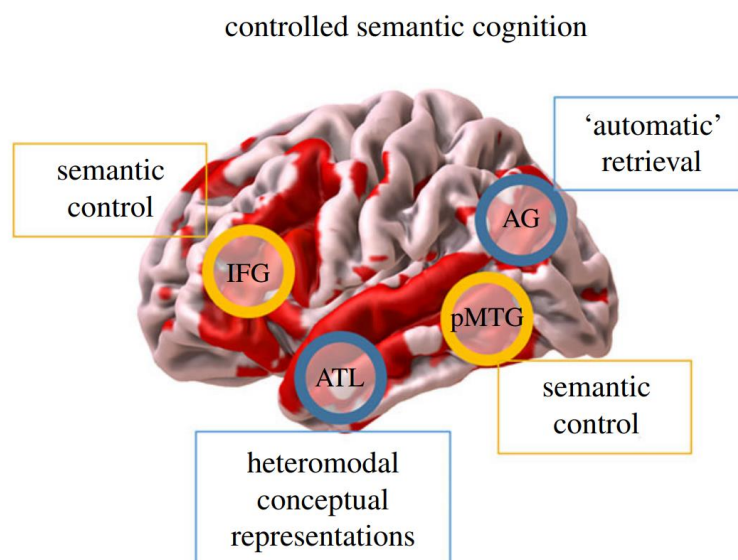


Figure 1.1. Schematic depiction of the CSC framework and its neural components. The CSC framework proposes that the ATL plays an important role in the storage of conceptual information, and that pMTG works in concert with other regions such as IFG to support semantic control processes. Adapted from Jefferies et al. (2020).

As mentioned earlier, effective semantic cognition relies both on the conceptual representation of information and on executive control processes that regulate and shape retrieval within the semantic system, exerting control over these representations in a task specific context. In accordance with the CSC framework, semantic processing emerges from the flexible interaction of crossmodal semantic representations in the ATL, with a semantic control network, which includes the inferior frontal gyrus (IFG) as well as more posterior regions of the middle

temporal gyrus (pMTG) and the angular gyrus (AG) (Davey et al., 2016; Noonan et al., 2013). The model further suggests that the ATL supports patterns of coherent auto-associative retrieval, while semantic control sites respond when ongoing conceptual activation needs to be altered to suit the task or context (Jefferies et al., 2020).

The contrast in impairments observed between SD and SA can be explained by the location of the trauma: whereas SD affects the ATLs and consequently results in the loss of the conceptual representations, SA is a product of a cerebrovascular accident, less likely to occur in the aforementioned areas – the ATLs, which receive two arterial supplies, are rarely damaged in the event of a stroke, in addition to which, the probability of bilateral lesions would be extremely unlikely (Jefferies & Lambon-Ralph, 2006). The location of damage observed in patients with SA is, therefore, consistent with findings pertaining to semantic control. In transcortical sensory aphasia patients in particular, the area of lesion corresponds to the prefrontal cortex which, in healthy volunteers, consistently shows greater activation when semantic tasks require higher levels of control in contrast to those that require less control (Grossman & Irwin, 2018).

## **1.5 Camel and Cactus Test**

The distinction presented in the CSC framework between semantic representation and semantic control processes essential to the effective functioning of semantic cognition, and the impairment of said processes as a result of pathologies of differing nature, requires the accurate measurement and assessment of their individual functioning. The present study intends to closely look at a widely used tool for measuring and assessing semantic processing in patients with neuropsychological damage – the Camel and Cactus Test (CCT) – and investigate the extent to which this test enables to disentangle representation vs. control deficits. This is an important endeavour that would help promote a more fine-grained analysis of each patient’s impairment and hence conceive rehabilitation programs that tackle the specific semantic deficit.

Of note, the most frequently used exams for the evaluation of semantic function are often based on verbal identification of objects, image-word pairing and testing of categorical fluency (Peristeri et al., 2021), all of which have the limitation of being highly dependent on language production and comprehension, and are therefore, highly sensitive and susceptible to failure when in contact with language production disorders. This disadvantage of verbal testing disallows for a thorough assessment of semantic memory on patients who are incapable of producing the necessary verbal cues for concept identification, and calling therefore for the usage of other, non-verbal means for semantic memory examination.

The CCT, first introduced by Bozeat et al. (2000), accounts for one such non-verbal tool consistently used in clinical environments to assess semantic processing. The test draws from a previously designed, and similarly non-verbal test, frequently used in aphasia, agnosia, and

dementia research, called Pyramids and Palm Trees (PPT), in which minimalistic line-drawn representations of familiar objects are shown in order to elicit nonverbal demonstration of semantic knowledge. The PPT consists of 52 items, each comprising a target picture (e.g., a pyramid), along with a set of 2 interrelated pictures (e.g., a pine tree and a palm tree), from which participants are called to pick the one which is more closely associated to the target (in this case, the pyramid goes with the palm tree as they are both found in the desert; Howard & Patterson, 1992).

At the time of its creation, the PPT was one of the only non-verbal examinations of semantic memory reliably utilised in diagnosis of semantic impairment. Among its several advantages, it counted with the requirement for minimal motor functioning (e.g., pointing right or left) which allowed for the possibility of application on individuals with severe motor and verbal impairments. The PPT was often utilized in aphasia research for its practical ability to examine semantic access in spite of phonological or motor deficit, used with both impaired, older populations, and in nonimpaired populations, for the purpose of research in areas such as language processing. Most frequently, however, it was utilized in measuring semantic knowledge of individuals diagnosed with dementia given its nonverbal response format.

In spite of its regular and systematic use in clinical assessment, a thorough examination of its validity has shown that the test lacked reliability (as it regards to test-retest measures), and consistency, indicating that the test may not be an entirely convenient measure for accessing and gaging semantic memory, in its original 2-picture format, and further suggesting that a restructuring of the test would be best indicated in order to screen for item recognition and removal of obscure associations, as well as the measure of item difficulty and reliability for the general population (Klein & Buchanan, 2009).

The CCT was then developed with the objective of upping the degree of item difficulty and specificity. The total number of items was changed from 52 to 64 and the number of alternatives presented for each of the target objects increased from 2 to 4. Participants are presented with a target picture (e.g., camel) and asked to pick from a set of 4 other pictures (e.g., cactus, tree, sunflower, rose) the one that most closely associates with the target (the camel goes with the cactus because they are both found in the desert). Thus, in addition to the correct response, 3 distractor objects were included to disperse the participant's automatic association. The adjustment of the difficulty of the CCT test, has the advantage of allowing for the diagnosis of patients with mild semantic deficits, and permitting for a more accurate assessment of semantic disorder, both in the case of control and representation processes, following its application in aphasic and SD patients, along with other semantic disorders that may result in loss in these systems (Bozeat et al., 2000).

In the case of the Portuguese population in particular, recent efforts have been made in the cultural adaptation of the CCT, screening for ambiguous, unclear, or otherwise obscure

associations in the original version of the test, which may prove inadequate for the Portuguese population (e.g., associating “tennis court” with “strawberries”, which are frequently consumed during the Wimbledon tournament). Also, the Portuguese version is considerably improved (compared to the English or Spanish versions) in regard to the standardization of the visual cues utilized in the test, with all pictures being coloured photographs of real objects/scenes (rather than a mix of photos and drawings, as is the case in previous versions) (Fonseca et al., 2016). Further evaluation of the validity of the updated CCT, and subsequent production of preliminary normative data has provided the basis for clinical assessment of Portuguese patients with suspicion of semantic impairment.

