Department of Applied Informatics
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The Role of Executive Attention in Controlled Semantic Cognition

Diploma Thesis

Bratislava, 2020
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Názov:	The role of executive attention in controlled semantic cognition *Úloha exekutívnej pozornosti v kontrolovanej sémantickej kognícii*
Anotácia:	Sémantický systém vytvára a uskladňuje poznatkové štruktúry, ktoré regulujú kognitívne funkcie a adaptívne správanie. Schopnosť vyhľadať a sprístupniť relevantné sémantické informácie je podmienená viacerými kognitívnymi mechanizmami, ktorých povaha ostáva nejasná. Tento projekt sa sústredí na preskúmanie kognitívnych systémov a mechanizmov, ktoré riadia vybavovanie informácií zo sémantickej pamäti. Pre tento účel využijeme systematickú manipuláciu záťaže exekutívnej pozornosti, čím určíme jej úlohu pri automatickom a kontrolovanom vybavovaní informácií zo sémantickej pamäti.
Cieľ:	Cieľom projekt je určiť hlavné determinanty a koreláty lexikálne-sémantického spracovania informácií so zameraním na exekutívnu pozornosť.
Literatúra:	Badre, D., Poldrack, R. A., Paré-Blagoev, E. J., Insler, R. Z., & Wagner, A. D. (2005). Dissociable controlled retrieval and generalized selection mechanisms in ventrolateral prefrontal cortex. Neuron, 47(6), 907–918. https://doi.org/10.1016/j.neuron.2005.07.023 Lambon Ralph, M. A., Jefferies, E., Patterson, K., & Rogers, T. T. (2016). The neural and computational bases of semantic cognition. Nature Reviews Neuroscience, 18, 42.
Kľúčové slová:	Sémantická kognícia, sémantické vybavovanie, exekutívna pozornosť, kognitívna kontrola, pracovná pamäť

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THESIS ASSIGNMENT

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Title:	The role of executive attention in controlled semantic cognition
Annotation:	Semantic system creates and structures knowledge that guides adaptive cognition and behavior. The ability to access and use relevant semantic information is underpinned by several neurocognitive mechanisms, which are poorly understood. This project aspires to investigate the cognitive systems and mechanisms that regulate the retrieval of information from semantic memory. Using a systematic manipulation of attention load, we will inspect the role of executive attention in automatic and controlled semantic retrieval.
Aim:	The goal is to define fundamental determinants and correlates of lexical-semantic processing with the main focus on executive attention.
Literature:	Badre, D., Poldrack, R. A., Paré-Blagoev, E. J., Insler, R. Z., & Wagner, A. D. (2005). Dissociable controlled retrieval and generalized selection mechanisms in ventrolateral prefrontal cortex. Neuron, 47(6), 907–918. https://doi.org/10.1016/j.neuron.2005.07.023 Lambon Ralph, M. A., Jefferies, E., Patterson, K., & Rogers, T. T. (2016). The neural and computational bases of semantic cognition. Nature Reviews Neuroscience, 18, 42.
Keywords:	Semantic cognition, semantic retrieval, executive attention, cognitive control, working memory

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Declaration

I hereby declare that I elaborated the presented master's thesis independently using the cited literature.

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Abstrakt

Dva spolupracujúce neurálne systémy zapezbečujúce sémantické vybavovanie, ktoré je nevyhnutné pre prístup k informáciám v pamäti sa nazýva kontrolovaná sémantická kognícia (CSC; Ralph et al., 2017). Prvý systém je zodpovedný za sémantickú reprezentáciu a považujeme ho za automatický systém, zatiaľ čo druhý systém je zodpovedný za sémantické riadenie. Tento systém podporuje a koordinuje prvý systém. Nedávne zistenia naznačujú, že systém exekutívnej pozornosti môže hrať dôležitú úlohu v sémantickom vybavovaní. Na to, aby sme objasnili túto funkčnú interakciu, sme zaťažili exekutívnu pozornosť počas súvislého sémantického vybavovania využitím paradigmy dvojitej úlohy. Našou hypotézou bolo, že spracovanie a vybavovanie podporované sémantickým systémom sa naruší simultánnou záťažou pozornosti. Nedávno vyvinutý Test asociatívnej reťaze (TAR) zapájajúci automatické a riadené lexikálno - sémantické spracovanie (Marko et al., 2019b) bol aplikovaný v paradigme dvojitej úlohy. TAR úloha sa skladá z dvoch podmienok: automatická (asociatívne sémantické vybavovanie) a riadená (disociatívne sémantické vybavovanie). Tieto podmienky boli dodatočne zaťažené súvislým výkonom úlohy a taktiež striedaním záťaže, aby sme videli, či sú funkcie pozornosti využité pri sémantickom vybavovaní. Zistili sme, že reakčný čas (RČ) pri disociatívnych odpovediach bol vyšší ako pri asociatívnych odpovediach pri všetkých záťažiach. Súbežná monitorujúca záťaž mala podobné negatívne efekty pri oboch vybavovacích podmienkach (t.j. spomalenie oboch RČ v asociatívnych aj disociatívnych podmienkach). Obe vybavovacie podmienky významne ovplyvnila aj striedajúca záťaž, ale riadené (disociatívne) spracovanie bolo viac narušené ako automatické (asociatívne) sémantické spracovanie. Tieto zistenia indikujú, že exekutívna pozornosť hrá dôležitú úlohu pri sémantickom vybavovaní. Avšak na to, aby sa dal presnejšie určiť vplyv rôznych funkcií pozornosti, je potrebný ďalší výskum.

Kľúčové slová: Sémantická kognícia, sémantické vybavovanie, exekutívna pozornosť, kognitívna kontrola, pracovná pamät'

Abstract

Semantic retrieval, necessary for accessing stored information in our memory, is enabled by two interacting neural systems referred to as the controlled semantic cognition (CSC; Ralph et al., 2017). The first system of semantic representation is considered to be automatic, while the second system of control supports and coordinates the first system. Recent findings suggest that the executive attention system may play a crucial role in semantic retrieval. To clarify this functional interaction, during continuous retrieval we loaded the executive attention using the dual-task paradigm. We hypothesized that simultaneous load on attention would impair the processing and retrieval supported by the semantic system. The recently developed Associative Chain Test (ACT), engaging automatic and controlled lexical-semantic processing (Marko et al., 2019b) was used under the dual task paradigm. The two ACT task conditions: automatic - associative and controlled - dissociative semantic retrieval, were additionally loaded with a continuous performance task (CPT) and a switching load, to see whether semantic retrieval engages these executive attentional functions. We found that the reaction times (RTs) for the dissociative responses were higher in all load conditions than for the associative ones. The concurrent monitoring load had a similar negative effect on both retrieval conditions (i.e. slowing both associative and dissociative similarly). Both retrieval conditions were also significantly affected by the switching load, but the controlled (dissociative) processing was more impaired than the automatic (associative) processing. These findings indicate that executive attention plays an important role in semantic retrieval. However, further research is necessary for pinpointing the exact contribution of different attentional functions.

Keywords: Semantic cognition, semantic retrieval, executive attention, cognitive control, working memory

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Introduction

Understanding the world and making sense of it is not an easy task, yet most of the time we accomplish it seemingly easy. Although we often are not aware of it, we use words to describe our environment, can read various signs and symbols, and manipulate them to create meaning. These processes involve various neural mechanisms that most of the time work unconsciously, i.e., we do not think about how or why we reach for a cup when we want to pour ourselves some coffee or tea, we just know that a cup is better than a fork for this task. How do we know that?

As humans we are able to retrieve meaningful information in a flexible way to meet task demands (Badre and Wagner, 2002). This question of how we encode, store and retrieve information in our brains is a question that concerns the field of semantic memory. In the course of the last decades, there have been various views on how semantic memory works. Most of these views were based on behavioral studies involving language decision tasks, picture naming and similar settings. With the advance of new neuroimaging methods, researchers were able to find out more about the actual neural mechanisms underlying these processes.

Recently, Ralph et al. (2017) proposed a two-system framework called the Controlled semantic cognition (CSC) framework which was to replace the 'hub- and-spoke' theory of semantic representation devised about a decade ago. The CSC system involves a system of automatic knowledge retrieval and another system supporting the representational system, a system of control. More recently Jefferies et al. (2020) compared the CSC framework to another model in which semantic stores contain knowledge of taxonomic classes (anterior temporal lobes) and thematic associations (angular gyrus or posterior middle temporal gyrus). Although the specific neurocomputational mechanisms governing semantic cognition become more and more understood, the current understanding how such semantic mechanisms interact with general-domain executive control mechanisms remains poorly understood.

