Revi
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Working Memory and Consciousness: Three Theorical Frameworks*

[English Version]

Memoria de trabajo y Consciencia: tres perspectivas teóricas

Memória de trabalho e consciência: três quadros teóricos

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Abstract

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The view of Working Memory (WM) as a conscious process has allowed defining consciousness as the content of working memory. However, concerns have emerged over comparisons between consciousness and working memory. **Goal**: although the relationship between these two study fields has been the matter of psychology, philosophy and neuroscience, a theoretical review addressing the core elements of highly cited perspectives would enrich the discussion in this study area. **Method**: this review focuses on three theoretical frameworks: 1) the multi-component model of working memory, 2) the global workspace theory, 3) the hierarchical framework. The authors analyzed 113 articles which discussed the previous three models. **Results**: the multi-component model of working memory contributes a basic functional description on how mental representations remain on-line during complex cognitive processing. Thereby, the information exchange between the central executive and the episodic buffer, in one sense, and the phonological loop and the visuo-spatial sketchpad in the other is given through conscious processing. **Conclusions**: likewise, the central executive controls and changes attention but the episodic buffer allows multimodal information availability.

Keywords: consciousness; working memory; global workspace theory; hierarchical framework; self.

Resumen

La perspectiva de la Memoria de Trabajo (MT) como proceso consciente ha permitido definir la consciencia como el contenido de la MT; sin embargo, han surgido inquietudes sobre las comparaciones que se han realizado entre ambas. **Objetivo**: aunque la relación entre estos dos campos de estudio ha sido planteada desde la psicología, la filosofía y la neurociencia, una revisión teórica que aborde los elementos centrales de las perspectivas más citadas enriquecería el debate en esta área de conocimiento. **Metodología**: esta revisión se centra en tres perspectivas teóricas: 1) el modelo multicomponente de memoria de trabajo; 2) la Teoría del Espacio de Trabajo Global (GWT); 3) el modelo jerárquico. Se analizaron 113 artículos en los que se abordaron las tres perspectivas anteriores. **Resultados**: el modelo multicomponente de memoria de trabajo aporta una descripción funcional básica sobre cómo las representaciones mentales permanecen en línea durante un procesamiento cognitivo complejo. De este modo, de un lado, el intercambio de información entre el ejecutivo central y el búfer episódico; y de otro lado, el bucle fonológico y la agenda visuoespacial se presenta a través del procesamiento consciente. **Conclusiones:** asimismo, el ejecutivo central controla y modifica la atención, pero el búfer episódico permite la disponibilidad de información multimodal.

Palabras-clave: consciencia; memoria de trabajo; teoría del espacio de trabajo global; modelo jerárquico; yo.

Resumo

A visão da Memória de Trabalho (WM) como um processo consciente permitiu definir a consciência como o conteúdo da memória de trabalho. No entanto, surgiram preocupações sobre as comparações entre consciência e memória de trabalho. **Objetivo**: embora a relação entre estes dois campos de estudo tenha sido a questão da psicologia, filosofia e neurociência, uma revisão teórica abordando os elementos centrais de perspectivas altamente citadas enriqueceria a discussão nesta área de estudo. **Metodologia**: esta revisão se concentra em três estruturas teóricas: 1) o modelo multicomponente de memória de trabalho, 2) a teoria do espaço de trabalho global, 3) a estrutura hierárquica. Os autores analisaram 113 artigos que discutiam os três modelos anteriores. **Resultados**: o modelo multicomponente de memória de trabalho contribui com uma descrição funcional básica sobre como as representações mentais permanecem on-line durante o complexo processamento cognitivo. Assim, a troca de informações entre o executivo central e o buffer episódico, em um sentido, e a alça fonológica e o bloco de desenho visuoespacial no outro se dá por meio de processamento consciente. **Conclusões**: da mesma forma, o executivo central controla e muda a atenção, mas o buffer episódico permite a disponibilidade de informações multimodais.

Palabras-chave: consciência; memória de trabalho; teoria global do espaço de trabalho; estrutura hierárquica; auto.