## **1.6 Present study**

In spite of its clear ability in the diagnosis of generalized semantic impairment, it is as of yet unclear if the CCT is fine-tuned enough to make the distinction between loss of semantic representation or loss of semantic control. The goal of the present study is to examine at length the characteristics of the CCT and determine if it is a viable test to differentiate between semantic representation and control dysfunctions. To achieve this goal, the present study comprises two phases.

First, I conducted an item-by-item analysis of the two components of the test by measuring different factors that define the degree of difficulty for both semantic representation and control. For that, young and healthy participants classified each item of the test in regard to its perceived demands in representation and control, defined by a series of questions, in accordance with a previous proposal by Jefferies and Lambon Ralph (2006).

Second, this data provided the basis over which a reanalysis of previously collected data on patients was performed. Specifically, I inspected the extent to which performance of SA patients was lower for the items classified as more demanding in semantic control processes (but not representational processes). SA patients were contrasted to a group of stroke patients with left hemisphere lesion, but without aphasia who do not have control deficits, and hence should reveal a different performance pattern in the CCT (control group 1) as well as with a group of healthy controls with similar age and school years (control group 2). In sum, it is expected that patients suffering from SA, but not other stroke patients without aphasia or older participants, perform more poorly in the items evaluated as more demanding in control skills by healthy young participants.

As it will be further considered in the Discuss section, a full test of the ability of the CCT to discriminate between semantic control and representation processes requires the complementary analysis of performance of patients with representation deficits, like SD. By focusing on data from SA and non-aphasics patients as well as healthy participants, this

dissertation constitutes a first step towards a full understanding of the potential of the CCT in discriminating different semantic processes.

## **2 Method**

This study comprised two phases. The first pertained to the discrete evaluation of the items in the test to determine the semantic representation and the semantic control demands associated with each of the 64 items individually. This phase involved data collection in a group of 100 healthy young adults. The second phase consisted in the re-analysis of the data from patients diagnosed with acute and chronic aphasia in light of the newfound measures of representation and control demands previously established. In addition, two control groups were assessed in this phase: one comprising age matched healthy participants, and another comprising patients with lesions in the left hemisphere that do not result in semantic impairment. The data of the patients and control groups had been previously collected in the context of another project (Fonseca, 2017), and are re-analyzed here in a novel way to address the research question.

### **2.1 Phase 1: Items' representation and control demands**

#### **Participants**

A total of 100 participants (90 female and 10 male) took part in this study, in small groups of 5 participants per session. All were university students from the Faculty of Psychology of the University of Lisbon (FPUL). Volunteer participation in this study was offered in the scope of a first-year class to students of the psychology course in exchange for credit in that same class. As a result, participants were both healthy and young in age, with the vast majority being under the age of 20. All experimental procedures were approved by the Ethics Committee of FPUL. Prior to the start of the session, participants received information about the study and provided written consent for their participation in accordance with the Declaration of Helsinki.

#### **Materials**

Participants were presented with the CCT items in digital format and answered to different questions on an excel sheet, for ease of data recording. Two versions of the CCT were created: one in its original format, with the target object and 4 response options labelled A, B, C and D (Figure 2.1), and another in a modified format, containing the target object and the correct answer (Figure 2.2). Excel answer sheets were created, containing radio buttons for each question. The buttons recorded the participants' answers in a Likert scale, as well as the correct association choice in the test.

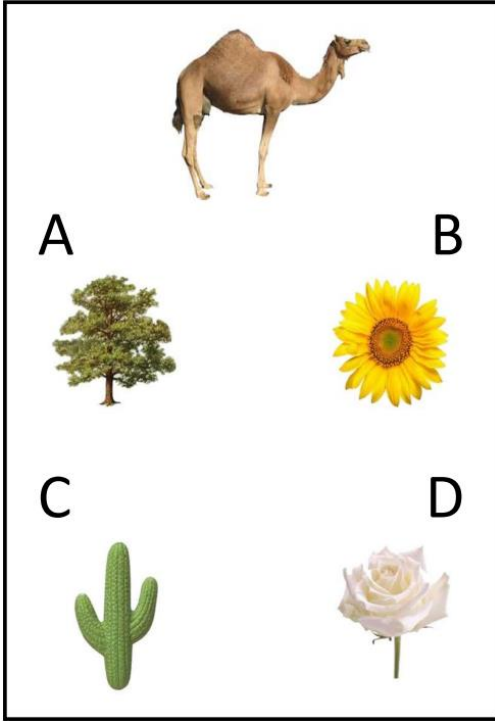


Figure 2.1. Example of an item plate in the original format of the Camel and Cactus Test, based on the Portuguese version by Fonseca et al. (2016). The camel is the target object and the four objects below correspond to the four options containing the correct response and three distractor objects.

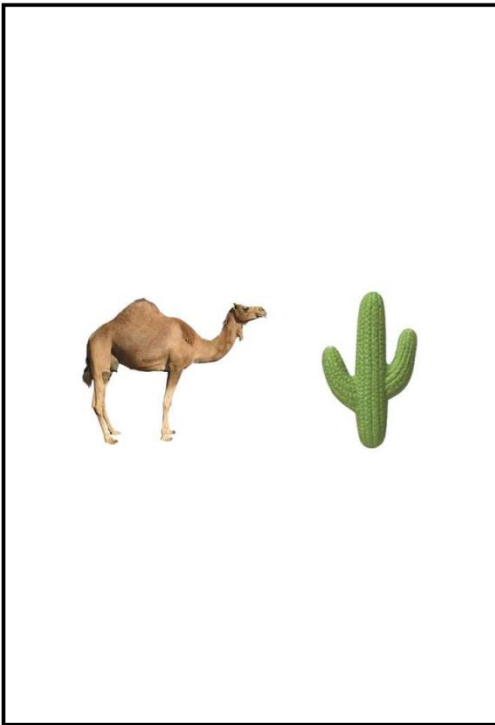


Figure 2.2. Example of an item plate in the modified format of the Camel and Cactus Test, based on the Portuguese version by Fonseca et al., 2016. The camel and the cactus are presented. The nature of the relationship between the two objects is left undetermined.

## **Procedure**

The test was administered at the experimental psychology laboratory of FPUL in small groups of 5 participants per session, Instructions were given both written (in digital format), and orally by the researchers at the start of each session.

For the first task, participants were presented with the CCT in full, containing the four response alternatives. They were asked to select, among the four alternatives, the one that is associated with the target and, subsequently, to rate the degree of difficulty in excluding the distractors for the proper identification of the correct object using a Likert scale from 1 to 5 (where 1 was very easy, and 5 was very difficult). Following Jefferies and Lambon-Ralph (2006), this question is used as an index of the degree of semantic control necessary to respond (i.e., select among competing alternatives, by inhibiting intrusion items).

