Title

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Publication Date
2020-05-01

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Acknowledgements

This work is supported by the Cognitive Science and Psychology Division of the Undergraduate Laboratory at Berkeley (ULaB) at the University of California, Berkeley. We are grateful for Stanley von Ehrenstein-Smith and Sophia Batchelor acting as undergraduate student and graduate student mentor, respectively, for leadership and assistance in data analysis and research management for the production of this extension study. We are also grateful for Professor Mark D'esposito as the faculty advisor of the Cognitive Science and Psychology ULaB. Additionally, we are grateful to Professor Benjamin Pageler for providing relevant literature and discussing aspects of the cognitive model or SPAN. Finally, we would like to thank our research director Hareen Seerha and other ULaB board members for the development and production of this paper.

Abstract

Psycholinguistics is the study of how neuroanatomical processes influence language acquisition, language structure, and language use (Menn & Dronkers, 2017). According to the field of psycholinguistics, a concept is represented in the mind and is different from the word associated with those representations. Representational theory of mind seeks to explain concepts through symbols and models of cognitive processes (Williams, 1984). In order to be relevant from a psychological standpoint, representational theory of mind must utilize a computational model rather than focus on individual beliefs. Many different theories use a representational model to explore how individuals acquire and categorize concepts. The aim of this study is to develop a theoretical cognitive model—titled the Semantic-Phonological Association Network (SPAN)—of singular concept generation. While developing SPAN, an examination of the current literature and different theories of models relating to concept generation are used as the foundation for the research. For example, Pinker's "Why We Curse" explores the relationship between the phonetics of swear words and the physical manifestations they represent (Pinker, 2007). It is necessary to represent the phonological and semantic networks as separate but intricately connected systems. SPAN seeks to symbolize the connection between the phonological and semantic system. The main goal is to establish auditory-semantic priming effects from the relationship between the mental systems and introduce a nuanced version about how one is able to generate singular concepts that contain semantic, phonological and lexical information.

Keywords: Psycholinguistics, Representational Theory of Mind, Symbols, Semantic System, Phonological System, Cognitive Model, SPAN

Introduction

In the first half of this project, a replication of the study is completed which established the semantic system and detailed semantic maps that outlined semantic categories residing on the cerebral cortex (Huth, Gallant, Heer & Griffiths, 2016). The replication is an imperative part to the breakdown and understanding of the way language is grafted out in the brain. This replication allows for insight into how the semantic system interacts with other language processing systems in the brain. Do these semantic mappings provide us with conceptual frameworks and what role does the semantic system play in the process of singular concept generation? What other systems work in congruence with the semantic system and which systems are involved in language processing abilities? From these questions, SPAN is constructed that details the nuances of the semantic system in relation to the auditory/phonological system. This relationship forms a comprehensive picture of how these systems interact to acquire and produce singular concepts.

One imperative step is to research contemporary cognitive models of lexical selection and models of word processing. An important overarching theme is the model of spreading activation: 1) retrieving items from memory involves activating internal representations 2) activation spreads from a concept to related concepts 3) residual activation accumulates across multiple concepts to facilitate their subsequent retrieval (McNamara, 2014). Due to spreading activation, more concepts are activated in the conceptual framework than needed and this is an important piece to conceptualizing the relations between concepts. With the prerequisite of spreading activation, models in the literature depict what is happening in a person's mind as they select a word. Two important models exist: 1) The Cascade or Waterfall Model and 2) The Electricity Model. The Waterfall Model shows a hierarchical relationship in which one semantic category is selected. The semantic category translates to multiple semantic representations flowing downstream to attach to their associated sound representations (McClelland, 1979). However, the Waterfall Model has its shortcomings because the waterfall is unable to flow in the opposite direction. It does not allow for the bidirectional relationship of the impact of sound on meaning. The Electricity Model is more accurate by allowing for this bidirectional communication between semantic and phonological systems (Aitchison, 2012). SPAN builds on the Electricity Model by including the convergence of both systems to allow for a complete lexical representation and characterizes the effects of the phonological/semantic relationships.