Introduction

According to integrated information theory (Tononi and Koch, 2015), consciousness is the brain's ability to promptly integrate information. It is a holistic context synthesizer in which the individual is immersed. This type of ability requires a functional thalamocortical system which generates oscillations in gamma frequency (Tononi *et al.*, 2016). In fact, thalamocortical injuries are highly related to global loss of consciousness, as can be seen after comas (Laureys *et al.*, 2004). Neural activity correlated with conscious experience is widely distributed over the cortex which suggests that consciousness depends on the thalamocortical network instead of a unique cortical area (Tononi *et al.*, 2016). This statement suggests that injuries over specific cortical regions can impact conscious experience without affecting global consciousness like the inability to perceive faces (Kolb and Whishaw, 2006).

The Neural Correlate of Consciousness (NCC) is defined as the minimum neuronal mechanisms jointly sufficient for any one specific conscious percept (Crick and Koch, 1990; Frith, 2005). There are two possible interpretations of this definition, depending on whether referring to the specific content of consciousness or to the overall state of being conscious.

The specific content of consciousness are the neural mechanisms that determine a particular characteristic within the experience. For example, the NCC for experiencing the specific content of a face are the neurons that fire on every trial, whenever a person observes, imagines or dreams a face, and are silent under other circumstances (Frith, 2005). When these neurons are artificially activated trough transcranial magnetic stimulation (TMS), an individual should see a face, even if there is none on the screen, but if these neurons' activity is blocked, an individual should not see any faces, even if showed on the screen (Koch *et al.*, 2016). From a different perspective, the NCC is the neural substrate that promotes the conscious experience as a whole (Koch *et al.*, 2016).

Research around the NCC has seen the discovery of synced neural discharges over the visual cortex, as a response to two visual stimuli that produce gamma waves (30-70 Hz). However, this has raised questions and doubts in the scientific community (Gray *et al.*, 1989). It is now well accepted that consciousness requires neurons to be synced trough rhythmic discharges (gamma waves) (Crick and Koch, 1990) to explain multiple stimuli integration in a single experience (Singer, 1999). Syncing over the visual cortex is elicited trough attention (Roelfsema *et al.*, 1997) and reticular activating system stimulation (Herculano-Houzel *et al.*, 1999; Roelfsema *et al.*, 1997). Likewise, it reflects perceptual dominance in binocular rivalry tasks, although firing rates might not change (Fries *et al.*,1997). Previous works using electroencephalography and magnetoencephalography suggest that gamma synchrony correlates with visual consciousness as well (Melloni *et al.*, 2007; Rodriguez *et al.*, 1999).

However, most studies did not differentiate conscious visibility from selective attention. Once this has occurred, wide range gamma waves syncing correlate with attention, whether the stimulus was seen or not, but middle range gamma waves correlate with stimulus visibility (Wyart, andTallon-Baudry, 2008). Gamma synchrony might increase during non-rem sleep in anesthetized patients (Imas *et al.*,2005; Murphy *et al.*, 2011) or in seizures (Pockett and Holmes, 2009) or even when exposed to stimuli that provoke unconscious emotional responses (Luo *et al.*, 2009). These findings suggest that gamma synchrony might occur when there is a lack of awareness. A previous study used electrocorticography over the visual cortex and showed that low amplitude gamma oscillations are elicited through spatial patterns (light grids) but not with noise or images that can be seen (Hermes *et al.*, 2015). Finally, these findings suggest that gamma waves are not entirely necessary to be seen (Ray and Maunsell, 2011).

Another electrophysiological marker for consciousness is an event related potential (ERP) around 300 ms (P3b) after the stimulus presentation. It is provoked by visual or auditory stimuli and found over the frontoparietal region (Sutton *et al.*, 1965). Some studies using paradigm-based tasks have shown that the P3b component is a neural correlate of the stimulus detection report (Dehaene and Naccache, 2001; Del Cul *et al.*, 2007; Sergent *et al.*, 2005). Therefore, the P3b component which is measured through the auditory odd-ball paradigm has been proposed as an accurate signal of consciousness over the frontoparietal network (Dehaene and Changeux, 2011).