Next, participants were presented with a modified version of the CCT, containing only the target object and the correct response (e.g., camel and cactus), and questioned on the nature of the association at hand. Participants were also asked to rate how hard it is to identify the nature of the association, using the same 5-point Likert scale. Finally, they were asked how frequently the two items co-occur using a Likert scale (where 1 corresponded to very rarely seen together and 5 to very frequently seen together). In line with Jefferies and Lambon Ralph (2006), these questions are used to index semantic representation demands (i.e., the ease of association/frequency of co-occurrence between two items).

## **2.2 Phase 2: Performance in Stroke Aphasia**

In the second phase of this study, I conducted an analysis of previously gathered data from patients with aphasia as a result of stroke, as well as two control groups pertaining to patients with left-hemisphere stroke without aphasia, and healthy older adults with no brain injury nor aphasia.

Data from these groups was analyzed in light of the collected measures in the first phase of the study in order to inspect if SA patients (but not the control groups) show greater difficulties in items judged by young adults as more demanding in semantic control functions (but show no greater difficulty for items with higher semantic representation demands), as it would be predicted by the CSC framework.

## Participants

A sample of 240 participants (120 female and 120 male) was included in this phase of the study, with ages ranging from 50 to 92 (mean age of 68 years). Participants were from urban and rural backgrounds, with school years ranging from 4 to 21 (mean schooling years was 9). Participants belonged to one of four groups, according to their aphasia diagnosis. Screening, assessment and diagnosis of aphasia were carried out independently of the current study by clinicians at Hospital de Santa Maria, in Lisbon, where participants were recruited.

**Chronic Aphasia Group.** 43 participants (23 female and 20 male) had a diagnosis of chronic aphasia. This group contained patients diagnosed with Wernicke's aphasia (2), Broca's aphasia (8), transcortical sensory aphasia (1), transcortical motor aphasia (8), transcortical mixed aphasia (5), anomic aphasia (11), conduction aphasia (1) and global aphasia (10). Of these, 16 patients were fluent and 27 were non-fluent. Participants were on average 63.3 years old ( $SD=9.8$ ) with 9.6 years of formal education ( $SD=5.4$ ).

**Acute Aphasia Group.** 39 participants (20 female and 19 male) had a diagnosis of acute aphasia. This group likewise contained patients diagnosed with Wernicke's aphasia (6), Broca's aphasia (5), transcortical sensory aphasia (2), transcortical motor aphasia (5), transcortical mixed aphasia (2), anomic aphasia (8), conduction aphasia (3) and global aphasia (8). Of these, 19 patients were fluent and 20 were non-fluent. Participants had a mean age of 67.5 ( $SD=11.4$ ) and 7.7 years of formal education ( $SD=4.7$ ).

**Non-Aphasic Control Group.** The non-aphasic control group comprised 32 patients (12 female and 20 male) sustaining lesions in the left hemisphere, particularly the frontotemporal regions of the brain, without however sustaining any aphasia. All participants presented, therefore, fluent speech. Participants were on average 66.3 years old ( $SD=7.2$ ) and had 10.2 years of schooling ( $SD=5.6$ ).

**Healthy Control Group.** This group was composed of 126 participants (65 female and 61 male), reporting neither brain damage nor aphasia. They were on average 70.3 years old ( $SD=11.8$ ) with 8.8 years of formal education ( $SD=4.8$ ).

The groups did not significantly differ in age, the only exception being that older healthy adults were significantly older than the chronic aphasia group ( $p=.001$ ). Regarding the number of school years, all groups were matched ( $p>.1$  in all cases). The experimental procedures were approved by the Ethics Committee of the Faculty of Medicine of the University of Lisbon (FMUL). Prior to the start of the session, participants received information about the study and provided consent for their participation.

## **Materials**

All participants performed the CCT in its original format in the context of another research project (Fonseca, 2017), and answers were registered by the investigators. The test was administered in physical format.

## **Procedure**

Participants were tested individually in a quiet room of Hospital de Santa Maria. The test was administered orally, with each participant being instructed at the start of the session and answering directly to the investigator. An initial demo of 3 items was carried out, where participants were coached in how to answer, followed by the rest of the 64 items of the test, where the participants were left to answer freely.

All of the groups were presented with the CCT in full and asked to answer which of the four options provided was more closely associated with the target object. Answers were provided by physically pointing to the correct option or orally indicating the response (rather than writing it down) so as to eliminate any requirement other than basic motor or oral skills.

## **Statistical Analysis**

The Statistical Package for the Social Sciences (SPSS, 27.0 version) software was used for the statistical analysis. Results were considered significant if they reached a  $p$  value of .05 or lower.

### 3 Results

#### 3.1 Items' representation and control demands

Data from the first phase of the study can be found in Table 3.1. For the control task, 5 participants were excluded from the analyses: 4 for failure to answer in the allocated places in the answer sheet and 1 for not finalizing the test. For the representation task, 2 participants were excluded for not answering in the allocated places in the answer sheet.

In the semantic control question (i.e., how difficult it is to reject the distractors), the items with the 25% highest values had a mean difficulty of 2.75 ( $SD=0.48$ ) whereas the items with the 25% lowest values had a mean rate of 1.30 ( $SD=1.23$ ). The items judged as more difficult in this question were often also the ones with the lowest number of correct responses ( $M=62.13$ ;  $SD=10.14$ ). As for semantic representation demands, the items with the 25% highest values in difficulty for establishing a target-response association had a mean rate of 2.18 ( $SD=0.49$ ) while the items the 25% lowest values reveals a mean rate of 1.13 ( $SD=0.06$ ). In terms of target-correct response co-occurrence, the 25% of the items that scored lower in co-occurrence had a mean of 2.90 ( $SD=0.54$ ) whereas the items with higher rates scored 4.67 ( $SD=0.12$ ).

Table 3.1. Mean responses for each item. The shaded cells concern the highest degree of perceived difficulty reported for each question, and the Q1 lowest percentage of correct responses.

Item	Target Object	% Correct responses	Difficulty to reject distractors (control)	Difficulty to identify association (representation)	Items co-occurrence (representation)
1	Penguin	97.89	1.22	1.05	4.82
2	Cherry	93.68	1.62	1.39	3.81
3	Rabbit	76.84	2.70	1.59	3.56
4	Ostrich	44.21	3.69	2.43	2.12
5	Frog	93.68	2.03	1.56	4.18
6	Rhinoceros	92.63	1.98	1.57	3.84
7	Pear	91.58	2.07	1.26	4.49
8	Water Can	92.63	1.74	1.68	3.77
9	Airplane	86.32	2.05	1.51	2.84
10	Power plug	83.16	2.41	1.63	4.16
11	Key	95.79	1.35	1.09	4.92
12	Bicycle	87.37	1.64	1.40	4.12
13	Horse	94.74	1.47	1.52	3.48
14	Bus	86.32	2.10	1.59	3.99
15	Eagle	81.05	2.33	1.65	4.14
16	Hatchet	87.37	1.70	1.35	4.20