In the present work, the aim is to explore what role domain-general executive brain functions pertaining to attention may play in both automatic and controlled semantic retrieval. We investigated this using a concurrent load of domain-general executive attention during the retrieval task and correlating semantic retrieval measures with executive attention tasks (Stroop and Response inhibition task). This work will look at these mechanisms through the scope of the cognitive science paradigm, using interdisciplinary methods combining psychology, neuroscience, and linguistics. This work is also a part of a bigger project aiming to uncover the role of cognitive mechanisms involved in semantic retrieval with the help of cognitive load manipulation and non-invasive transcranial electrical stimulation (tES) to the prefrontal cortex.

In the following section, we will focus on the emergence of the concept of semantic cognition up to the theories dominating the field today, as well as mention some computational models, which developed in parallel. In the third section, we will further draw on the two systems of the controlled semantic cognition framework and focus more closely on the executive attention mechanisms involved. Finally, we will present the aim of this research, the experimental design, the obtained results, and a discussion on what these results might mean for future research.

Chapter 1

Semantic Cognition

Under the term of semantic cognition we most often understand the general knowledge about the world that we have and which we are able to retrieve when needed. This knowledge includes objects, concepts, but also facts necessary for our everyday lives. Ralph et al. (2017) refer to semantic cognition as a selection of neurocognitive mechanisms that reinforce semantically related behaviors, which we use not only for linguistic purposes, but also for actions and other non-verbal behaviors. It is necessary to distinguish the linguistic narrow view of semantic research, which refers only to the meaning of words, phrases, or sentences. Semantic cognition is part of our long-term memory and thus helps us in storing, manipulating, and retrieving knowledge about concepts, facts and beliefs when it is necessary.

One of the first mentions of semantic memory was by Tulving in 1972, when he described the difference between semantic and episodic memory. This distinction helped in the development of a new field of memory research and opened up a new view of the workings of our memory system. With the development of various new methods of brain research, cognitive psychologists and neuroscientists gained interest in the semantic retrieval and its underlying mechanisms, so the interest slowly shifted from a language-directed to a cognitive-oriented perspective. In the classic view of semantic memory, Endel Tulving has stated the division of long-term memory into declarative (facts) and procedural (skills) elements, with a further subdivision of the declarative memory into semantic and episodic (McRae and Jones, 2013). Situated at the second level of Tulving's monohierarchy, the semantic memory system entails general knowledge of the world which is not related to specific events in one's life (Radvansky and Wyer, 1994), thus differentiating it from episodic memory.

It might seem that Tulving insisted on a clear-cut distinction between episodic and semantic memory, but this is not the case. The considerations that inspired the notion of semantic memory were the information that could not be fitted under procedural or episodic memory. The way in which semantic memory differs from procedural memory is that most people are able to explain (i.e., explicitly declare) the information contained in semantic memory, whereas procedural memory is often automatic and unconscious and therefore hard to describe. Although episodic memory has a closer relationship to semantic memory due to the fact that we can retrieve semantic knowledge through memories of certain episodes, we cannot know the context or episode in which we learned the facts or concepts as they get abstracted from the autobiographic episodes. Accordingly, the distinction between episodic and semantic memory is not clear-cut and was discussed further through the years of research. Often the process of forgetting the two memory types was also considered. Semantic memory seems less susceptible to processes of forgetting than episodic memory (Renoult and Rugg, 2020).

Another interesting characteristic of semantic memory noted by Tulving (1972) was that information stored in semantic memory did not have to be learned. We can easily infer information by comparing the knowledge that we already have stored and deduce new knowledge. This leads us to consider that semantic memory might help not only in storing and retrieving relevant information, but also organizing it to fit our needs. Renoult and Rugg (2020) state that Tulving considered semantic memory as not noticing properties of inputs related to percepts, but rather attending to cognitive referents, which contradicts current views of memory being “embodied” or “grounded” in action and perception and emerging from modality-specific and amodal information interaction.

Nowadays researchers describe semantic memory more broadly to indicate it is the general world knowledge, which is culture dependent and implicated in experience (McRae and Jones, 2013). According to Greenberg and Verfaellie (2011) semantic memory also supports the process of acquisition of new episodic memories, and episodic memory aids in the addition of new information to the semantic memory store. Although newer perspectives on semantic and episodic memory describe their interaction, it is still not clear how it works.

Recent findings proposed that processes of retrieving information can change the content of episodic memory, but the same does not stand for semantic memory (Renoult and Rugg, 2020). Once acquired, semantic memory does not change. It can, however, be used to infer about concepts that are connected or to manipulate existing knowledge to create new information. In the classical model of semantic structure, meaning was portrayed as a hierarchical network model (Collins and Quillian, 1969), in which knowledge about concepts was stored only once without repeating it throughout the memory. A limitation of this early model is the lack of specification on how the meaning representations are learned (McRae and Jones, 2013).

The classic view of semantic memory was slowly replaced with the rise of the grounded cognition paradigm. This paradigm contributed by describing how - when people approach a word meaning, sensorimotor information gets activated and is used to perceive and act on the real-world environment to which a word relates to (McRae and Jones, 2013). Nowadays, semantic memory is more broadly seen as an element of a unified memory system, which is distributed throughout important brain regions and grounded in motor, perceptual and sensory systems (McRae and Jones, 2013). Most of this knowledge about semantic cognition was gathered through various neuropsychological studies, especially the ones related to semantic impairments, such as semantic dementia. Patients suffering from this type of dementia typically have no problem with speech and grammar, but struggle with finding the correct word, identifying objects, concepts, and people regardless of the method of stimuli presentation (Yee et al., 2014).

With the development of new neuroimaging-based experimental approaches and methods of data analysis that aim to support cognitive scientists and neuroscientists in examining the neural mechanisms of memory retrieval, we have recently gained more insight into the functioning of semantic cognition. Modern noninvasive brain stimulation techniques, such as transcranial magnetic stimulation (TMS) and transcranial direct current stimulation (tDCS), help experimenters “impair” a specific brain region for a short time and monitor the behavioral effects without a possibility that neural functions reorganize (as it happens over time with lesions) (Yee et al., 2014).

The conditions of semantic deterioration have also inspired some computational models. The gradual decay of the concepts within semantic memory could be explained by suddenly or gradually dissolving the links between the nodes that represent the meanings (in the large-scale structure model of Steyvers and Tenenbaum (2005)). Many of the semantic models are based on the “human model” and how the researchers think that semantic cognition works. More recent models based on distributional methods (words that appear in similar contexts are more likely to be related in meaning) recreate cognitive mechanisms of producing semantic representations from statistical evaluations of text corpora (McRae and Jones, 2013).

Since Collins and Loftus developed the Spreading Activation Model in 1975, many computational models were inspired by the ever-growing research on biological neural networks. In this model, concepts were connected through nodes, and the distance between the nodes denoted the strength of the connection. In cognitive science, spreading activation is situated in the cognitive paradigm of connectionism, which concerns neural networks whose nodes get activated through action potentials and thus activate other nodes of the network (words related in meaning or associations). Connectionist networks have been employed to show how word meaning is described and computed, but also for numerous empirical semantic memory phenomena simulations (McRae and Jones, 2013), such as the one mentioned above.

Not only did semantic cognition contribute to creating a whole field of research (Computational Semantics) in the discipline of Computer Science, but it also, by inspiring these computational models, helped developing new theories for the neuropsychological studies. McClelland et al. (2009) implemented a computational model (the PDP model – a parallel distributed processing approach) that includes modelling the CSC framework. The hub is modelled as an intermediate "representation" layer connecting associations between input and output layers, which are supposed to resemble the spokes – the modality-specific cortical areas. It also includes a computational analog of the control network, which is thought to be the hidden layer of the Rumelhart model (Folstein and Dieciuc, 2019). This model captures the capacity to learn from experience gradually, so as to model the development (e.g., how children acquire meaning), as well as the tendency to deteriorate in a step-by-step manner, in order to apprehend the fractional nature of the impairments caused by brain injury (e.g., in semantic dementia).

Chapter 2

Current View on Semantic Cognition

Through the many years of research on semantic cognition, different theories have been postulated on how semantic cognition might work and what mechanisms might be involved in this process. Often internal processes are described as activities of “search, generation, differentiation, decision making, discrimination, comparing, ‘accessing’, locating, transforming,” and other (Tulving, 1979, p. 28). These processes greatly depend on different neural mechanisms said to be involved in semantic cognition. In this section, we will present the two main current theories that dominate the research and the neural correlates underlying these theories.

2.1 The Dual Hub Model

In the review of Jefferies et al. (2020), they compared the CSC framework to another model of functioning of the semantic cognition (Figure 2.1). This model proposed by Schwartz et al. (2011) describes that semantic cognition is organized in two hubs - (1) the ATL in charge of taxonomic processing and (2) the temporoparietal junction (TPJ) in charge of thematic representations. The roles of these two distinct areas were established by analyzing naming-error data in aphasic patients, which leaves room for speculating about how this model could explain other retrieval patterns of the semantic memory. Specifically, task-related retrieval may be supported by the different patterns of pairing the hub and the spokes (Chiou et al., 2018). Because of the lack of explanations for some functions of the semantic cognition in this model, Jefferies et al. (2020) concluded that the CSC framework fits the data better than the dual-hub theory.