However, this perspective has been underestimated along experimental studies. For example, an irrelevant stimulus for the execution of a task will not activate the P3b component (Silverstein *et al.*, 2015) even if an individual is completely aware of it (Pitts *et al.*, 2014) but, those stimuli that the individual is not aware of can activate the P3b component (Silverstein *et al.*, 2015). This is not a signal of conscious perception once the stimulus is already in working memory (WM) (Melloni *et al.*, 2011). On the other hand, an ERP starting 100 ms after the stimulus has been presented will reach its peak around 200-250 ms. It is located in the posterior cortex (Pitts *et al.*, 2014; Railo *et al.*, 2011) and correlates with conscious perception.

Low-voltage rapid discharges in the EEG while awake, also known as active EEG (Moruzzi and Magoun, 1949) was one of the first consciousness index and remains as one of the best sensitive markers. Intracellular recordings of cortical and thalamic neurons in cats have revealed the underlying mechanisms of the transition from low-voltage rapid discharges (awake) to high voltage slow discharges which is common in deep sleep or even under anesthesia (Steriade, 2000). When thalamic neurons are hyperpolarized, they change from a tonic mode to a fast trigger mode which results in the EEG syncing in theta waves (5-7 Hz) (Steriade, 2000). The widest oscillations in delta waves are seen when cortical neurons start alternating between depolarization and hyperpolarization states every second (Steriade *et al.*, 2001).

This group of physiological changes will present along with loss of consciousness under pharmacological, pathological, and physiological conditions (Brown *et al.*, 2010). Within the most accurate strategies to assess loss of consciousness, the detection of slow waves with large amplitude has been found to be the best choice (Kertai *et al.*, 2012; Murphy *et al.*, 2011). As an example, slow waves are more common under deep sleep the first hours of the night and once every individual has been awakened, they would deny any perception (Siclari *et al.*, 2013). Likewise, a sudden increase in the wave power matches loss of consciousness when inducing anesthesia trough Propofol (Murphy *et al.*, 2011; Purdon *et al.*, 2013). In a clinical setting, a pattern change from delta to alpha waves will explain the transition from vegetative state to minimally conscious state (Schiff *et al.*, 2014).

Given these previous findings, some studies have stated that consciousness is a way of processing information and have set the importance of the NCC (Aleksander, 2011; Baars, 1988; Earl, 2014; Fingelkurts and Fingelkurts, 2017; Tononi, 2012). Consciousness allows the transmission and processing of information. Now, because the information it produces, is meaningful for the person who consciously experiences it, the person, who consciously experiences it, knows what it means for him/her. Finally, because the information it produces is "individuated" (Jonkisz, 2016), in the sense that it has "that" meaning only for the person experiencing it, and not for other people. For example: I know what it means for me to experience "fear," but another person cannot directly know what it means for me to experience "fear" (and vice versa).

Therefore, a relevant issue when analyzing consciousness is addressing *the self*, which is understood as a mechanism that allows individuality and continuity of the conscious experience. That is how the self becomes relevant to the organism, it makes up body and mind in a single unit: personality. So, the self is an autobiographic characteristic, constantly being updated and at the same time it expands on the subjective representations of reality, even on the emotional setting. This device owns a physiological correlate which is understood in the representation of the body (neural circuits), its projections to the hippocampus, amygdala, and middle prefrontal cortex (Damasio, 2003a, Damasio, 2003b). To make this happen, the conscious self requires continuous storing and updating of every single experience in memory. This perspective has WM as the basic cognitive domain underlying consciousness (Marchetti, 2018).

WM is a cognitive system involved in the temporary storing and processing of information to be able to perform a task (Baddeley, 2007). Likewise, WM discriminates between relevant and non-relevant information when performing a cognitive task (Unsworth and Engle, 2007). WM is heavily involved in attentional control (Broadway and Engle, 2011). This point of view has allowed considering WM as a "working space" where thinking and cognition take place (Baars and Franklin, 2003). This statement has been proved empirically given the strong association between WM and higher cognitive processes (Engle, 2002).

The relationship between WM and consciousness is clear in Alan Baddeley's multicomponent model, which is relevant in current research (Baddeley, 2017). For example, it is assumed that information that remains in WM is conscious. This previous idea would consider that WM operates with information that is accessed consciously and, somehow it is assumed that WM and consciousness are the same. This is a very arguable perspective that may justify a better definition of consciousness than merely the content of WM. However, doubts have been raised against the idea of WM being compared to consciousness given that both concepts are integrated units (Cowan, 2012).