Item	Target Object	% Correct responses	Difficulty to reject distractors (control)	Difficulty to identify association (representation)	Items co-occurrence (representation)
17	Banana	77.89	2.69	1.96	2.17
18	Dog	91.58	1.48	1.12	4.56
19	Chicken	90.53	2.51	1.92	3.43
20	Stool	55.79	3.16	2.97	2.95
21	Duck	90.53	1.50	1.24	4.45
22	Wrench	93.68	1.57	1.30	4.60
23	Orange	95.79	1.21	1.09	4.76
24	Swan	75.79	2.21	1.71	4.04
25	Turtle	89.47	1.55	1.33	2.92
26	Truck	87.37	1.79	1.54	4.10
27	Suitcase	88.42	1.91	1.49	3.89
28	Basket	48.42	1.97	1.97	3.49
29	Saw	88.42	1.44	1.16	4.46
30	Scissors	68.42	1.46	1.12	4.61
31	Barrel	88.42	1.15	1.11	4.51
32	Hammer	86.32	1.49	1.12	4.73
33	Screwdriver	73.68	2.83	1.96	3.63
34	Toaster	64.21	3.17	2.26	3.84
35	Cat	87.37	1.78	1.27	3.77
36	Comb	84.21	2.09	1.57	4.32
37	Owl	77.89	2.35	1.63	3.47
38	Crocodile	65.26	2.22	1.72	3.15
39	Tiger	69.47	2.54	1.75	4.10
40	Wine Glass	85.26	1.41	1.19	4.69
41	Pliers	83.16	2.15	2.45	2.27
42	Elephant	87.37	1.38	1.43	3.71
43	Strawberry	91.58	1.44	1.30	4.22
44	Kangaroo	90.53	1.51	1.24	2.36
45	Hamster	86.32	1.32	1.30	4.45
46	Apple	72.63	2.00	1.84	3.23
47	Paintbrush	88.42	2.17	2.16	3.09
48	Hairbrush	89.47	1.55	1.24	4.15
49	Pineapple	56.84	2.31	2.05	3.79
50	Tomato	75.79	2.28	1.24	4.69
51	Candle	69.47	2.04	1.26	3.42
52	Trash Can	81.05	1.81	1.47	4.46
53	Squirrel	87.37	1.35	1.18	4.56
54	Piano	96.84	1.26	1.18	4.70
55	Toothbrush	88.42	1.13	1.04	4.84
56	Cow	93.68	1.10	1.09	4.59
57	Motorbike	98.95	1.15	1.33	4.44
58	Monkey	88.42	1.88	1.48	4.42
59	Train	94.74	1.90	1.26	3.88
60	Sled	92.63	1.71	1.52	4.14
61	Camel	90.53	1.45	1.07	4.56
62	Letter	52.63	2.46	1.41	4.54
63	Helicopter	78.95	2.69	2.19	3.74

<b>Item</b>	<b>Target Object</b>	<b>% Correct responses</b>	<b>Difficulty to reject distractors (control)</b>	<b>Difficulty to identify association (representation)</b>	<b>Items co-occurrence (representation)</b>
64	Peafowl	76.84	3.81	3.53	1.99

### 3.2 Performance in Stroke Aphasia

We first compared performance on the CCT of the aphasia patient groups. An analysis of variance (ANOVA) was carried out with discourse (fluent, non-fluent) and time post-onset (chronic, acute) as independent factors and patients' proportion of correct responses on the CCT as the dependent measure. There was a main effect of time post-onset,  $F(1, 78)=9.7, p=.003$ , such that chronic patients showed significantly higher proportion of correct responses ( $M=.75$ ) than patients in the acute stage ( $M=.64$ ). There was no significant effect of discourse,  $F(1, 78)=2.8, p=.101$ , and no significant interaction between discourse and time post-onset,  $F(1,78)=.05, p=.830$ .

To compare performance of SA patients with performance of the remaining groups, another ANOVA was conducted with the 7 groups of participants (fluent chronic, fluent acute, non-fluent chronic, non-fluent acute, patients without aphasia, healthy older, and healthy young) as the independent factor and proportion of correct response as the dependent factor (Table 3.2). A main effect of group was observed ( $F(6, 328)=20.4, p<.001$ ).

Table 3.2. Descriptive statistics for correct answers given by each group of participants.

<b>Group</b>	<b>Mean</b>	<b>Std. Deviation</b>	<b>N</b>
Healthy Young	.83	.17	95
Healthy Older	.87	.08	126
Non-Aphasic Patients	.87	.06	32
Non-Fluent Chronic Aphasia	.73	.17	27
Fluent Chronic Aphasia	.78	.13	16
Non-Fluent Acute Aphasia	.61	.14	20
Fluent Acute Aphasia	.68	.16	19
Total	.82	.15	335

To further investigate the effect of group on the CCT scores, a 2 by 2 post hoc comparison test with Bonferroni correction was performed between the groups. Performance of the acute aphasic groups (both fluent and non-fluent), and of the non-fluent chronic group was significantly lower than performance of both control groups (age-matched and non-aphasic patient group) and of the young participants (all  $p<.05$ ). Hence, the fluent chronic aphasia group was the only group who did not demonstrate significant differences in performance relative to the control groups or the young student group ( $p>.05$  in all cases).

### 3.3 Performance in Stroke Aphasia as a function of items' demands

To evaluate the extent to which performance in the different groups was affected by control demands (difficulty to reject distractors) and representation demands (difficulty in associating the pair and items' co-occurrence), a multivariate linear model was carried out, where performance of each group per item was used as dependent variables and the 3 factors (difficulty in rejection, difficulty in associate, and co-occurrence per item) were introduced as covariates.

The "Rejection" factor, utilized to account for demands of control for each item, showed a significant effect on the performance of all groups of patients with aphasia ( $F > 7.0$  and  $p < .01$  in all cases) as well as performance of young adults ( $F = 16.1$ ,  $p < .001$ ). This factor did not significantly affect accuracy of the non-aphasic patient ( $F = 2.9$ ,  $p = .09$ ) and healthy older ( $F = 3.7$ ,  $p = .06$ ) control groups see Figure 3.1). The "Association" factor, pertaining to one of the measures accounting for the items' representation demands, only significantly affected performance of the chronic aphasic patients, both in the fluent ( $F = 4.5$ ,  $p = .04$ ) and non-fluent groups ( $F = 8.0$ ,  $p = .006$ ). Lastly, the "Co-Occurrence" factor, concerning the other measure of the items' representation demands, revealed, once more, a significant effect on accuracy of the chronic aphasic patients in both the fluent ( $F = 12.6$ ,  $p = .001$ ) and non-fluent groups ( $F = 9.1$ ,  $p = .004$ ), significantly affecting the non-aphasic control group performance as well ( $F = 4.2$ ,  $p = .04$ ).