In their review of the two models, Jefferies et al. (2020) questioned the need for an integrated semantic control process, which is a crucial part of the controlled se-

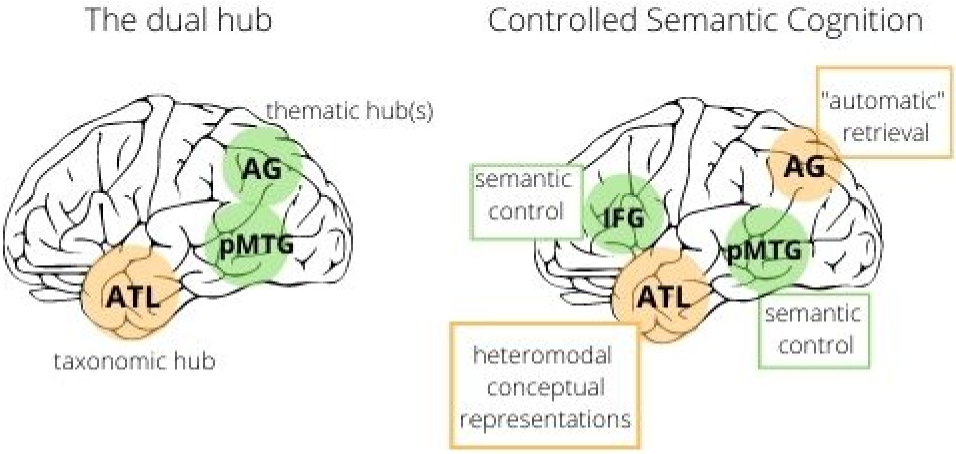

Figure 2.1: An overview of the two alternative theories - the dual hub and CSC (the image is adapted from Jefferies et al. (2020)). It is suggested that the temporoparietal cortex, including the AG and/or the pMTG, plays a role in representing thematic knowledge, whereas the ATL is in charge of the taxonomic knowledge. The CSC framework offers another view where the ATL includes both taxonomic and thematic relations, and the pMTG works together with other regions such as the IFG to help processes of semantic control. ATL – anterior temporal lobe, AG – angular gyrus, IFG – inferior frontal gyrus, pMTG – posterior middle temporal gyrus

mantic cognition model. Unlike the dual hub model, the CSC suggests the importance of the ATL in representing both taxonomic and thematic relations and the pMTG in supporting semantic control actions in cooperation with regions such as the inferior frontal gyrus (IFG) (Jefferies et al., 2020; Figure 2.1). These regions work together in cases when the semantic cognition processes become less automatic and more demanding. Ralph et al. (2017) points out that the control network seems to underpin working memory and executive descriptions encoding currently important knowledge from the situation, time, or task environment.

The contribution of the dual hub model is seen in the correspondence of the roles of the two hubs with the impairments observed in individuals suffering from lesions in the left temporoparietal region (Jefferies et al., 2020). A serious weakness with this argument, however, is that patients appear to have large lesions spanning over both AG and pMTG, making it hard to pinpoint the exact neurological base of the thematic hub in one of these regions. This suggests that more research is necessary to show the plausibility of the proposed framework.

In the following section we will focus on a more detailed description of the neural correlates said to be involved in the CSC model. We will distinguish between the automatic and controlled retrieval processes, which play an important role in the study design and research questions of this work.

2.2 The Controlled Semantic Cognition Framework

In a recent review, Ralph et al. (2017) suggested that semantic cognition employs two principal interacting neural systems. The first system of representation uses various sensory, motor, linguistic, and affective percepts of information distributed throughout the cortex, and by learning their higher order relationships encodes the knowledge of concepts (Ralph et al., 2017). This system of representation is considered to be automatic and fast. Additionally, its activation is controlled by the second system that has the role of creating inferences and behaviors appropriate for each specific situation or task (Ralph et al., 2017). This second system is the control system that manipulates and supports the first automatic system. Together these systems are known as the controlled semantic cognition framework (CSC).

The current framework serves to explain which brain areas are involved in semantic memory and how these areas access and use the stored knowledge. A decade ago, Ralph and his colleagues (2007; Ralph et al., 2017) proposed a theory called the “hub – and – spoke theory” of semantic representation. Their theory was built on the evidence that a multitude of brain regions were involved in semantic processing and that the processing involved multimodal perceptions encoded in modality-specific areas (the “spokes”) across the brain. The second part to this theory was the “hub” region. This region, situated bilaterally in the anterior temporal lobes (ATLs), was proposed to mediate (at least partially) the cross-modal interactions of all the modality-specific areas (Ralph et al., 2017). The hub-and-spoke theory served as a starting point and got integrated into the later proposed CSC framework.

The hub and the spokes can be seen as two components of the CSC framework (Folstein and Dieciuc, 2019). The first component combines the information from different modalities and is distributed across different neocortical areas (Ralph et al., 2017). The information does not flow only in one direction – the spokes communicate with the ATL hub and receive feedback from the ATL, as well. However, this interaction was regarded as partial, not all information coming from the modality-specific areas was mediated by the hub region. Only through evidence of brain damage to these areas, did research get steered into the direction that other general-domain executive functions such as attention might be playing an important role in semantic processing.

Detailed studies of patients suffering from semantic dementia (SD) opened the possibility that the ATL area might be important for all conceptual modality domains, as patients suffering from SD did show impairments in all the modality-specific areas (Ralph et al., 2017). Some brain imaging techniques (fMRI, PET) often displayed discrepancies in the results of the areas involved in semantic processing, thus making it hard to determine the actual areas involved. By introducing transcranial magnetic stimulation (TMS), experimenters were able to create temporary “lesions” in areas of interest and thus test the involvement of different areas in the semantic processing. As an example, Pobric et al. (2010) stated that inhibitory TMS of the lateral ATL produced domain-general slowing in semantic processing, whereas TMS of “spoke” areas caused effects related to category-specific knowledge (as cited in Ralph et al., 2017, p. 44).

This finding meant that the ATL got activated in all semantic tasks, regardless of their requirements. At times, in order to solve a task our mind comes up with the knowledge automatically, in a bottom-up manner, by simply processing stimuli from the environment (Badre and Wagner, 2007). However, sometimes our environment poses problems that call for higher-level processing and control processes in order to meet the task or other requirements at hand. In these situations, we usually employ a search process within our memory and focus on important information. According to Badre and Wagner (2007), we engage cognitive control mechanisms, supported by the prefrontal cortex (PFC) that allow us to use strategies for adhering memory to our needs and intentions. Such control processes may be required to "accentuate subordinate meanings, focus attention on non-dominant features or suppress strong associates of a given concept" (Ralph et al., 2017, p. 49).

Within the CSC framework, the control is achieved inside of a distributed neural network, including both left inferior frontal gyrus (IFG) and posterior middle temporal gyrus (pMTG) (Jefferies et al., 2020), which interacts with the semantic representation (automatic) network, but is clearly separated from it (Ralph et al., 2017). The automatic processes can occur by activating the posterior cortical regions, regardless of the control processes (Badre and Wagner, 2007). In turn, suggesting that these two systems can work in synchrony, but also to a certain degree be independent.

2.2.1 The Neural Correlates of the CSC Framework

The general use of the term Controlled Semantic Cognition refers to a framework consisting of two functionally distinct systems, which to our benefit interact when the cognitive demands on our semantic processing become high. The first system of semantic representation employs the polymodal ATLs and is also said to activate the angular gyrus in processes of automatic retrieval. The second system of controlled semantic processing supports the first system by activating regions of the IFG and the pMTG. Recent evidence (Chiou et al., 2018) reveals that two major groups of brain regions showed greater connections to the IFG:

1. the broadly distributed control areas, including a part of the left prefrontal "executive control" regions together with the intraparietal sulcus and the pMTG, and
2. interestingly also the left visual cortex with peaks at the lateral occipital area as well as the middle fusiform gyrus.

These control areas will be partially discussed in section 3 describing the proposition that the CSC activates the executive function regions in situations of high cognitive load.

Semantic Representation System

The semantic system of representation is also referred to as the automatic semantic system. Radvansky and Wyer (1994) state that semantic cognition is a highly unified system “in which related concepts are stored together” (p. 140) and that by using information from one concept, other associated concepts also get activated and brought to attention. This suggests that concepts are usually stored in close proximity if they are related in meaning or share some common features. Often when recalling one entry from our semantic repository, we automatically activate other strongly related representations, which could be explained by the spreading semantic activation theory proposed by Collins and Loftus (1975). Baror and Bar (2016) describe spreading activation as a factor of relatedness that was usually seen as a key prediction for associative processing depending on executive resources.