Although consciousness and WM share functional properties, how they relate to each other is of great interest. For example, a research field is focused on how WM content may impact consciousness. This perspective addresses how visuo-spatial representations are kept on-line and assesses consciousness through stimuli suppression (Jiang *et al.*, 2007). When performing this task, a group of stimuli projected toward one of the eyes, suppress the visibility of a fixed stimulus which is presented simultaneously to the other eye (Tsuchiya and Koch, 2005). Finally, each individual should indicate once they are conscious of the fixed stimulus, this usually takes a couple seconds.

A clear example of the previous idea is a study where patients had to remember a color while taking a circle detection task (Gayet *et al.*, 2013). These findings have shown that the content of visuo-spatial WM trigger an alert threshold. This threshold was lower when the color of the circles was similar to the one kept on-line in WM. It has also been found that an awareness threshold was lower when a sample face shown in a screen was similar to the face kept on-line in WM (Pan *et al.*, 2014). Together these studies suggest that the content of visuo-spatial WM can impact a visual awareness threshold but also biases the access to conscious information.

Another research line has related consciousness to several WM processes and to prefrontal activity. For example, a study had participants learn a group of letters while they performed a masking task where they had to detect a specific digit (De Loof *et al.*, 2013). These findings have shown that the detection task had lower scores when the number of letters had increased. This would indicate an increase in the awareness threshold once information reaches WM (Lavie, 2005).

These previous findings indicate that WM impacts consciousness. However, the relationship between them is still unclear. In the next section, three theoretical frameworks that address this relationship will be explained. Although WM is explained from diverse perspectives this review article will not address the embedded-process model (Cowan, 2012) since its main focus is to emphasize links between memory and attention. From this point of view, stimuli with physical features that have remained relatively unchanged over time and are of no key importance to the individual still activate features in memory, but they do not elicit awareness.

Another approach to explain WM comes from Oberauer who defined WM as a medium for building, holding, and manipulating temporary representations that control current thoughts and actions (2009). However, like Cowan's model it has maintained the role of attention as a selection mechanism, then WM is a form of attention: the contents of WM are selected for being relevant for the current task. Often, different theories—of WM or otherwise—cannot be compared directly because the theories, though nominally on the same topic, actually are based on subtly different definitions of what is being studied (Alloway *et al.*, 2005).

Since this article aims at reviewing the close relationship between WM and consciousness, other approaches that have explicitly introduced this interest will be presented. In the last section, a research line is proposed for future studies.

The Multi-component Model of Working Memory

Baddeley's WM model suggests a hierarchical organization composed by the central executive and some slave systems for storing of information (Baddeley, 2007). Slave systems allow the temporary storing of modality-specific information: verbal (phonological loop), visual, spatial (visuo-spatial sketchpad). Likewise, access to slave systems is considered to be conscious. In fact, an individual is conscious of verbal rehearsal of information stored in the phonological loop.

An arbitrary fact about the phonological loop is that verbal rehearsal itself has no internal storage capacity. In other words: "the inner voice cannot be heard itself" or "the inner voice is deaf" (Buchsbaum, 2013). On the other hand, if verbal rehearsal is thought of as a mechanism that stores and reactivates its own content, then, verbal rehearsal becomes self-sufficient from the information processing theory: it is an inner voice that can be heard.

Leaving aside these behavioral considerations in favor of or against the architecture of the phonological loop, it would seem that they were against the scientific evidence that states: inner speech is a private version of outer speech. Therefore, auditory qualities of the inner ear are quite similar to listening to external speech. For example, from a phenomenological perspective once a green dot has been imagined, it is like observing the same stimulus (Shepard and Chipman, 1970; Smart, 1995). Likewise, during inner speech, verbal information is related to the content of an auditory image in the inner ear, therefore it can be reported consciously.

However, it is not the same case for the inner voice: although someone may report a feeling of agency during inner speech (Morsella *et al.*, 2011), this feeling does not have linguistic content and there are no other types of feelings that can be described as the representation of a verbal message. Consequently, an introspective analysis of the inner speech favors the existence of two independent and conscious components.