Literature Review:

Psycholinguistic Explanation of Language

Psycholinguistic theories suggest that different subsystems work in union in a partly cascadic and partly parallel manner (Friederici, 2017). This means that language systems (i.e. semantic, phonological and syntactic) must process information simultaneously and be connected in specific ways to provide people with robust language abilities. The language processing model proposed by Menn and Dronkers illustrates the levels through which language processing takes place. First comes the ‘Message Level-Conceptual’ that introduces the arousal of conceptual frameworks, event structures and relations between concepts (Menn & Dronkers, 2017). Next, activation continues to the ‘Functional Level-First Linguistic Level’ to establish semantic associations and roles (Menn & Dronkers, 2017). Then, the ‘Positional Level-Second Linguistic Level’ focuses on the rule-based order in which words are placed (i.e. the syntactic or grammatical structure) (Menn & Dronkers, 2017). Activation then travels to the ‘Phonological Encoding Level’ which attaches sound structures to the semantic symbols (Menn & Dronkers, 2017). Lastly, when all the information to a sentence has been realized, the ‘Speech Gesture Level’ provides the ability to interpret and articulate language (Menn & Dronkers, 2017). In this paper, the focus is primarily on exploring how concepts are structured in the Message Level, how concepts interact with their lemmas in the Functional Level and how the phonological-encoding level is related to support the efficient acquisition and generation of singular concepts.

Theories of Concept Formation

In psychology, there are multiple theories of concept formation and there is no commonly accepted definition of a concept. A concept consists of a set of objects, symbols, or events (referents) which have been grouped together because they share some common characteristics (Merrill & Wood, 1974). The current prominent theories are classical theory, prototype theory, exemplar theory, and theory theory. Classical theory establishes defined categories to place concepts or objects (Stöckle-Schobel, 2012). According to classical theory, new concepts are based upon their features and a concept is exhausted by a list of all its necessary and sufficient features (Wisniewski,2002). In this theory, concept learning must be innate and perceptually mediated. In contrast, prototype theory classifies objects based upon how similar they are to a mental image, or prototype, of what that object should be (Geeraerts, 2016). This allows for boundaries between each category to be blurred. Prototype theory holds that concepts are built around typicality effects where certain features are more common to concepts (Gibbs, 2010). Some psychological concepts, such as emotion, cannot be modeled using classical or prototype approaches and can be better explained by exemplar theory (Siemer, 2008). Exemplar theory categorizes concepts based upon a function of existing human experiences (Ashby & Rosedahl, 2017). Exemplars are built on the experiences or instances of that concept to which people are exposed (Wisniewski, 2002). Theory theory based approaches involve recognizing connections among conceptual categories as less perceptually obvious and more causally connected (Bloch-Mullins, 2015). In theory theory, the concept of a category is judged by specific rules that govern the properties of that category (i.e. the genetic makeup of a cat is causally responsible for cats' various properties) (Bloch-Mullins,2015). SPAN supports the concept of theory theory in which there are causal structures that determine what is essential to a concept. The contents of mental representations include relevant features and the rules governing the semantic category to which the concept belongs.

Neuroanatomical Profile

Numerous parts of the brain play a role in language processing and production. Research still needs to be conducted in order to attribute functional characteristics of language to precise anatomical locations. SPAN is grounded in neuroanatomy by expanding on the Wernicke-Lichtheim-Geschwind model, which emphasizes four main areas of the brain: Broca's area, Wernicke's area, Arcuate fasciculus, and the Sylvian fissure (Hagoort, 2013).

Broca's area is approximately located in the posterior part of the frontal lobe. Per the traditional model, it is responsible for speech production (Nasios et al., 2019). However, more recent studies show that Broca's area, more specifically, the inferior frontal gyrus (IFG) plays a greater role in language processing than previously thought (Altvater-Mackensen & Grossman, 2016). Though the exact function of the different areas of the IFG is still debated, a recent meta-analysis of neuroimaging results indicates that posterior-dorsal (BA 44) of the left inferior frontal gyrus (LIFG) contributes more to phonological cued word retrieval; whereas, anterior-ventral parts (BA 45) of the LIFG contribute to semantically cued word retrieval (Costafreda et al., 2006). Katzev et al. further conclude that by comparing phonological to semantic fluency, and vice versa, higher activation is observed in BA 44 and dorsal BA 45, respectively (Katzev, 2013).