Depending on the number of their previous co-occurrences, shared features or the category relationship, the strength of the associations might be different (Badre and Wagner, 2002). Compared to some computational models, some nodes might be closer and have stronger connections to other nodes, whereas the concepts that do not share features with other concepts or are not related in meaning might be distant from each other. Neely (1991) and Carr (1992) describe this automatic semantic system as fast, obligatory, resistant to conscious control and not depending on context, which means that the knowledge retrieved can be both task- relevant or irrelevant (as cited in Badre and Wagner (2002), p. 207).

The associative semantic system is considered to be part of the ATLs that work together with the AG. The stronger the connection in meaning for groups of concepts, the stronger the response exhibited by both the ATL and AG (Jefferies et al., 2020). However, if there is a task at hand, automatic retrieval often does not provide the required answer. Badre and Wagner (2007) claim that relying solely on processes of automatic semantic retrieval might impede that goal-relevant knowledge is reached or might even interfere by retrieving irrelevant information. Therefore, processes of control are necessary in situations when retrieval gets demanding or specific higher-level information is required.

Ralph et al. (2017) state that the CSC framework is probably unique in producing a shared interest of both representation and control in semantic cognition. The interaction of these two anatomically distinct systems employs many different brain areas. Recent research supports the notion of semantic representations being grounded in the anterior temporal cortices by interacting with different modality-specific brain regions (Hoffman, 2018; McRae and Jones, 2013).

Semantic Control System

The semantic control system is the second system in the CSC framework, which is in charge of supporting and coordinating the first system of automatic representations. Operating semantic knowledge in a controlled way is connected to the activation in a network consisting of the inferior prefrontal cortex (IPFC), posterior middle temporal gyrus (pMTG) and the intraparietal sulcus (considered to be part of the multiple-demand network) (Hoffman, 2018). These areas work together to support automatic retrieval to meet task demands. According to Badre and Wagner (2007), the role of guiding the control processes to access relevant information from semantic memory has been enabled by immediate connections from the ventrolateral PFC (VLPFC) to the inferior and lateral temporal regions.

The automatic system is often not enough for successful semantic processing or retrieval. As already mentioned, spreading activation initiates the activation of many irrelevant, but strongly connected representations that do not meet the task at hand. In order to get the right information in a given situation, the activation flow of the network has to be constrained by the current task or goal description, encoded within the fronto-parietal networks (Rogers et al., 2015).

Different subregions of the left VLPFC are engaged in memory retrieval in different ways. Thus, the left anterior VLPFC engages more when there are increased demands on the controlled retrieval of semantic knowledge, rather than on post-retrieval selection processes (Badre et al., 2005). The multiple representations retrieved for the post-retrieval selection process may be retrieved in both an automatic (bottom-up) or controlled (top-down) manner. In order to activate the relevant representations over competing irrelevant and other retrieved concepts, the post-selection process requires the maintenance of task information (Badre and Wagner, 2007).

Renoult and Rugg (2020) argue that while left PFC regions are thought to play an important part in semantic control, the right PFC seems to be involved in monitoring post-retrieval in addition to maintaining the retrieval mode. This means that both the automatic and control systems work together to retrieve knowledge and process the retrieved knowledge to fit the situation. Most of the areas involved in the neural workings and portrayal, which are underlying conceptual information were discovered by studying semantically impaired patients, who showed more damage to the temporal lobe affecting the lateral and also medial cortex (Ralph et al., 2007).

Tasks demanding atypical or more precise processing would need more help from the control system, which increases the activity in the frontoparietal network (Chiou et al., 2018). The left IFG and the pMTG involved in semantic control seem to be partially coinciding with multiple-demand regions involved in executive control (Jefferies et al., 2020), which might be employed to sustain and carry out the task or goal at hand. In the following section, we will discuss the role of the executive attention and control in the controlled semantic cognition.

Chapter 3

The Role of Executive Attention in CSC

As mentioned in the previous section, the automatic semantic processes seem to be unconscious and fast, whereas controlled semantic processes require actively focusing on task requirements. In order to fulfill the task at hand, controlled semantic processing might require the help of executive attentional mechanisms especially under higher task demands or time restrictions. Executive attention refers to the capacity to maintain memory representations (action plans, states, goals, task-relevant cues) in a continually active state under interference (Kane and Engle, 2002). This suggests that control processes need executive attention most when the demands are high (e.g., response competition or inhibition of unnecessary responses).

Often, working memory (WM) and the capacity to retain information are connected to the executive attention functions. This connection relates to the processing capacity that limits the amount of information one can store and use in WM and our capacity to use attention for improving the speed of semantic processing in semantic tasks requiring control (Sabb et al., 2007). In long-duration tasks of semantic association, participants usually write the first words that come to mind and are connected in meaning. Yet as these associations get exhausted, the executive attention is activated to maintain active search and to refrain from repeating previously recalled words that are highly active in the automatic retrieval (Kane and Engle, 2002).

In their review, Kane and Engle (2002) describe the crucial role of the dorsolateral PFC to executive-attention functions. However, some regions involved in the controlled retrieval as well as WM processes might be also overlapping with the ones involved in executive attention activities. According to Marklund and his colleagues (2007), it remains unclear to what degree prefrontal areas, found to be engaged during different long-term memory tasks, may indicate activation of WM processes or basic attentional functions connected to maintaining a state of response readiness. Since these areas of activation are overlapping, it is often challenging to distinguish which functions can be ascribed to which smaller subregion.

The dorsolateral PFC (together with the inferior frontal sulcus), parts of the insular cortex, posterior regions of the IFG, supplementary motor area (also the pre-supplementary part), parts of the anterior cingulate and regions of the intraparietal sulcus are often referred to as the "cognitive control network" or "multiple-demand network" (Fedorenko, 2014). This network is said to get activated in highly demanding or task-oriented situations. Such situations give way for the controlled distribution of attention, with the PFC underlying the neural mechanisms of this process (Badre and Wagner, 2002). The posterior part of the left inferior PFC gets activated when semantic tasks show increased selection demands with conditions of high WM competition, during the Stroop task as well as other inhibitory tasks, and it exhibits a strong connection in structure to the multiple-demand network (MDN) (Hoffman, 2018). Diachek et al. (2020) state that one of the tasks supported by the domain-general MDN, but also by the language-specific network may be language comprehension. Such findings may be an indication that the domain-general MDN works closely with domain-specific areas when there is need for additional processing.

Davey et al. (2016) suggest that the pMTG allows for an increase in controlled retrieval as it is a functional center connecting the two large-scale networks, the default mode network (DMN) involved in automatic semantic processing and the MDN involved in executive control. The left pMTG is thought to be involved both in controlled retrieval and processes of understanding events, relations and actions and thus connects the two networks that otherwise seem to be working in oppositional correlation. This might explain why the pMTG coactivates together with the AG in certain semantic tasks, but not in all of them.

The functional connectivity of the AG and the pMTG seems to belong to different couplings since the pMTG together with the IFG are involved in the semantic control network (Noonan et al., 2013), whereas the left AG seems to be tied more to undemanding semantic retrieval and is part of the DMN, which usually does not participate in demanding tasks (Jefferies et al., 2020). These findings are consistent with the finding that inhibitory repetitive transcranial magnetic stimulation of the IFG or pMTG contributes to temporary deficits on semantic tasks, which are executively demanding but not on non-semantic tasks (Humphreys and Ralph, 2017).

Undemanding tasks of semantic retrieval, which seem to fall under the domain of the AG, activate unguided spreading activation. The spreading activation restores strong associations in the ATL, even when these are irrelevant for the task at hand and may cause problems when the task asks for non-dominant knowledge. This is solved by employing control processes with the help of the pMTG which combines knowledge from the MDN and DMN and shapes the spreading activation to conform to a specific context (Davey et al., 2016). Krieger - Redwood and her colleagues (2016) suggest that the posterior cingulate cortex is also involved in the controlled use of information from memory and increases its collaboration with cortex regions (in particular dorsolateral PFC) in support of cognitive control not only for semantic tasks but also for WM tasks.

A major drawback in the research of semantic cognition is the lack of clarity regarding the role of executive functions like attention in the controlled retrieval. New findings aid in solving pieces of the puzzle, but some mechanisms remain a mystery. In their report, Teige et al. (2018) state that there is a fair amount of controversy about the pMTG involvement in semantic cognition as dominant theories suggest “that this site: (i) represents particular aspects of lexical or semantic knowledge – such as event representations; or (ii) supports controlled semantic cognition as part of a large-scale network that includes IFG” (p. 343).

Nevertheless, current theories might be overlooking the possible interaction of domain-specific and domain-general systems. The CSC integrates this interaction by allowing the domain-general executive attention process to guide the domain-specific semantic retrieval. Even though the research on semantic cognition is concentrated on two systems: a representational system and a control system that helps solve the task at hand, the brain processes, which support this ability, remain poorly understood.