The inner voice is a well-known agency marker, it conveys the idea: "It is you who is speaking," but the inner ear carries the conscious content of the message: "This is what you are saying." In fact, the conscious experience of the inner behavior lacks content, except some agency markers like impulses, plans and intentions (Morsella *et al.*, 2011). To be able to have conscious access to the motor program of speech, the representation of behavior should be able to project itself to the sensory-perceptual space. Therefore, it could be stated that the content of the motor program is not vulnerable to introspection without being completed. This is a necessary quality of a self-conscious organism: it will be able to anticipate a behavior once it has been executed or at least internally simulated (Libet *et al.*, 1982). One more way to understand the access to the motor program content is to assume that conscious representations are independent from each other. In other words, a representation cannot observe itself.

On the other hand, the conscious state of the central executive is less clear. It is focused on controlled cognitive processing (Atkinson and Shiffrin, 2016) so, it should be conscious. Conscious executive processes seem to be related to voluntary change of attention or inhibiting distraction from irrelevant stimuli to perform a task. This WM model also relates conscious experience to the central executive (Baddeley, 1992). Empirical evidence is seen when realizing that daydream suppression does not depend on a single modality; it relies solely on the central executive. Given that daydreaming is a state where the mind is completely independent, the central executive has become the WM component who access conscious information (Baddeley, 1992).

However, executive processes like search strategies in long term memory are not under conscious control. Therefore, conscious access to the central executive is partial (Velichkovsky, 2017).

As every WM slave system was thought as modality-specific, it was updated later trough the episodic buffer to keep on-line multimodal episodes (Baddeley, 2000). Episodes on the episodic buffer are the result of sensory integration, remembrances and imagination. On one side, the episodic buffer interacts with single-modality storing systems and on the other side with long term episodic memory. This is how the episodic buffer links memory and consciousness (Baddeley, 2000). Moreover, it is a passive store that holds integrated information units (chunks) and allows the central executive to access consciousness (Baddeley *et al.*, 2010).

In summary, the storing system holds consciously experiences representations. The episodic buffer holds multimodal integrated units to be able to encompass the conscious experience. However, it is the central executive that interacts with consciousness and allows conscious access to those stimuli that remain in WM (Baddeley, 2010).

The multi-component model of WM has introduced one of the strongest theories to back up a conscious WM. In fact, it is assumed that every WM operates on conscious content. The central executive is a conscious system due to the fact that it carries out conscious control over WM and attention. The storing systems themselves, represent consciously its content as is evident in the phonological loop and the visuo-spatial sketchpad. Once stimuli have dissipated from consciousness, it is assumed they have completely left WM (Velichkovsky, 2017).

Given the above, it is not an easy task to reconcile the idea of an unconscious WM with the multi-component model. It seems to be the challenge inside Baddeley's WM model given that on one side a difference between WM and long-term memory is proposed and, on the other side, the difference is posited between controlled and automatic cognitive processing. To be able to understand unconscious WM in the multi-component model is a future research line. It will require changes in the current model such as incorporating the representational states to the slave system (Velichkovsky, 2017).

Global Workspace Theory of Consciousness

A widely accepted model that addresses the close relationship between WM and consciousness is the Global Workspace Theory (GWT) (Baars, 2005). From this perspective, (1) The brain can be shaped as a massive parallel processing system so that, (2) brain processors can work together through data interchange. The role of consciousness is data availability for brain processors. A common example of shared data through the global workspace is the sensory input. The GWT is based on scientific evidence that states that the conscious experience involves multiple activations along the brain (frontoparietal network) as compared to unconscious states as sleep and coma (diminished interhemispheric activity) (Baars, 2005).

The GWT is also known as the metaphor of consciousness where actors (data) in a scenario (WM) are lighted up by a spotlight (attention) (Baars and Franklin, 2003). The dark area of the scenario is related to those aspects of immediate memory that are not the focus of attention. The work done by the actors is controlled "behind the scenes" by executive processes like the *self* (Baddeley, 2007). Finally, the whole scene is observed by an unconscious audience composed of motivational systems and automatic processes (Baddeley, 2007).