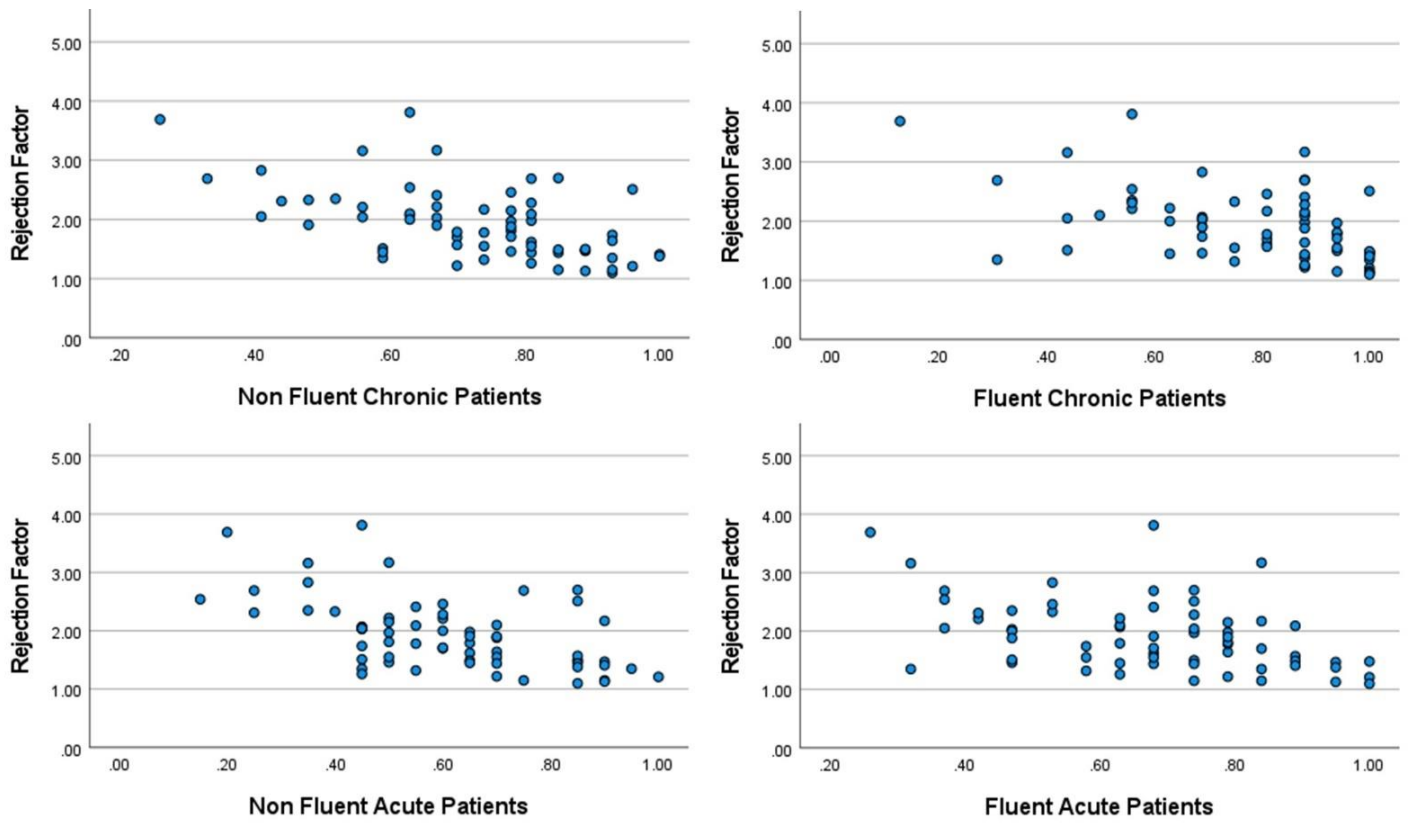


Figure 3.1. Scatterplot graphs of the rejection factor by performance of each of the patient groups

## 4 Discussion

### 4.1 Items' representation and control demands

Phase 1 of the study aimed to develop indexes of semantic control and of semantic representation demands for each item of the CCT. Healthy, young participants were asked to take the test and, following suit, to rate each item on three factors: difficulty to reject distractors (tapping into semantic control), difficulty to associate the targets with the correct answers and rate of items' co-occurrence (which tap into semantic representation).

An analysis of the 25% highest scores showed a clear tendency of some items towards higher demands of control or representation, with a total of 5 items rated highly difficult on all accounts (the Ostrich, Banana, Chicken, Stool, and Peafowl items), 11 items rated as particularly demanding in semantic association and/or co-occurrence but with lower rates in the control index (the Airplane, Horse, Swan, Turtle, Basket, Crocodile, Pliers, Kangaroo, Apple, Paintbrush, and Candle items), and 5 items rated higher in control demands but with lower difficulty in association and co-occurrence factors (the Power plug, Eagle, Tomato, Letter, and Rabbit items). These results were complemented with the proportion of correct answers for each of the items. These data, which helps to characterize each item of the CCT in terms of representation vs. control demands, will be made available to other researchers in the field. These indexes will enable researchers to conduct finer-grained analyses concerning the nature of the CCT items and associated performance, which may be useful not only to assess different semantic impairments but also to design the best rehabilitation and intervention programs.

It is not surprising that some items present an overall high or low degree of difficulty for all factors, given that the test was constructed to differentiate different degrees of impairment (Fonseca et al., 2016). Here, we took a step further and analyzed which specific functions (representation vs. control) impact the difficulty of the items. The results provide compelling evidence that the CCT items vary in these dimensions and as such the test may be a useful tool for assessing semantic representation and control abilities. Nevertheless, two precautions should be considered. First, these ratings were acquired with healthy young adults, and, in the future, similar ratings should be collected with other populations so to ensure greater representativeness. Second, there were cases where participants have judged the items to be very demanding in either control or representation but have successfully answered the test (as is the case with the Chicken and Helicopter items), likewise there were other instances where they rated the items to be low demanding in several or all accounts but have failed to answer correctly (as is the case with the Scissors item). These cases can be indicative of the existence of other associations between the listed options of a particular item (i.e., the scissors could mistakenly be associated with the wood planks as being the only listed material that can't be cut by them). These items deserve a more detailed analysis in the future, so as to understand where the difficulty is coming from and which cognitive processes are relevant.

## **4.2 Performance in Stroke Aphasia**

The analysis of the patient data has revealed a significant group effect on the proportion of correct responses. The aphasic groups (with the exception of patients with fluent chronic aphasia) demonstrated a significantly lower performance on the CCT than the healthy and non-aphasic control groups, as would be expected from the reported impairment. Moreover, the chronic patients answered globally better on the test than the acute patients. This is consistent with expected results, given the timeframe of the disorder on chronic versus acute stroke patients. Patients diagnosed with chronic aphasia have gone through the early and late subacute stroke phases, during which a critical neural restoration period typically takes place following cerebral edema resolution, as well as benefitting from residual recovery from compensatory mechanisms persisting well into the chronic phase (Gerstenecker & Lazar, 2019). It is unsurprising then that patients having gone through that stage of function repair have a better performance than patients on earlier stages of recovery, who would perform significantly worse on account of their much more recent diagnosis.

We did not find a significant effect of discourse, or interaction between discourse and time post-onset, suggesting that, overall, fluent and non-fluent individuals had similar performance in the CCT. This result is surprising since fluent aphasic patients have been characterized by their difficulty in semantic access and production of semantically specific words, whereas non-fluent patients struggle the most with function words (Goodglass & Kaplan, 2001). It would therefore be expected that an effect of discourse be observed, with non-fluent patients performing worse in tasks pertaining to the use of syntactically laden words (i.e., determiners, prepositions, pronouns), and fluent patients performing worse in tasks pertaining to the use of content words (i.e., nouns, verbs, adjectives). In a test such as the CCT, heavily reliant on content words, it would be expected that fluent patients would perform worse than their non-fluent counterparts. A deeper look into different types of aphasia, with larger population sizes per aphasia type, could perhaps better shed light on the effect of discourse on CCT performance.