Chapter 4

The Current Research

4.1 General Objective

Little is known about the degree to which the general-domain executive system supports the processes of controlled semantic retrieval. The main purpose of this study is to investigate the cooperation between these two systems using cognitive load. We consider that semantic memory retrieval will employ the domain-general attention processes when the demand gets high and goal-oriented behavior is necessary (for both automatic and controlled retrieval). In order to find out more about this interaction, we manipulated the load on the semantic retrieval task by introducing a secondary concurrent task, including monitoring load as well as a task including switching load, implemented by an additional requirement for alternating between the two retrieval conditions of the main task (associative and dissociative retrieval).

4.2 Methodological Approach

For the purpose of this study, we conducted a behavioral experiment consisting of two parts: (1) the main experiment in which we implemented the dual-task paradigm in order to examine the functional determinants of the two systems involved and (2) the control measures of executive functions (tasks related to attention: Stroop task and Response inhibition task) that were assessed to evaluate the association between executive attention and semantic retrieval.

4.3 Hypotheses

We predict that both load manipulations on attention will affect both automatic-associative and controlled-dissociative responses and that the impairment caused by the load will be higher for dissociative responses requiring inhibitory processing than for the associative responses. We also predict that the Stroop effect will correlate with the inhibition cost (dissociate RTs - associate RTs) from the retrieval task.

Chapter 5

Methods

5.1 Participants

We recruited 45 healthy students (19 men and 26 women) between 18 and 31 years of age (*M*= 22.68, *SD* = 3.05). Participants were recruited through advertisement on social media (mainly Facebook), but also through faculty noticeboards. An a priori power analysis was used to estimate the required sample size (5% Type I error rate, 20% Type II error rate, and expected effect size $R^2 \geq .10$, one-sided test). In total, 45 young and healthy adults participated in the study. Due to multivariate outlying values, one participant had to be excluded from the sample.

All the participants were native Slovak speakers. Due to one of the experimenters not being native to the Slovak language, we made sure that at least half of the participants were able to follow instructions in English (participants were asked to self-assess their knowledge according to descriptions of the CEFR levels[1]). All except three participants were right-handed and none had cognitive, motor or language impairments. A financial compensation was provided for the participation of approximately one hour. The research was conducted in accordance with the Declaration of Helsinki and approved by the institutional review board. With study participation, all participants signed a written informed consent and were informed about situations during the experiment that could result in feelings of stress or discomfort.

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[1] Short description of the CEFR (Central European Frame of Reference for Languages) levels in Slovak.

5.2 Procedure

The experiments were carried out using a computer and the PsychoPy software, version 3.0. There were two administrators of this study, but the setting was individual and required only one administrator and one participant at a time. Upon arrival participants were asked to fill out a short questionnaire on their demographic data and sign the informed consent. All participants were required to come only once and were administered two parts of the experiment in random order: one involving executive attention measures/loads and another including working memory measures/loads.

For this work, we will only consider the part related to attentional executive functions. The experimental part evaluating the role of executive attention in semantic memory retrieval consisted of two control measures assessing cognitive interference (Stroop task and the Response inhibition task) and the main task (the Associative chain task - ACT).

5.2.1 The Associative Chain Test

In the recently developed Associative Chain test (ACT) participants had to continuously produce chains of words under two retrieval conditions (Marko et al., 2019b). During the association condition, the participants were creating word chains in which each consecutive response word needed to be semantically related to the previous word (e.g., [starting word] *Apple* → [1] *Tree* → [2] *Branch* → [3] *Leaves* → [4] *Paper*).
In the dissociation condition, each consecutive response word needed to be semantically unrelated to the previous word (e.g., [starting word] *Suitcase* → [1] *Window* → [2] *Book* → [3] *Glass* → [4] *Head*).

Participants were explicitly instructed to pay attention not to type associated words during the dissociation condition, i.e., to suppress the automatic associations. These retrieval conditions were used for assessing automatic and executive semantic retrieval, respectively. The participants were prompted to type as many words in Slovak as possible in a given time frame (50 seconds per trial) creating word chains in each trial of the task. There were 12 trials of the ACT task in total; four trials of each *Response type* (association/dissociation) – of which 2 were with and 2 without *monitoring load* (see below) – and four trials of the *switching load* (alternating the associative/dissociative responses) in a fixed order. Each trial started with a randomly assigned word from a list of words. The participants were also asked to provide new words and not repeat the words used before and were advised to ignore typing errors in order to save time. There was a short training for each *Response type* (associative, dissociative) and load condition, i.e., *Switching load* (alternating associative and dissociative responses) and *Monitoring load* (monitoring, no load) before the actual task started.

During the ACT we measured the response time (RT) of each typed word (from time of entering the last response until initiating a keypress when delivering a new response). Additionally, inhibition cost was measured by calculating the difference between the dissociate RTs in comparison to the associative ones. Marko et al. (2019b) proposed that such a measure of inhibition cost reflects controlled semantic processing associated with response suppression. Two independent reviewers checked for response correctness (whether associations were typed only during associative chains and whether the switching was followed through correctly) and English and nonsense words, which were then excluded from the data as errors.

5.2.2 Manipulation of Cognitive Load (Dual-Task Paradigm)

The experiment was designed as a within-subject study with two factors: 1. *Response type* (association and dissociation) and 2. *Cognitive load* (monitoring or switching load versus no load). The experimental approach used is also known as dual-task paradigm (D'Esposito et al., 1995), which in our work aimed at participants solving the ACT, that involved semantic retrieval (automatic and controlled), while concurrently paying attention to a secondary monitoring task (a continuous performance task, CPT) or while alternating between semantic rules (switching task).

In the main (ACT) task with the *switching load*, we instructed participants to type associations and dissociations in an alternating way. The target word was presented either in green color indicating associations were required or in red color indicating dissociation. Each entered word by the participant turned into the next target word for the opposite condition
(e.g. [starting word] *Chair* (A) → [1] *Table* (D) → [2] *Moon* (A) → [3] *Stars* (D) → [4] *Computer* (A)[2]). The switching cost was calculated by subtracting the difference of providing responses within the alternating chains compared to the fixed ones (independently for the association and dissociation chains).

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[2] (A) - associative condition, (D) - dissociative condition

The monitoring task involved dividing the attention between producing the word chains in the ACT and tracking the changes of letters in front of them on the screen. The CPT task was presented on the screen in front of the participants, below the text box for the ACT task input (see Fig. 5.1). For the monitoring task, we instructed participants to press the spacebar each time the target letter of the same color appeared, while simultaneously solving the main ACT task (i.e., typing the associative/dissociative word chains). The target letter was selected at random at the beginning of each trial, but it remained the same throughout the chain. The letters changed pseudo-randomly, approximately once per 900 ms, using all possible combinations of the used letters and colors (see Fig. 5.2). We informed the participants that pressing the spacebar would not create a space in the word they were typing or change it in any way. We made sure that the participants felt comfortable with touch typing, however, it still presented a bit of a problem for some participants.

5.2.3 Control Tasks

The Stroop task (Stroop, 1935) is a neuropsychological task used to determine the ability to inhibit cognitive interference occurring when the processing of a certain stimulus feature interferes with the simultaneous processing of a second stimulus feature (Scarpina and Tagini, 2017). The task consisted of three different conditions (blocks). The first (neutral) condition implied that the participants determine the color of the presented string of letters ("XXXXX"). The second (congruent) condition implied determining the presented color names written in the same colored ink. The third (incongruent) condition implied determining the color of the ink whilst ignoring the text that is written (ink and text were mismatching). This means that participants need to inhibit the interference coming from a more automated task, as is reading the word versus the more controlled task of naming the ink color (Scarpina and Tagini, 2017). There were several practice trials before the actual task. In the main task we recorded 84 neutral, 48 congruent and 48 incongruent responses. After removing the incorrect responses, the Stroop effect was calculated by subtracting the congruent RTs from the incongruent ones (Incongruent RTs – Congruent RTs).

The Response inhibition task is an interference task in which participants have to indicate the direction in which the white arrow on the screen is pointing to (up, down, right, left) by pressing the corresponding arrow on the keyboard (congruent condition). However, in some trials, an arrow of a different color appears (red) and then the opposite response is required (i.e., if it is showing left, the participant should click right, and

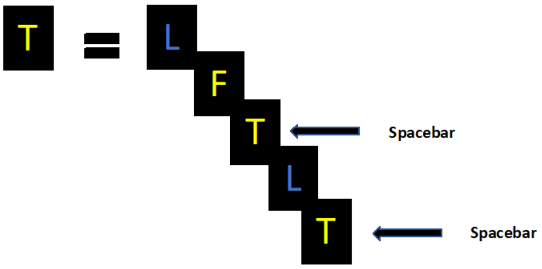

Figure 5.1: An illustration of the CPT task and the target letter response. The colored letters appeared on the screen in a pseudo-random order, once per 900 ms. Note that for simplifying the illustration, the display of ACT task is not shown here, although both tasks were on-screen simultaneously (see Fig. 5.2).