Wernicke's area is located in the temporal lobe. By the traditional model, it is responsible for speech comprehension. Different aspects of language processing are thought to activate different regions of the temporal lobe. The use of positron emission tomography scan (PET) to examine brain activity during phonological and lexical semantic processing shows that phonological processing is associated with greater activation of the left superior temporal gyrus (Démonet et al., 1992). Lexical semantic processing is associated with greater activity of the left middle and inferior temporal gyri (Démonet et al., 1992). This is further supported by an fMRI study that employs "auditory pseudoword repetition task as a semantics-free model of lexical (whole-word) phonological access" (Graves et al, 2008). The study bears significant effects which suggests that the left posterior superior temporal gyrus (pSTG) is involved in accessing lexical phonology (Graves et al, 2008).

Conceptual features of the word elicit different patterns of responses from different parts of the brain. For instance, reading action words that are semantically related to different body parts activates the motor and premotor cortex (Hauk et al, 2004). Reading names related to tool action activates the sensorimotor regions (Van Dyke, 2006). In addition, words associated with these conceptual features are accessed in adjacent brain regions. For instance, words associated with color activate the left ventral lobe whereas words associated with motion perception activate the medial temporal lobe. Properties of the words are not only grouped by the logical categorization of the word (Van Dyke, 2006). Rather, the left and right hemisphere of the brain are active when one attempts to understand language in a certain context, such as specific sub-processes like metaphors. The activation of both the anterior temporal lobe and the fronto-medial cortex during this task suggest that they are involved in language processing in context (Ferstl et al, 2008).

The arcuate fasciculus "contains long and short fibers that connect the frontal, parietal, and temporal lobes" and transmits information between the Wernicke's and Broca's area (Catani & Thiebaut de Schotten, 2008). Another parallel route, the inferior parietal lobule (IPL), is also a vital region of the brain that intersects a host of important neurological processes. The IPL explains the variety of deficits (such as impaired speech repetition) resulted after a stroke or surgery in this area (Fridriksson et al, 2010). The inferior parietal lobule is composed of the supramarginal gyrus (rostrally) and the angular gyrus (caudally). An fMRI study of infants shows, when presented with speech stimuli, the superior temporal and angular gyri are active in language processing, similar to those of adults (Dehaene et al, 2002). An ALE analysis of eight fMRI studies on categorical phoneme perception suggests that the left supramarginal and angular gyrus are more likely to be activated during this task (Turkeltaub et al, 2010). SPAN aims to make these connections between anatomical systems clearer and to gain a further understanding to depict the diverse relationships between brain regions.

Methods and Materials

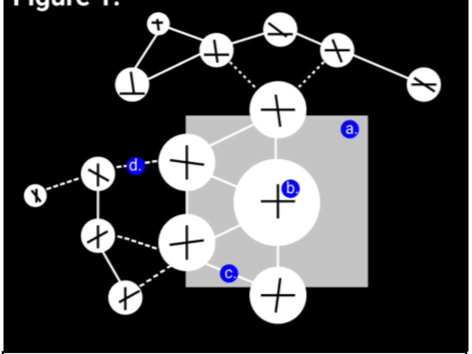
The Semantic System

This section is a description of the different components that comprise the semantic system proposed by SPAN. The section identifies the process by which these components are integrated and how they align with the literature and data from empirical studies. The components of the semantic system are: 1) the nodes (circles in the conceptual network) 2) the symbols within the circles (semantic representations) 3) the lines that connect the nodes (either continuous or dotted lines) 4) the boxes which act as the target locations and platforms for conceptual representations and 5) the selection of the concept lemma. One important model is Menn, Levels of Language Processing. SPAN expands upon Messenger Level, part of Levels of Language Processing, which represents the conceptual network. The Functional Level, part of

Levels of Language Processing, characterizes the lemmas and semantic representations that are attached to the conceptual representations propagated from the conceptual network.

The conceptual network, shown in Figure 1, is found at the top of the semantic system. The conceptual network demonstrates how spreading activation excites relations between types of categories and kinds of tokens that fit into each category. There are nodes of different sizes that directly correlate to the level of activation needed to excite a specific concept (i.e. if the semantic category of pets is activated, dogs, cats and birds are thought of more frequently than pigs, horses or snakes, displaying typicality effects). A larger node indicates that more activation has spread to those concepts, whereas a smaller node indicates smaller amounts of activation. The dotted lines represent inter-category associations (i.e. differences between the different types of categories such as the category pets vs. food). The continuous lines represent intra-category associations (i.e. differences between specific kinds of a category such as dogs, cats and birds). The gray square in the conceptual network can be conceptualized as the target location for the conceptual representation. The grey square is analogous to a chemically mediated receptor site and denotes the conceptually mediated receptor site of the target concept. The conceptually mediated receptor site is shaped in a particular way in order for the concept to attach and its content to become accessible for use.