Both the GWT and the WM model seem alike, in fact, it has been stated that several WM processes comply with the GWT principles which sets a close relationship between the two theories (Velichkovsky, 2017). However, a more demanding analysis of the GWT discloses the differences between WM and consciousness. From this perspective, WM assumes several unconscious processes (Bergström and Eriksson, 2014). For example, the pre-conscious storing of information over the slave systems is supposed to be modality-specific. Then, the cognitive interplay between WM and consciousness could be explained as: once the sensory input has been recorded, it is sent through the attentional processes to the brain processors to become conscious. The content of consciousness is kept in the phonological loop (Soto *et al.*, 2011). Therefore, action plans and goals start working once operating over conscious data. Likewise, these plans are under the supervision of WM that operates unconsciously. For that reason, conscious operations encompass a single part of the cognitive cycle (Velichkovsky, 2017).

It seems that consciousness as an attentional spotlight is essential to better understanding the relationship between consciousness and WM in the GWT (Baars, 2005). This spotlight chooses a fraction of the cognitive representations that will be accessed by the unconscious cognitive processors. Universal availability of data allows brain processors to start planning a task under little conscious control (Hassin *et al.*, 2009). Consequently, the aim of consciousness is to pick the inner representations inside the content of WM. This idea turns consciousness into an inner attentional process. Then, the relationship between consciousness and WM from this perspective is inclusive. Consciousness is incorporated into WM and is composed by unconscious motor, executive, and perceptual processes. Thereby, consciousness is a subset of WM (Baars, 1988).

Some concerns have been raised around the GWT since it was developed to describe the role of consciousness in goal-directed behaviors (Baars and Franklin, 2003). This theory has not explained the inner mechanisms of WM; therefore, it is not an easy task to explain the interplay between the conscious and unconscious content of the model. A future research line is related to the qualitative differences between the conscious and unconscious content of WM (Velichkovsky, 2017).

The Hierarchical Framework (Donald Stuss)

A series of articles about the study of the frontal lobes were published (Burgess and Stuss, 2017). As a result, three study stages about the frontal lobe function can be identified: (1) the development of tests to assess executive symptoms, (2) the current knowledge in neuroanatomy, (3) studies using neuroimaging techniques to better understand the human brain (Burgess and Stuss, 2017). Finally, three levels of brain hierarchical organization were proposed.

The first level is related to shared brain activity of the functional systems (Stuss and Alexander, 2005). Its neuroanatomical correlate is over the frontal medial and dorsolateral cortex. These two brain areas seem to allow: (a) information organization in a meaningful sequence and (b) skills to direct behavior. The second level of frontal lobe functioning is related to control; its anatomical base is the prefrontal cortex (Andrs and Van der Linden, 2001). This control function is related to consciously focus on a goal and can be divided in several psychological functions: anticipation, goal selection, planning, and monitoring (Crick and Koch, 2003). The last level of the frontal function is consciousness and self-awareness. The neuroanatomical correlate is over the prefrontal cortex which is also close to metacognition (Stuss and Alexander, 2005).

However, a later study about this model allowed to establish three cognitive processes related to performance in executive tasks: *energization*, seen as the process of initiating and sustaining a response; *task setting*, the ability to establish a stimulus-response relationship to respond to a target with specific attributes (planning and organizing); *monitoring*, the process of checking a task over time; and for quality control (Burgess and Stuss, 2017). Most likely, monitoring is

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the closest cognitive process to WM because it can be assumed as an on-line supervision. It is also one of the most important skills related to metacognitive regulation (Schraw and Dennison, 1994).

Finally, metacognitive monitoring involves a calibration process where a subject monitors his/her own thought process and state of knowledge through each WM slave system (Schraw and Moshman, 1995).

Next, some clinical examples about the previous stages are presented:

Energization: an individual with dorsomedial cortex damage exhibits a series of specific deficits like slow processing speed. For example, they cannot keep information on-line (word list) during the last 45 seconds of a verbal fluency task as compared to the first 15 seconds. This is due to a failure to initiate and maintain a response (Picton *et al.*, 2007).

Task setting: an individual with left hemisphere damage will increase the false positive rate in tasks like the Stroop test. This deficit is quite common during the first stages of learning (Stuss and Knight, 2009).