## **4.3 Performance in Stroke Aphasia as a function of items' demands**

A critical finding concerned the relationship between performance of the different groups and the factors analysed in the phase 1 of this study. Across items, the degree of difficulty in rejecting the distractors (a measure of the items' semantic control demands) was associated with lower performance in all four groups of patients with aphasia. These findings are in line with the hypothesis. They reveal that there are fluctuations in control demands in the items of the CCT and items with increased control demands correspond to those that SA patients struggle to answer the most. These findings corroborate the idea that semantic impairment in SA patients are specifically associated with semantic control deficits, as proposed by the CSC framework

(Jefferies et al., 2020). Moreover, it shows that the CCT is an adequate instrument to assess these difficulties, as long as an index of the items' control requirements is incorporated in the test.

Importantly, the control demands of the items did not impact performance of the two control groups, showing that the effect observed in the aphasic patients was not merely due to ageing or general brain lesion. Indeed, semantic control processes seem to remain intact for both the older healthy population and patients with left hemisphere damage not diagnosed with aphasia. The latter group in particular emerges as a relevant demonstration that semantic control impairment is specifically linked to lesions in language processing areas, and that semantic impairments do not arise in patients with left hemisphere lesions that do not specifically target the language areas.

Surprisingly though, there was a relationship between the items' control requirements and the young participants' performance, with greater control demands being associated with worse performance in this age group. Although unexpected, I advance two potential explanations for this relationship. First, young participants were the only group that performed the CCT test and, simultaneously, evaluated the factors associated with the items' difficulty. The position of the student group as the source of the indexing rates may cause a bias on the group for rating the items according to their own answers and how confident they were on that particular concept association, especially because rating the control demand of the items and performing the test were done at the same time. It is unsurprising then that a correlation arises between one and the other in this group of participants. Second, when considering mechanisms for cognitive control, another possibility presents itself, related to the young age of the student participants. The IFG plays a fundamental role in semantic memory and particularly in semantic control, by supporting our ability to select relevant information among competing alternatives (Binder & Desai, 2011), as required in the CCT. Importantly, the IFG, and the prefrontal cortex more generally, is one of the last brain regions to reach maturation, with development going well beyond adolescence until young adulthood (Barnea-Goraly et al., 2005; Cohen et al., 2016; Pfefferbaum et al., 1994). The majority of the participants in this group were first year university students, under the age of 20. Hence, it is possible that these participants would be subject to underperformance in the control tasks, due to ongoing development of the PFC. Note that performance of the student group was not significantly affected by representational demands (either the association or co-occurrence factors). Representation processes are not linked to PFC activity, but rather rely on the ATL, a region that has a lower age of maturity (Arain et al., 2013; Tanaka, 2012).

Turning to the item's semantic representation demands, consistently with the predictions, there was no effect of representation demands in the performance of the SA patients in the acute stage. This is consistent with previous research in the area (Jefferies & Lambon Ralph, 2006) failing to show a significant effect of object familiarity and frequency in the impairment reported by SA patients. Even though we do not have information about lesion location in these patients, aphasic patients usually do not sustain injuries incurring in the impairment of semantic

representation, such as the ATL region (Jefferies et al., 2020), which presumably explains why there is no significant effect of these factors (semantic association and co-occurrence) on the proportion of correct answers given for each item by SA patients. However, there was an effect of both measures (difficulty of association and item's co-occurrence) in the accuracy of chronic patients. These results may be due to the nature of the impairment of this group of patients. Chronic patients who have maintained a significant impairment in function past the early and late subacute phases of stroke recovery, may have initially incurred in more extensive or severe lesion. In order to ascertain the features of the injury and its subsequent effect on the performance of these patients in tasks of semantic representation, a broader analysis of the severity of aphasia, and both the extent and location of the lesion is necessary.

Similarly, item co-occurrence impacted performance of the control group of patients with left hemisphere lesion but without aphasia. This is an unexpected result, as these patients do not demonstrate language deficits. In order to determine if this is a true result or is simply due to chance (as the  $p$  value was .044), one should complement the analysis of the CCT results with neurological data which will help ascertain whether or not the left hemisphere lesion affected language areas, notably those responsible for semantic representation processes. One possibility is that compensatory mechanisms have come into play counteracting lesion-related deficits (Cabeza et al., 2002). Yet, under certain conditions, semantic variables (such as items' co-occurrence) may still impact performance of these patients.

#### **4.4 Caveats and future directions**

It is important to note some limitations of the present study, namely the lack of specific individual information pertaining to the ages of the participants from the young healthy group, which would allow for further analysis of the development of semantic processing, particularly as it regards to the development and maturation of the prefrontal cortex and its relation to the younger participants' performance in the semantic control tasks.

Likewise, it would be pertinent to look into additional diagnostic measures such as neuropsychological tests and neuroimaging of aphasic patients so that specific semantic deficits could be confirmed with measures other than CCT.

Future studies in the area would also benefit from a closer look into the specific performance of patients diagnosed with different types of aphasia, within the wider scopes of fluency and time post-onset. A larger population of aphasic individuals per aphasia type would allow for a deeper look into the mechanics of semantic control and particularly into the specific performance of different types of aphasia, and effect of discourse, in the CCT.

Importantly, in order to fully understand the scope of the CCT, further analysis of data from patients with representation impairment is needed. The relationship between the items most

consistently failed by SA patients and the semantic control ratings from the healthy participants suggest that the CCT allows the identification of semantic control deficits. However, this is only part of the distinction proposed by the CSC framework. In order to assess if the test is valid for assessing representation impairments, we must conduct a similar study with patients diagnosed with semantic representation deficits (sustaining injury to the ATL), as is the case with SD patients, and inspect the extent to which their accuracy across CCT items covaries with the items' semantic representation (but not semantic control) demands. An item-by-item analysis of answers given by SD patients would permit a full assessment of the test for both control and representation impairments and a full evaluation of its ability to differentiate between the two.

The associations across the items vary in both taxonomic and thematic nature – item number 7, ostrich-penguin, being an example of a taxonomic association, while item number 8, frog-lily pad is an example of a thematic association (Mirman et al., 2017). However, no such distinction has been made when indexing control demands for each of the items. The relationship between highly demanding items for control and the proportion of correct answers given by the SA patients showed great significance, regardless of the thematic or taxonomic nature of the association at hand, suggesting that the difficulty in the control exerted by the different concepts for each of the items is sufficient to anticipate the likelihood of failure in the answers of aphasic patients. It would, nevertheless, be pertinent for future research in this area to take a deeper look at the relationship between location of lesion and the rate of correct answers in items pertaining to taxonomic and thematic relations, as proposed by the dual hub theory (Schwartz et al., 2011).