Figure 1.



a) The box or target platform for the concept; multiple concepts can encroach into the target space depicting semantic priming effects.
b) The nodes where the symbol/mental representation resides inside.
c) Continuous lines represent intra-category relationships.
d) Dotted lines represent inter-category relationships.

The symbols inside the nodes represent the concepts themselves. The symbols emphasize that the concepts are not identical to the lexical words which denote them; therefore, a symbol is used in order to align with the Language of Thought. Language of Thought determines that unconscious thought is represented by symbols which code for the complete content of that concept (Fodor, 1990). SPAN supports theory theory because the content of the symbol is denoted by what is causal of that concept. Symbol orientation represents different concepts that are similarly structured. The orientation provides insight into why those symbols are connected in this framework as opposed to symbols belonging to other semantic categories. Activation moves on from the conceptual network by propagating a conceptual representation. Once the conceptual representation has been retrieved, the lemma (meaning with no sound structure attached or semantic representation) is attached in the Functional Level.

In the Functional level, the symbol is processed by attributing meaning to the conceptual representation shown in Figure 2. There is no sound structure accounting for the Tip of the Tongue Phenomenon (the meaning of a concept is known but the sound representation is missing). With all the components integrated together, an account of the semantic system in the unconscious mind is produced. The conceptual system is represented by a nested hierarchy of categories and concepts. Due to spreading activation caused by the conscious input of a semantic category, more concepts and categories are activated than are necessary. This activation processes a target conceptual representation. The target symbol is then propagated and its lemma is attached (most likely retrieved from long term memory).

Figure 2.

The semantic representation is being attached to its lemma in order to imbue the conceptual representation with a specific semantic representation.

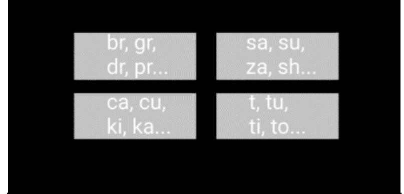
Phonological System

The basic sound representations or phonemes are formed in the phonological system (right-hand side of SPAN). Phonemes are the smallest unit of sound that carry no meaning (i.e.

ca, br, gr). In Figure 3. there are four grey rectangles that contain sound representations.

The grey rectangles act as “phonological area codes” in the sense that the phonemes of each grey rectangle sound similar compared to the other phonemes (Aitchison, 2012). This implies a neighborhood of neurons that will be activated at the same time for similar sound structures. Adjacent neighborhoods will be activated for different sound structures. The phonological area code region is similar to the Messenger Level of Language Processing but applies to sounds. Parallel to the spreading activation in the conceptual network, more phonemes are activated than are necessary and the activation spreads to sounds that are similarly structured. Only singular phonemes and sound representations will be projected when a certain threshold level of activation is reached. Once a semantic category is established, the sound representations will become active and be projected to the theorized phoneme organizer mechanism.

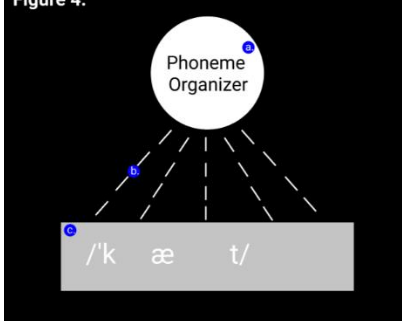
Figure 3.



The sound representations denoted as phonemes are depicted.

As shown by Figure 4, the phoneme organizer mechanism is in place to ensure that constituent phonemes are organized properly and in the right order when structuring a word. The mechanism creates the morpheme template necessary to attach to the semantic representation. Humans need some mechanism to produce words with the proper organization of sound representations. The placement of sound representations accounts for the compositionality of an acoustic word. The organizer works on a millisecond time scale. The mechanism continuously excites sound representations and inhibits irrelevant sound representations that pass the initial level of activation. The phoneme organizer

Figure 4.