Monitoring: an individual with right hemisphere damage will increase the false positive rate. Likewise, it is not easy to perform arithmetic tasks (calculation, retrieval, strategy use, decision making) (Stuss, 2011).

Probably, anosognosia is one of the most known clinical cases where an individual sees a decrease in his levels of consciousness. This is a domain-specific deficit and is related to a single functional system where the lack of consciousness seems to be the absence of factual knowledge (Stuss, 1991).

Patients with a focal posterior right hemisphere brain injury display several deficits such as: left hemianopsia, prosopagnosia, and heminattention (Stuss, 2011). If this injury extends to anterior areas, the patient will display left hemiplegia. Likewise, anosognosia can also be interpreted as a secondary deficit related to the preservation of necessary abilities to perform the basic activities of daily living.

The Self as an Integrating System of the Conscious Experience in WM

The self is one of the basic cognitive systems underlying the conscious experience. It develops on biological values, naturally selected and culturally acquired. It is the engine that allows holding and expanding an individual's welfare as a whole. The self is expressed through the central and peripheric nervous system which maps the body, its background and the environment. It is through the self that an organism's complex structure becomes the voice of a single individual (Marchetti, 2018).

A wide set of values rules the self, an individual may feel overwhelmed by multiple internal and external stimuli, the body is constantly adjusting to the environment. This requires a mechanism to focus on the most important data to achieve a goal according to the context, but on the other hand it inhibits the noise of irrelevant stimuli. This mechanism is known as attention (Marchetti, 2018).

Attention allows an individual to control large amounts of information, but it also lets him/her select the most important data to meet a goal (Awh *et al.*, 2012). This can be achieved in multiple ways: through an exogenous, unintentional bottom-up processing; through an endogenous, voluntary top-down mechanism (Carrasco, 2011; Chica *et al.*, 2013); addressing internally or externally the focus of attention (Corbetta *et al.*,2008; Corbetta and Shulman, 2002), holding attention for a limited time (Zeman, 1996), even when it has been distributed in multiple stimuli (Eimer and Grubert, 2014).

Attention is an accurate tool for problem solving: in fact, it allows to divide the information flow in attentional episodes and every episode will only consider the content of a momentary subset of problems (Duncan, 2013). Finally, the process of attentional selection sets up new experimental dimensions in addition to those previously established. When selecting non-related stimuli, simulating new scenarios that an individual may not have consciously experimented if attentional capabilities were not available becomes possible (Marchetti, 2018). Therefore, human consciousness is able to use the brain power to build sequential thinking and do simulations while awake with no need of sensory input (Baumeister and Masicampo, 2010).

Although the role of attention can be theoretically assumed as an uninterrupted and continuous process which allows task switching, current data support the idea of attention acting periodically. This periodicity is the product of brain oscillations (Marchetti, 2018). Attention provides a template to shape conscious experiences, therefore, these experiences adjust to the role of attention to detect changes in the self.

However, attention itself is not enough to make the most complex conscious experience happen. Attention is in charge of selecting the core elements of the conscious experience but a mechanism like WM is still necessary to combine and assemble these elements (Marchetti, 2018).

WM is not only about recalling information it is a more general skill related to attentional control that performs top-down control on cognition. WM also allows sequentially combining stimuli. One of the main functions of WM is keeping representations through temporary binding between the content (stimuli, words) and context (stimulus location in a visuo-spatial task)

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(Oberauer, 2009). Likewise, binding has also been involved with declarative and procedural features of WM.