Figure 5.2: The view of the dual-task design: The ACT input box (associative chain indicated by the green color and written above in Slovak - súvisiace) and below the continuous performance task.

so on – incongruent condition). Again, the initial (automatic) response is inhibited, and a more controlled answer is expected. This measure is usually observed in the number of errors and the longer reaction times. There were several practice trials before the actual task started. In the main task there were three blocks with 10 second breaks between each block. In total there were 288 trials, of which 192 were congruent and 96 incongruent trials. After incorrect responses were removed, the Response inhibition effect was calculated (Incongruent RTs – Congruent RTs).

5.3 Data Analysis

The gathered data was analyzed in R Studio (R Studio Team, 2018) with the R language and environment (R Core Team, 2018). Before the statistical analysis was done for the ACT, we removed all responses with RTs longer than 20 seconds ($< 0.1\%$ RTs removed). Two independent raters assessed the remaining answers for accuracy by identifying responses, which did not conform to the rule – words that were not related in the associative conditions and words that were related in the dissociative ones ($<$ 3% of responses were removed in this way). As a result of overall high response accuracy ($> 97\%$) only RTs were analyzed. Before the statistical analyses, the data was winsorized (trimming of 10%, two-sided) independently for each participant and ACT aspect, due to various outlying findings among the RT values (values surpassing ±1.5 interquartile range).

Using linear mixed effect models (LMEM; R package lme4, Bates et al., 2015) we analyzed the retrieval RTs (s) from both experimental ACT tasks to account for the measurements embedded within participant (individual RTs) by estimating a random intercept for each participant (default unstructured covariance matrix). For the ACT task, in which we manipulated attentional monitoring and switching, the LMEM involved the main effects of *Response type* [associative, dissociative], *Load* and their interaction. *Load* was modeled as either *Switching load* [fixed, alternating] or as, *Monitoring load* [monitoring, no load], using two separate LMEMs, as these two load factors import two qualitatively different manipulations. Particularly data from ACT chains with less than 70% performance (hit ratio % - false alarm ratio %) in the maintenance task were removed from the analyses. Using restricted maximum likelihood (REML), LMEMs were fitted and p-values were derived using Satterthwaite approximation for degrees of freedom, since these produced optimal estimates even for smaller sample sizes (Luke, 2017). Later pairwise comparisons between the *Response type* and *Load* conditions were assessed using Wald's statistic and Satterthwaite approximation of degrees of freedom. The p-values of the later tests were corrected with Tukey HSD adjustment to account for family-wise error rates (reported are adjusted p-values).

LMEMs were also used for the analyses of the Stroop test and the Response inhibition test using the same methods and parameters, but only the main effect of *Condition* [congruent, incongruent] was included (for the Stroop test the ink-text congruency and for the Response inhibition test the direction-response congruency), as described in the methods. Additionally, the individual data points (RTs) for each participant were averaged, separately for each task and condition (or combination of conditions). Several derived measures were computed using the averages: *inhibition cost* (dissociative RT – associative RT), *switching cost* (dissociative alternating RT – dissociative fixed RT). As it was not feasible to estimate reliable aggregate values for maintenance RTs for a few participants because of the low accuracy of the maintenance task ($<$ 70 %), the *monitoring load effect* (monitoring load RT – no load RT) was not included in the analysis. The calculated average values were then examined to find outliers (4 datapoints, $< 0.004\%$) and missing values (8 datapoints, $< 0.007\%$), which were interchanged and imputed using a recently favored multivariate imputation by chained equation approach (MICE; van Buuren, 2018). The basic and extracted (average) measures from ACTs and control tasks' measures (Stroop and Response inhibition) were then used in a correlation analysis.

Chapter 6

Results

6.1 The Main Task - ACT

Two LMEM analyses were conducted in order to evaluate the effect of two cognitive load factors (switching, monitoring). We first investigated the effects of *Response type* (associative vs. dissociative) and *Switching load* on RTs in the ACT task. For the switching load, the LMEM showed a significant main effect of *Response type*, $F(1{,}3836) = 1064.0$, $p < .001$, a significant main effect of *Load*, $F(1{,}3836) = 106.26$, $p < .001$, and their significant interaction, $F(1{,}3836) = 34.19$, $p < .001$ (see Table 6.1). Figure 6.1 shows that RTs for the dissociative condition were substantially higher than for the associative condition and that the switching load further increased the dissociative RTs (indicating the switching cost) in comparison to associative RTs.

Table 6.1: Effects of Response type and Switching load and their interaction.

Effect	***F***	***p***
Response type	1604,002	< 0.001 ***
Switching load	106,256	< 0.001 ***
Response type x Switching load	34,193	< 0.001 ***

Note: (*** = $p < .001$, a very significant effect).

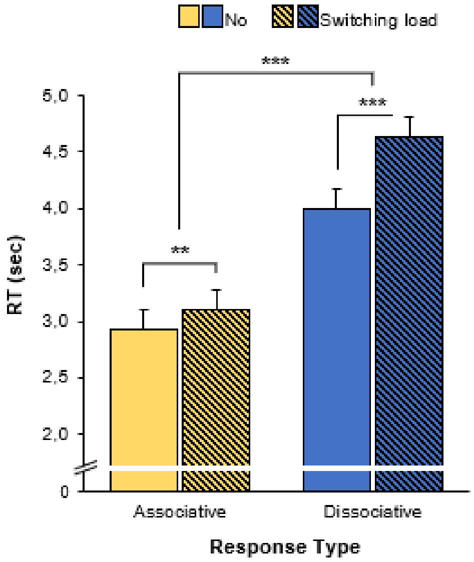

Figure 6.1: The effects of switching load on associative (yellow bars) and dissociative (blue bars) retrieval RTs. The conditions involving switching load are marked with dashed lines. Note that switching load affected both retrieval conditions but more strongly the dissociative production. Error bars represent ± SE. ** $p < .01$, *** $p < .001$

For the second analysis, we investigated the effects of *Response type* (associative vs. dissociative) and *Monitoring load* on RTs in the ACT task. The LMEM interaction showed a significant main effect of *Response type*, $F(1{,}2471) = 201.21$, $p < .001$, and a significant main effect of *Load*, $F(1{,}2480) = 82.33$, $p < .001$. The interaction of the two effects was not significant $F(1{,}2471) = 2{,}09$, $p = 0{,}149$ (see Table 6.2). As expected, response latency was higher for the dissociative condition than the associative condition in both the no-load and monitoring load conditions. Moreover, the latency was further prolonged under the monitoring load (see Figure 6.2). The monitoring load had a similar negative effect on both retrieval conditions, impairing both associative and dissociative responses similarly, i.e. there was an additive but not interactive effect (see Fig. 6.3).

Table 6.2: Effects of Response type and Monitoring load and their interaction.

Effect	***F***	***p***
Response type	201,2137	< 0.001 ***
Monitoring load	82,3285	< 0.001 ***
Response type x Monitoring load	2,0875	0,149

Note: (*** = $p < .001$)

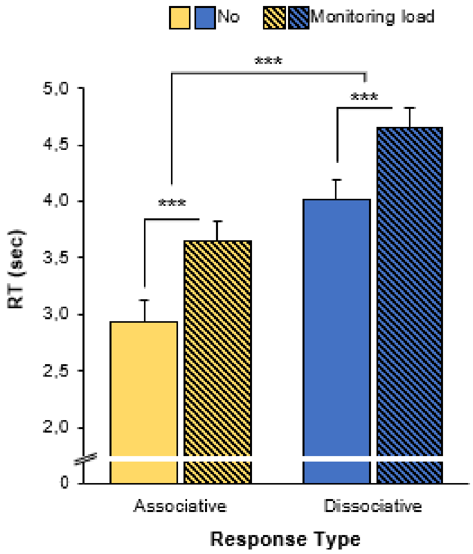

Figure 6.2: The effects of monitoring load on associative (yellow bars) and dissociative (blue bars) retrieval RT. The conditions involving monitoring load are marked with dashed lines. Note that monitoring load affected both retrieval conditions to a similar extent. Error bars represent ± SE. *** $p < .001$

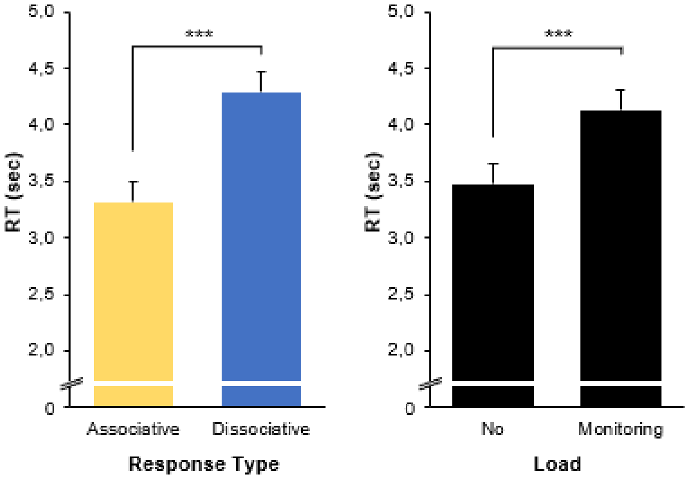

Figure 6.3: The main effect of response type and monitoring load on retrieval RTs in the ACT. On the left both response type conditions are depicted (associative – yellow bar, dissociative – blue bar) without load (indicating the inhibition cost) and on the right the effect of the monitoring load is depicted.