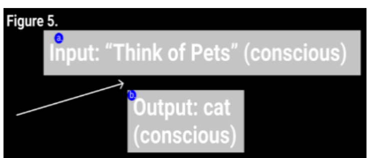
a) The phoneme organizer mechanism
b) Projections from the phoneme organizer to the sound representation platform.
c) The box represents the sound

projects relevant sound representations to a specific placement known as the sound representation platform (the grey rectangle). The sound representation platform is analogous to the Functional Level of Language Processing. The sound of the word without the attached meaning (morpheme template) is represented in the sound representation platform. All steps in the phonological system are processed unconsciously until semantic and phonological representations converge to produce the conscious generation of a singular concept.

Discussion of The Semantic-Phonological Association Network

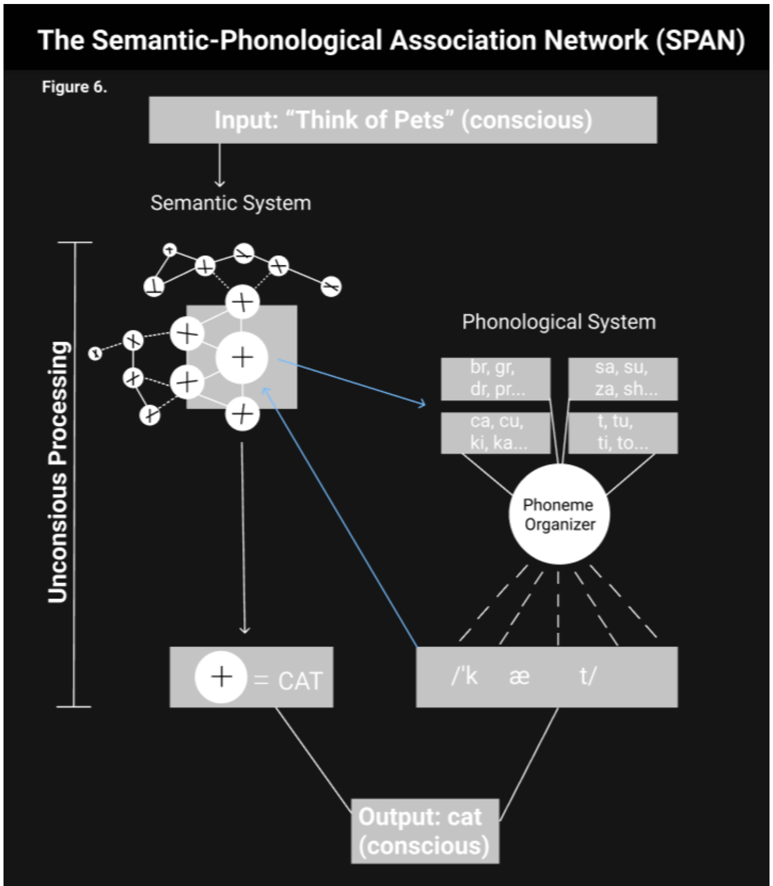
As seen in Figure 5, the input of this model begins with the conscious establishment of a semantic category (i.e. pets) and ends with the conscious output of a singular concept (i.e. cat). There is unconscious processing between input and output. SPAN details the mental systems implicated in that unconscious processing and depicts how mental representations can be manipulated, operated upon and structured. One aim is to further understand the robust ways in which different regions of the brain are functionally coupled. A theoretical description of the nuances in these regions is necessary because this will provide insight into how they could be computationally modelled.

Figure 5.



a) The input of the cognitive model begins with the establishment of a semantic category.
b) The output is the conscious generation of a singular concept as a lexical representation.

As seen in Figure 6, SPAN illustrates the relationship between semantically grounded concepts that form categories based on meaning and between phonetically grounded concepts that form categories based on sound structure/individual phonemes. SPAN contains two blue arrows that characterize the relationship between the semantic and phonological systems. These blue arrows can be represented in the brain as white matter fiber tracts (axons) that functionally connect these two regions for the purpose of singular concept generation. A semantic category needs to be established in order for phoneme representations to be activated. This relationship is depicted by the top blue arrow pointing from the semantic system to the phonological system. Once a semantic category is realized, sound representations start activating in parallel with the spreading activation realized in the conceptual network. The relationship from semantic to phonological is clear because sounds to a word cannot be conceptualized without knowing what



An overall integration of all the component pieces shows how they relate to one another and where the systems connect. The mental systems communicate as information is processed in a parallel fashion.

categories need to be used. The bottom arrow represents the relationship from the phonological system to the semantic system. This arrow represents the notion that sound can influence the meaning and activation of a certain concept in a semantic category.