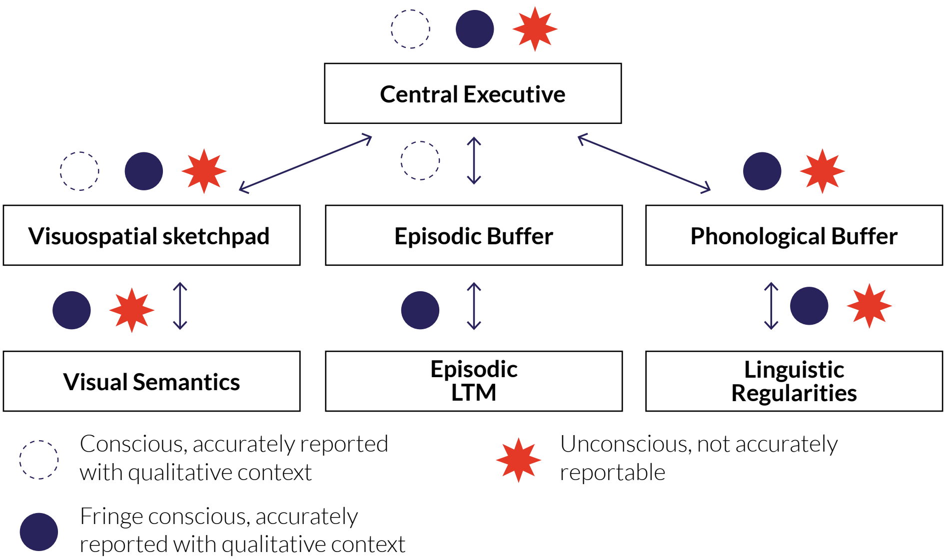
Some works using neurophysiological techniques like EEG have started focusing on this system. Studies have found that for the brain to be able to encode, hold, and retrieve information through WM, it needs to synchronize various tasks with the support of local neural assemblies that work in different temporary scales nested into the same operational hierarchy (Fingelkurts *et al.*, 2010; Monto, 2012). Specially, operational modules (span) seem to be necessary for a successful memory (Fingelkurts *et al.*, 2003). In fact, although memory encoding and retrieval share common regions in the brain cortex, the operational synchrony of every task is seen as a group of modules nested to short-term memory tasks (Fingelkurts *et al.*, 2003). Both, a large or small number of operational modules could cause a memory deficit.

Thereby, the interplay between theta band waves (4-8 Hz) and gamma band waves (30-200 Hz) is the core feature for sequentially ordered stimuli in WM (Lisman and Jensen, 2013). Once information is integrated, WM allows the combination and assembly of information in consciousness (Marchetti, 2014).

Concluding Remarks

Baddeley's WM model is perhaps one of the most influential in cognition over the last decades (Andrade, 2002; Baddeley, 2017). Every single component is easily assessed, like the phonological loop (word or number repetition), the visuo-spatial sketchpad (mental imagery), and the central executive (voluntary manipulation). Figure 1 shows that WM is heavily involved with consciousness, both from a qualitative perspective (inner speech), or conscious experiences like the intention of rehearsing previously stored stimuli in WM (Baars and Franklin, 2003). The self is involved both in the central executive and the phonological loop and allows the individuality and continuity of the conscious experience. This is how the self becomes a reference for an organism composed of body and mind. A single indivisible unit: *Personality.*

Figure 1. *A schematic presentation of the Working Memory Model*



This WM model contributes a basic functional description of how mental representations remain on-line along the complex cognitive processing (Baddeley, 2017). Both the phonological loop and the visuospatial sketchpad are involved in the storing of visual and verbal information. They are conceived as buffers, highly processed information containers which are not involved in the perceptual analysis of sensory information (Buchsbaum, 2013). They are both controlled and monitored through a cognitive control mechanism known as the central executive. The visuo-spatial sketchpad is also described as a single unit for the storing of information (Logie and Pearson, 1997). The phonological loop is composed by the phonological store and the articulatory rehearsal process.

The phonological loop can store speech-based information for a short period of time before it decays. The role of the articulatory rehearsal is to prevent this information decay by periodically refreshing the content of the phonological loop through subvocal rehearsal (Buchsbaum, 2013).

On the other hand, the episodic buffer is involved with information binding, although multimodal isolated pieces of information (moving object) are experienced through different channels, the episodic buffer allows the stimuli perception as a whole. At some point, representations converge and are consciously experienced as a single event (Angelopoulou and Drigas,

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2021). Therefore, the most important mechanism to retrieve information out of the episodic buffer is conscious awareness (Baddeley, 2000). Thereby, binding has become the most important biological advantage of consciousness (Baddeley, 2003).

Hence, the interplay between the central executive and the episodic buffer on one hand and the phonological loop and the visuospatial sketchpad on the other is mediated by conscious processing. The central executive controls and changes attention while the episodic buffer allows the availability of multimodal information (Baars, 2005).

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