The present study has been successful in the indexing of control and representation demands for each of the items, as well as in the demonstration that the CCT is a useful tool to identify semantic control deficits. The results argue in favour of the CSC framework by providing evidence for the specific impairment of semantic control, in patients with lesion in the purposed semantic control brain region. This analysis provides a solid base of exploration into the features and capabilities of the Camel and Cactus Test, not only as a diagnostic tool, but also as a research device for the nature of semantic cognition.



## References

- Acharya, A. B., & Maani, C. V. (2022). Conduction Aphasia. In *StatPearls*. StatPearls Publishing.
- Arain, M., Haque, M., Johal, L., Mathur, P., Nel, W., Rais, A., Sandhu, R., & Sharma, S. (2013). Maturation of the adolescent brain. *Neuropsychiatric disease and treatment*, 9, 449–461. doi:10.2147/NDT.S39776
- Barnea-Goraly, N., Menon, V., Eckert, M., Tamm, L., Bammmer, R., Karchemskiy, A., Dant, C. C., & Reiss, A. L. (2005). White matter development during childhood and adolescence: a cross-sectional diffusion tensor imaging study. *Cerebral Cortex*, 15(12), 1848–1854. doi:10.1093/cercor/bhi062
- Barsalou, L. (1999). Perceptions of perceptual symbols. *Behavioral and Brain Sciences*, 22(4), 637–660. doi:10.1017/S0140525X99532147
- Bernhardt, J., Hayward, K. S., Kwakkel, G., Ward, N. S., Wolf, S. L., Borschmann, K., Krakauer, J. W., Boyd, L. A., Carmichael, S. T., Corbett, D., & Cramer, S. C. (2017). Agreed definitions and a shared vision for new standards in stroke recovery research: The Stroke Recovery and Rehabilitation Roundtable taskforce. *International Journal of Stroke*, 12(5), 444–450. doi:10.1177/1747493017711816
- Berthier, M. L. (2001). Unexpected brain–language relationships in aphasia: Evidence from transcortical sensory aphasia associated with frontal lobe lesions. *Aphasiology*, 15(2), 99–130. doi:10.1080/02687040042000179
- Binder, J. R., & Desai, R. H. (2011). The neurobiology of semantic memory. *Trends in cognitive sciences*, 15(11), 527–536. <https://doi.org/10.1016/j.tics.2011.10.001>
- Bozeat, S., Lambon Ralph, M. A., Patterson, K., Garrard, P., & Hodges, J. R. (2000). Non-verbal semantic impairment in semantic dementia. *Neuropsychologia*, 38(9), 1207–1215. doi:10.1016/s0028-3932(00)00034-8
- Cabeza, R., Anderson, N. D., Locantore, J. K., & McIntosh, A. R. (2002). Aging gracefully: compensatory brain activity in high-performing older adults. *NeuroImage*, 17(3), 1394–1402. doi:10.1006/nimg.2002.1280
- Cohen, A. O., Breiner, K., Steinberg, L., Bonnie, R. J., Scott, E. S., Taylor-Thompson, K. A., Rudolph, M. D., Chein, J., Richeson, J. A., Heller, A. S., Silverman, M. R., Dellarco, D. V., Fair, D. A., Galván, A., & Casey, B. J. (2016). When Is an Adolescent an Adult? Assessing Cognitive Control in Emotional and Nonemotional Contexts. *Psychological Science*, 27(4), 549–562. doi:10.1177/0956797615627625
- Chertkow, H., Bub, D., Deaudon, C., & Whitehead, V. (1997). On the status of object concepts in aphasia. *Brain and Language*, 58(2), 203–232. <https://doi.org/10.1006/brln.1997.1771>
- Damasio, A. R., Tranel, D., & Damasio, H. (1990). Face agnosia and the neural substrates of memory. *Annual Review of Neuroscience*, 13, 89–109. doi:10.1146/annurev.ne.13.030190.000513

- Damasio, H., Tranel, D., Grabowski, T., Adolphs, R., & Damasio, A. (2004). Neural systems behind word and concept retrieval. *Cognition*, *92*(1-2), 179–229. doi:10.1016/j.cognition.2002.07.001
- Damasio, A. R. (1989). The Brain Binds Entities and Events by Multiregional Activation from Convergence Zones. *Neural Computation*, vol. 1, no. 1, pp. 123-132, doi: 10.1162/neco.1989.1.1.123.
- Damasio, A. R. (1992). Aphasia. *The New England Journal of Medicine*, *326*(8), 531–539. doi:10.1056/NEJM199202203260806
- Davey, J., Thompson, H. E., Hallam, G., Karapanagiotidis, T., Murphy, C., De Caso, I., Krieger-Redwood, K., Bernhardt, B. C., Smallwood, J., & Jefferies, E. (2016). Exploring the role of the posterior middle temporal gyrus in semantic cognition: Integration of anterior temporal lobe with executive processes. *NeuroImage*, *137*, 165–177. doi:10.1016/j.neuroimage.2016.05.051
- Fonseca, J., (2017). *Avaliação das capacidades cognitivas não-verbais na afasia de etiologia vascular*. Tese de Doutorado, Universidade de Lisboa.
- Fonseca, J., Miranda, F., Moura, O., Raposo, A. and Martins, I., (2016). Camels and Cactus: Preliminary portuguese normative values to a semantic memory test. *Sinapse*, *16*(2), 5-13.
- Gerstenecker, A., & Lazar, R. M., (2019). Language recovery following stroke. *The Clinical Neuropsychologist*, *33*(5), 928-947. doi:10.1080/13854046.2018.1562093
- Goodglass, H., & Kaplan, E. (1972). *The assessment of aphasia and related disorders*. Lea & Febiger.
- Grossman, M., & Irwin, D. J. (2018). Primary Progressive Aphasia and Stroke Aphasia. *Behavioral Neurology And Psychiatry*, *24*(3), 745–767. doi:10.1212/CON.0000000000000618
- Guérit, J. (2000). The temporal lobe and the limbic system, P. Gloor (Ed.). Oxford University Press (1997), 865. *Neurophysiologie Clinique-clinical Neurophysiology*, *30*, 56-57.
- Hoffman P. (2019). Divergent effects of healthy ageing on semantic knowledge and control: Evidence from novel comparisons with semantically impaired patients. *Journal of neuropsychology*, *13*(3), 462–484. doi:10.1111/jnp.12159
- Howard, D., & Patterson, K. (1992). *The Pyramids and palm trees test*. London: Harcourt Assessment.
- Jackson R. L. (2021). The neural correlates of semantic control revisited. *NeuroImage*, *224*, 117444. doi:10.1016/j.neuroimage.2020.117444
- Jefferies, E., Thompson, H., Cornelissen, P., & Smallwood, J. (2020). The neurocognitive basis of knowledge about object identity and events: dissociations reflect opposing effects of semantic coherence and control. *Philosophical transactions of the Royal Society of London. Series B, Biological sciences*, *375*(1791), 20190300. doi:10.1098/rstb.2019.0300
- Jefferies, E., & Lambon Ralph, M. A. (2006). Semantic impairment in stroke aphasia versus semantic dementia: a case-series comparison. *Brain*, *129*(8), 2132–2147. doi:10.1093/brain/awl153