The acquisition of a concept can be prompted by producing a sound that fits into the target semantic representation. For example, if asked to produce mammals that live in the water and the phoneme “Be” is prompted, people are likely to unconsciously activate the conceptual representation and consciously retrieve the lexical representation “beaver” faster than if left unprompted. Therefore, the sound representation platform can influence the spreading activation occurring in the conceptual network. This establishes auditory-semantic priming effects. Once the meaning representation and the parallel sound representation are activated and projected to their representational platforms, they need to converge in order to form the desired lexical word. There are two constituent representations (i.e. phonological and semantic) that fuse together. In the output of SPAN, the two constituent representations converge and one lexical representation (i.e. cat) emerges into the conscious mind. The semantic and phonological systems coordinate to have this process realized.

Experimental Design:

In our experiment, we intend to explore the influence of the phonological system on the semantic system and establish sound representations as a prime for semantic representations. Our experiment will contain two groups (one experimental and one control). The experimental group will be played a recording of six different phonemes for three seconds with each phoneme lasting one second (i.e. the recording would play “ra, ra, ra” with each “ra” lasting one second before transitioning to the phoneme until all six have been played). Once the recording ends, a semantic category such as pets would be established, and the group would be provided with 45 seconds to generate as many pet concepts as possible (singular concept generation). They would be placed through three trials where they would need to generate concepts for three separate semantic categories. The control group would be placed in the same conditions; however, they would not be exposed to the phoneme recordings and therefore, would receive no sound input before listing concepts belonging to the semantic category. We hypothesize that the experimental group will produce more concepts that contain the sound structures that they were exposed to than the control group. If this is the case, auditory-semantic priming effects would be established because the sound representations activated semantic representations with those sound structures in the conceptual framework of the semantic category. This experiment correlates directly to our model in the relationship from the phonological system's sound representation platform to the conceptual network in the semantic system.

Conclusion and Future Directions

SPAN depicts the nuanced relationships between the semantic and phonological system by functionally coupling the mental systems. Certain white matter fiber tracts connect auditory and semantic regions of the brain to support parallel processing of complete singular concept generation. Research of these anatomical relationships can establish other systems involved in systematic and productive language abilities. How do these systems communicate and interact with one another? SPAN provides insight into the flow of information. There is bidirectional bottom up and top down communication. This form of communication implicates that high-level processing (i.e. concept generation, creation or recognition) impacts low-level processing (i.e. phoneme organization or attachment as well as activation of types of semantic categories) and vice versa.

Speech errors bring up many questions and can be conceptualized in SPAN. Blend errors are the fusion of two acoustic words or morpheme templates from the same semantic category (i.e. “herrible” for horrible and terrible) (Aitchison,2012). Blend errors can be explained by the lemma attaching to one conceptual representation; however, a mistake is made at the level of the phoneme organizer. The organizer confuses the sound representations for that specific lemma or semantic representation. The organizer sends a mix of two morpheme templates of an acoustic word. The semantic representation proceeds to attach to the botched morpheme template. This produces a lexical representation that contains the fusion of two morpheme templates directed by the same semantic category. The interpretation of these errors is a topic of further discussion.

Semantic priming effects are incorporated into SPAN. Different concepts from the conceptual framework can encroach onto the conceptually mediated receptor site displaying partial activation for those words. If the target conceptual representation is not activated enough, the primed conceptual representations can slip into the receptor site (slightly imperfectly) which can be brought to conscious retrieval. Priming is an area of interest and SPAN establishes auditory-semantic priming effects that determine how the phonological system can prime the acquisition of word meanings in the conceptual framework.

Mental systems are complex, and SPAN does not incorporate all the interrelated connections among semantic networks. Additionally, many different brain areas such as Broca’s and Wernicke’s area, are involved in language processing. One limitation of SPAN is that it does not address the entirety of the brain’s language information processing structures. Many other mental systems are required to support concept generation and recognition. SPAN takes important steps into defining the content of mental representations, mechanisms required to achieve proper word coherency and the relationships between mental systems to efficiently generate singular concepts.

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