6.1.1 Control Measures for Attention

The LMEM for the Stroop effect showed a significant main effect of *Condition*, $F(1{,}4128) = 1066.1$, $p < .001$, as well as for the Response inhibition, $F(1{,}1301) = 4570.2$, $p < .001$. The incongruent condition yielded higher RTs than the congruent condition in both the Stroop task (see Fig. 6.4) as well as Response inhibition (see Fig. 6.5).

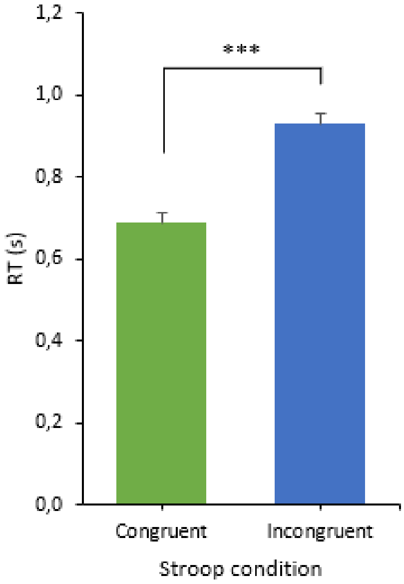

Figure 6.4: Average response times for both congruent and incongruent trials in the Stroop task with a statistically significant effect of *Condition* (*** = $p< .001$)

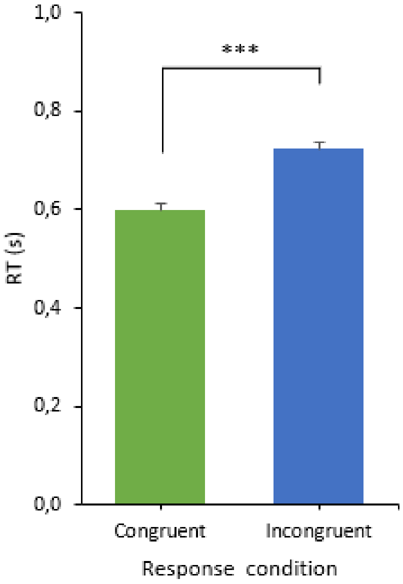

Figure 6.5: Average response times for both congruent and incongruent trials in the response inhibition task with a statistically significant effect of *Condition* (*** = $p < .001$)

6.2 Correlation Analyses

Finally, we investigated the association between controlled semantic measures derived from the main experiment (i.e., inhibition cost, switching cost) and the performance from the two executive attention measures (the Stroop test and Response inhibition test). The correlation analysis revealed that neither of the two control measures (Stroop task and Response inhibition task) were correlated with the retrieval performance. The switching cost correlated negatively with the inhibition cost, $p <.001$ (see Table 6.3 and Fig. 6.6 (A), for Pearson correlations). However, the response inhibition effect (red arrows – white arrows) correlated moderately positive with the Stroop effect, $p =$ .019 (see Table 6.3 and Fig. 6.6 (D)), whereas it was not significantly correlated with inhibition cost or switching costs (see Fig. 6.6 (C) and (F)). The other parameters did not show any significant correlation effect (Fig. 6.6 (B) and (E)).

Table 6.3: Pearson correlations of the inhibition and switching cost and the control tasks (Stroop and Response inhibition).

Pearson Correlations

		IC	**SC**	**SE**	**RIE**
Inhibition cost	Pearson's r	-			
	p-value	-			
Switching cost	Pearson's r	**-0,349**	-		
	p-value	**0,022**	-		
Stroop effect	Pearson's r	-0,052	0,088	-	
	p-value	0,739	0,573	-	
Response inhibition effect	Pearson's r	0,141	-0,150	**0,356**	-
	p-value	0,366	0,338	**0,019**	-

Note: The **IC** = Inhibition cost is a derived measure computed as the difference between dissociate RTs and associate RTs; **SC** = Switching cost, derived measure computed as difference of providing responses within the alternating chains compared to the fixed ones (independently for each response type); **SE** = Stroop effect; **RIE** = Response inhibition effect.

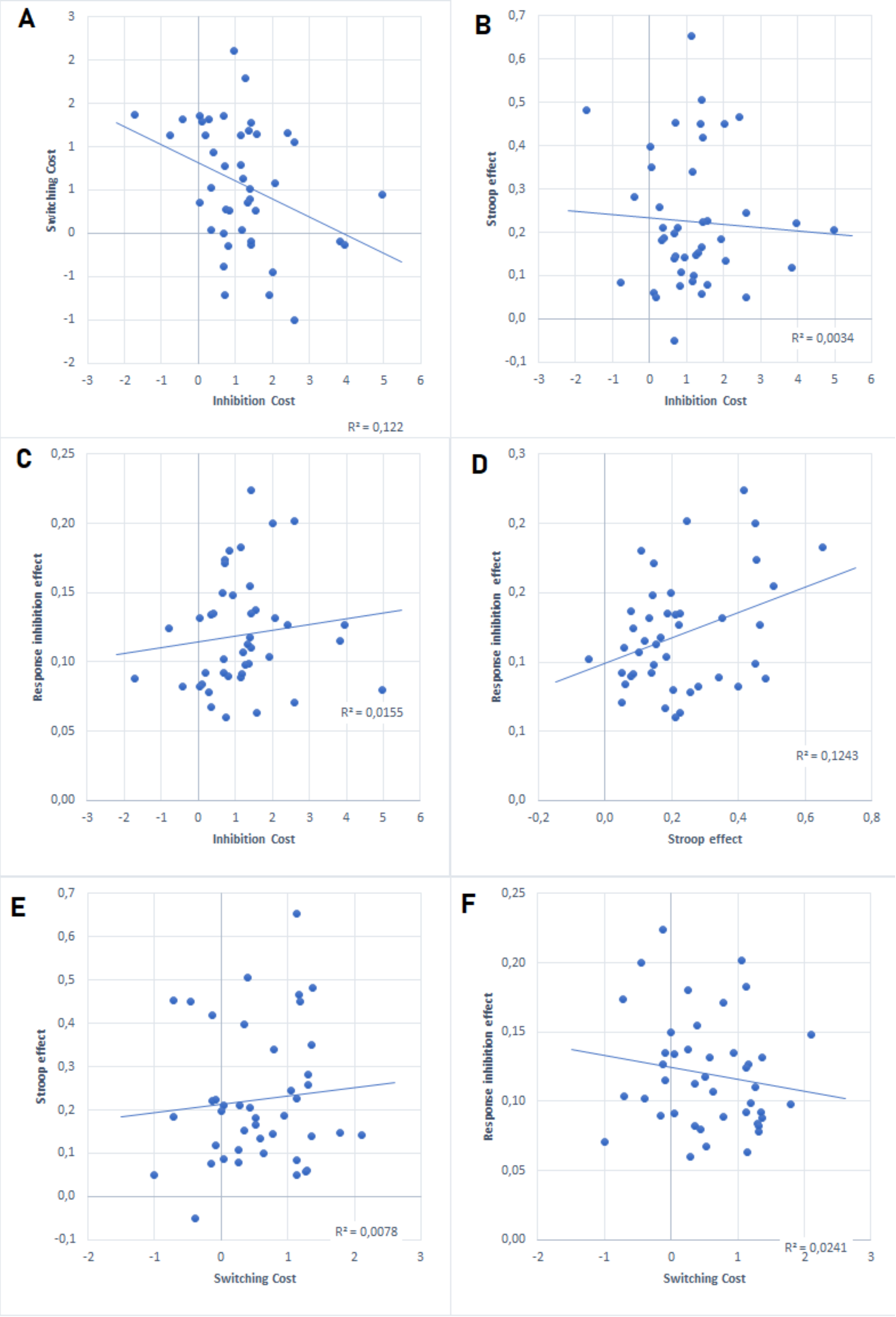

Figure 6.6: Associations between obtained measures from the ACT and the executive attention measures (Stroop effect and response inhibition). Each data point corresponds to averaged RTs for each participant. (A) switching cost and inhibition cost, (B) Stroop effect and inhibition cost, (C) Response inhibition effect and inhibition cost, (D) Response inhibition effect and Stroop effect, (E) Stroop effect and switching cost and (F) Response inhibition effect and switching cost in the control tasks.