- Jefferies E. (2013). The neural basis of semantic cognition: converging evidence from neuropsychology, neuroimaging and TMS. *Cortex*, 49(3), 611–625. doi:10.1016/j.cortex.2012.10.008
- Kertesz A. (1993). Clinical forms of aphasia. *Acta Neurochirurgica. Supplementum*, 56, 52–58. doi:10.1007/978-3-7091-9239-9\_9
- Klein, L., & Buchanan, J. (2009). Psychometric properties of the Pyramids and Palm Trees Test. *Journal Of Clinical And Experimental Neuropsychology*, 31(7), 803-808. doi: 10.1080/13803390802508926
- Lambon Ralph, M. A., & Patterson, K. (2008). Generalization and differentiation in semantic memory: insights from semantic dementia. *Annals of the New York Academy of Sciences*, 1124, 61–76. doi:10.1196/annals.1440.006
- Lambon Ralph, M. A., Jefferies, E., Patterson, K., & Rogers, T. T. (2017). The neural and computational bases of semantic cognition. *Nature Reviews Neuroscience*, 18(1), 42–55. doi:10.1038/nrn.2016.150
- Laska, A. C., Hellblom, A., Murray, V., Kahan, T., & Von Arbin, M. (2001). Aphasia in acute stroke and relation to outcome. *Journal of Internal Medicine*, 249(5), 413–422. doi:10.1046/j.1365-2796.2001.00812.x
- Le, H., & Lui, M. Y. (2022). Aphasia. In *StatPearls*. StatPearls Publishing.
- Martin A. (2007). The representation of object concepts in the brain. *Annual Review of Psychology*, 58, 25–45. doi:10.1146/annurev.psych.57.102904.190143
- Martin A. (2016). GRAPES-Grounding representations in action, perception, and emotion systems: How object properties and categories are represented in the human brain. *Psychonomic Bulletin & Review*, 23(4), 979–990. doi:10.3758/s13423-015-0842-3
- Martin, A., & Chao, L. L. (2001). Semantic memory and the brain: structure and processes. *Current Opinion In Neurobiology*, 11(2), 194–201. doi:10.1016/s0959-4388(00)00196-3
- Martin, A., Haxby, J. V., Lalonde, F. M., Wiggs, C. L., & Ungerleider, L. G. (1995). Discrete cortical regions associated with knowledge of color and knowledge of action. *Science*, 270(5233), 102–105. doi:10.1126/science.270.5233.102
- Mirman, D., Landrigan, J. F., & Britt, A. E. (2017). Taxonomic and thematic semantic systems. *Psychological bulletin*, 143(5), 499–520. doi:10.1037/bul0000092
- Msigwa, S., & Cheng, X. (2020). The management of subacute and chronic vascular aphasia: an updated review. *The Egyptian Journal Of Neurology, Psychiatry And Neurosurgery*, 56(1), 92-105. doi: 10.1186/s41983-020-00224-w
- Mummery, C. J., Patterson, K., Price, C. J., Ashburner, J., Frackowiak, R. S., & Hodges, J. R. (2000). A voxel-based morphometry study of semantic dementia: relationship between temporal lobe atrophy and semantic memory. *Annals of neurology*, 47(1), 36–45.
- Noonan, K. A., Jefferies, E., Corbett, F., & Lambon Ralph, M. A. (2010). Elucidating the nature of deregulated semantic cognition in semantic aphasia: evidence for the roles of prefrontal and temporo-parietal cortices. *Journal of Cognitive Neuroscience*, 22(7), 1597–1613. doi:10.1162/jocn.2009.21289

- Noonan, K. A., Jefferies, E., Visser, M., & Lambon Ralph, M. A. (2013). Going beyond Inferior Prefrontal Involvement in Semantic Control: Evidence for the Additional Contribution of Dorsal Angular Gyrus and Posterior Middle Temporal Cortex. *Journal of Cognitive Neuroscience*, *25*(11), 1824–1850. doi: 10.1162/jocn\_a\_00442
- Patterson, K., Nestor, P. J., & Rogers, T. T. (2007). Where do you know what you know? The representation of semantic knowledge in the human brain. *Nature Reviews Neuroscience*, *8*(12), 976–987. doi:10.1038/nrn2277
- Peristeri, E., Messinis, L., Kosmidis, M. H., Nasios, G., Mentis, A. A., Siokas, V., Aloizou, A. M., Kotrotsios, A., Andreou, M., & Dardiotis, E. (2021). The Impact of Primary Progressive Aphasia on Picture Naming and General Language Ability. *Cognitive and Behavioral Neurology*, *34*(3), 188–199. doi:10.1097/WNN.0000000000000275
- Pfefferbaum, A., Mathalon, D. H., Sullivan, E. V., Rawles, J. M., Zipursky, R. B., & Lim, K. O. (1994). A quantitative magnetic resonance imaging study of changes in brain morphology from infancy to late adulthood. *Archives of Neurology*, *51*(9), 874–887. doi:10.1001/archneur.1994.00540210046012
- Pulvermüller F. (2005). Brain mechanisms linking language and action. *Nature Reviews Neuroscience*, *6*(7), 576–582. doi:10.1038/nrn1706
- Rogers, T. T., Lambon Ralph, M. A., Garrard, P., Bozeat, S., McClelland, J. L., Hodges, J. R., & Patterson, K. (2004). Structure and deterioration of semantic memory: a neuropsychological and computational investigation. *Psychological Review*, *111*(1), 205–235. doi:10.1037/0033-295X.111.1.205
- Schwartz, M., Kimberg, D., Walker, G., Brecher, A., Faseyitan, O., & Dell, G. et al. (2011). Neuroanatomical dissociation for taxonomic and thematic knowledge in the human brain. *Proceedings Of The National Academy Of Sciences*, *108*(20), 8520-8524. doi: 10.1073/pnas.1014935108
- Tanaka, C., Matsui, M., Uematsu, A., Noguchi, K., & Miyawaki, T. (2012). Developmental trajectories of the fronto-temporal lobes from infancy to early adulthood in healthy individuals. *Developmental Neuroscience*, *34*(6), 477–487. doi:10.1159/000345152
- Teige, C., Cornelissen, P. L., Mollo, G., Gonzalez Alam, T., McCarty, K., Smallwood, J., & Jefferies, E. (2019). Dissociations in semantic cognition: Oscillatory evidence for opposing effects of semantic control and type of semantic relation in anterior and posterior temporal cortex. *Cortex*, *120*, 308–325. doi:10.1016/j.cortex.2019.07.002
- Tulving, E. (1972). Episodic and semantic memory. In Tulving, E. & Donaldson, W. (Eds.), *Organization of memory* (pp. 381–403). New York: Academic Press.
- Wilkins, R. H., & Brody, I. A. (1970). Wernicke's sensory aphasia. *Archives of Neurology*, *22*(3), 279–282. doi:10.1001/archneur.1970.00480210089012
- Yee, E., Jones, M. N., & McRae, K. (2018). Semantic Memory. In Stevens, S., & Wixted, J., *Stevens' handbook of experimental psychology and cognitive neuroscience* (4th Ed., pp. 1-38). Wiley.