Chapter 7

Discussion

This study set out to determine the role of executive attention in controlled semantic retrieval. Executive attention is considered to support the processes of semantic retrieval when it becomes demanding and the task at hand falls beyond automatic retrieval, but the exact mechanism remains poorly understood. Even though recent findings (Ralph et al., 2017) indicate a clear-cut distinction between the automatic and control systems in the CSC framework, we still cannot clarify whether the domain-general system works together with domain-specific systems and thus supports the process of (controlled) semantic retrieval. Our findings indicate that executive attention does seem to play a role in semantic retrieval and supports these processes.

In the main experiment (dual-task paradigm), we investigated the role of executive attentional functions in semantic memory retrieval by introducing two types of (executive) attentional load. We hypothesized that the loaded attentional functions, i.e., the monitoring and switching, play a role in semantic retrieval. We predicted that the load on attention would impair performance in both retrieval tasks, but especially the dissociative task that required control by inhibiting automatically retrieved associates (Allen et al., 2008; Collette et al., 2001). The supposed involvement of cognitive control processes in the dissociative answers was mirrored in longer reaction times, i.e., inhibition cost. This is consistent with authors stating that sustained responses support the preservation of a higher level of attentional focus and alertness while performing the task (Marklund et al., 2007).

Notably, this aspect of executive inhibitory control, to block distraction and keep focus on the task goal, strongly relies on dorsolateral prefrontal systems that are implied in supporting executive functions and working memory (Kane and Engle, 2002). However, within the CSC framework, additional regions as the pMTG and vPFC seem to be involved in semantic control and allow for the interplay of the semantic retrieval system and the domain-general control processes (Badre and Wagner, 2002; Ralph et al., 2017).

Pursuant to our hypothesis, loading attention with a secondary monitoring and switching task slowed semantic retrieval. Especially interesting is the fact that while monitoring load impaired both retrieval conditions similarly, the switching load impaired more the dissociative task condition. This is indicative of the two manipulations regulating semantic retrieval by employing different mechanisms.

Curiously, the switching load significantly impaired only the dissociative retrieval. Importantly, associative responses were also somewhat slowed, but this effect was weaker and less reliable (see Marko et al. (2019b) for similar results). This suggests that switching load interacted, in the first place, with a semantic-specific process that is engaged in the controlled (dissociative) retrieval rather than a general process that helps retrieval regardless of the processing type. If switching between the rules (exerted demand on the domain-general cognitive flexibility operating on different representational types, such as motor, visual, semantic (Diamond, 2013; Ravizza and Carter, 2008)) was supposed to cause longer RTs, then both retrieval performances should be impaired equivalently (the number of switches was the same for both tasks). This was not confirmed by our findings.

However, a unique trait of the dissociative production is requiring a suppression of automatic semantic representations and an arduous search for responses that are semantically unrelated. This response suppression has been connected with further activation in the left dorsolateral PFC and the orbitofrontal cortex, areas that seem to be involved in executive attention and working memory (Diamond, 2013). Therefore, according to the observed interaction, it is possible that switching load impeded this specific control process involved in the dissociative task. A reasonable explanation for the inconsistent switching load effect may come from the opposing nature of associative and dissociative retrieval (Marko et al., 2019a; Marko et al., 2019b). This means that by alternating the retrieval conditions, the activated associative set from the associative trial may interfere with the subsequent inhibitory processing of the dissociative trial (i.e., the association trial initiates a strong spreading activation process that continues into the dissociative trial, further stretching the inhibitory processing). Such an interference is only expected when the two retrieval conditions are alternating orderly and only in the case of dissociative trials, which fits our findings.

The consistent impairment of associative and dissociative retrieval using monitoring load demonstrates a common attentional mechanism underpinning a wider range of processing, including semantic processing (Hartwigsen, 2018). According to the global-slowing model (Mayr, 2002; Mayr and Kliegl, 2000), this finding suggests that executive capacity seems to advance the overall retrieval rate (an absolute constant parameter that is presumably independent from certain semantic characteristics of the retrieval tasks). Considering that dual-task interference stretches executive capacity (Szameitat et al., 2002), less resources are left to bias or guide semantic processing towards either related or unrelated representations, having as a result impaired associative and dissociative performance, accordingly. Another implication of the monitoring load effect is that it may involve representations overlapping with the representations of the ACT task, i.e., that they might be using parts of the same processing areas (e.g., letters were typed and monitored in the two tasks). Badre and Wagner (2007) state that if the secondary task, which is supposed to divide attention, uses the same representations as the retrieval task, then divided attention impairs retrieval significantly.

Additionally, the executive attention tasks (Stroop task and response inhibition task) yielded longer RTs for the incongruent conditions, indicating that additional activation of attention is necessary to inhibit the automatic processing. The Stroop and response inhibition effects did not significantly correlate with the retrieval measures from the ACT. This can be seen as an indication that the attentional control employed in the control tasks (Stroop task, response inhibiton) and in the semantic tasks is at least partially different. Further research is necessary to shed light onto the precise nature of attentional involvement in continuous retrieval from semantic memory.

Measurements of Executive Attention

Although we used the Stroop and response inhibition tasks as control tasks, we were, indeed, not able to assess all different forms of attentional processing, which means that our assessment of executive attention was rather limited. Perhaps a more extensive assessment of general-domain inhibition, switching, and updating would make our measures more sensitive and they would show some link to ACT measures. Therefore, further research should involve a wider span of measures pertaining to executive attention and possibly use multiple measures for the same attentional construct to enhance the reliability of the results.

7.1 Limitations

Some authors (Fernandes and Moscovitch, 2000) noted that people are much better at dividing their attention when it comes to tasks of different modalities. In the case of the dual-task paradigm, there is a possibility that the monitoring load additionally burdened the same modality of the ACT, as both typing words and recognizing letters activate letter patterns which may be using the same mechanism. Additional time delay may have been caused by participants who were not able to focus only on the screen while typing and kept looking at the keyboard, thus not being able to fully monitor the monitoring task. This study did not test for verbal fluency in the participants, nor did we test for the typing abilities as we used a population of students who are mostly required to type frequently and in a fast way.

The data presented was recorded in the same environment (i.e., an empty office space at the University) which should result in a relative homogeneity of the data. It remains an open question to what degree the measures used in our study can generalize to other populations and how strongly they are involved in natural behaviors and everyday use of semantic cognition. As this study did not include any neuropsychological or physiological measurements, there is a limitation on interpreting the data from the neurological viewpoint. Nevertheless, the greater project in which this study is embedded in, will correlate the attentional resources with the semantic memory processes using tDCS.

Another possible limitation that we uncovered was the influence possible strategies may have had on the response speed of the ACT task. Therefore, the participants were advised not to develop strategies for solving the task (e.g., generating words starting on a certain letter in dissociative chains) and the responses were later checked for such strategies before the statistical analysis, which means that this should not bias our results. The participants were also advised not to use the same words, and most of the participants fulfilled this requirement. Further research could find out more by asking participants whether they developed strategies and which strategies in particular helped them. A method that may be helpful is the use of first-person research methods, such as the micro-phenomenological interview (Bitbol and Petitmengin, 2017; Petitmengin, 2006), which may further help to account for individual differences in reaction times.

Additionally, further research including bilinguals would be interesting regarding the role of the executive system in semantic processing. Although this study was done with Slovak students, many of them received instructions in English which may have influenced their way of thinking and solving the tasks (e.g., Stroop task). The question that arises may be whether bilinguals would solve the task in the same speed, or if they would need more time because their control processes would have more to inhibit? This question may be answered by future research.

Conclusion

In this study we conducted a behavioral experiment using the dual-task and task-switching interference approaches to investigate the role of domain-general executive processes involved in semantic retrieval. Unlike previous studies, we employed novel generative tasks, that allowed us to distinguish between associative (automatic) and dissociative (controlled) retrieval mechanisms. This further helped us to explain the way in which these two processes interact with executive functions, in particular attentional functions. The interaction of the domain-general and the domain-specific systems is still not very clear, leading researchers to assign different mechanisms of control to the multiple-demand network, said to offer support to different domains and tasks when they become demanding.

From a more extensive perspective, our results confirmed the hypothesis that general-domain executive functions aid continuous retrieval from semantic memory, greatly agreeing with previous models on verbal fluency. Nonetheless, current findings significantly extend previous findings and show that different forms of load interference obstruct automatic and controlled retrieval in a different way (the monitoring load was additive, whereas the switching load was interactive). These findings provide a deeper insight into the possible mechanisms that dominate these interactions.

We hope that this study, in the greater scope of the project it is involved in, will shed light on these processes underlying semantic retrieval. As McRae and Jones (2013) state, the current high level of enthusiasm around semantic cognition research should be furthered with the help of researchers who will clarify, compare, and combine theories, and test the predictions resulting from the theoretical efforts.

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