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Title:

On the interplay between working memory consolidation and attentional selection in controlling conscious access: Parallel processing at a cost

A Reply to:

Raffone, Srinivasan, & van Leeuwen, (2014)

The interplay of attention and consciousness in visual search, attentional blink and working memory consolidation

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Theories of human cognition generally agree in assuming the existence of a fundamental limit in information processing, but these theories are challenged by findings that appear to circumvent these limitations. We argue that theories are needed which offer a principled account of why the limitations become manifest in some cases but not others.

Raffone, Srinivasan & van Leeuwen (2014) present a comprehensive theoretical framework that links behavioral effects, such as the Attentional Blink (AB), visual search and inattentional blindness to an overarching theory of the neurobiological substrates of consciousness and attention. Central to their model is the Global Workspace (GW), which is predicated on the notion that working memory, attention and consciousness arise from a network of neurons that can only focus on one representation at any time. This inability to simultaneously process multiple stimuli has been suggested to explain the AB as well as visual search behavior.

However, there is mounting evidence that the brain is capable of encoding multiple items into Short-Term Memory (STM) at once, such as lag-1 sparing, in which two targets are apparently encoded together (Chun & Potter 1995). Due to its strictly winner-take-all behavior, previous GW-based computational accounts of the AB (Dehaene et al 2003; Zylberberg et al. 2010) had particular difficulty explaining this effect.

Raffone et al. are responding to this challenge by attempting to reconcile the GW theory with such evidence. The Theory of Attention and Consciousness (TAC), boldly pushes the single-threaded nature of cognition even farther by proposing that STM encoding and attentional selection also time-share central processing capacity, so that only one of them can occur at a time. TAC permits lag-1 sparing through an intermediate buffer that can hold multiple items concurrently, as they await an opportunity to be encoded into STM. Thereby, the AB is not caused by direct competition between target one (T1) and target two (T2), but rather by competition between attentional selection and STM encoding.

In this respect, TAC is similar to computational models we have previously proposed (Bowman &Wyble 2007; Wyble et al 2009; Wyble et al 2011). In the episodic Simultaneous Type Serial Token model (eSTST), ongoing consolidation has an inhibitory effect on attentional selection. Furthermore, like the TAC, we proposed that attention can remain engaged over several consecutive targets to produce spreading of sparing (Kawahara et al. 2006; also Figure 1).

However, the theories differ dramatically in that the eSTST model permits parallel encoding of multiple targets. Furthermore, in eSTST, attentional selection is possible during encoding; it is just reduced in strength. We argue that permissiveness of parallel processing is essential to accommodate the full range of available data concerning the attentional blink. In particular, there are two specific empirical benchmarks that seem unattainable by TAC.

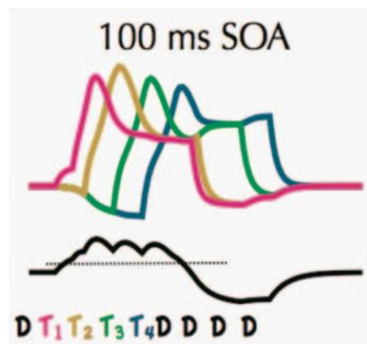

Figure 1. Simulates traces of 4 targets being simultaneously encoded by eSTST model (top) during a sustained attentional episode at 100ms stimulus onset asynchronoy(SOA) The black trace depicts changes in attention over time Wyble et al. (2011)

The first benchmark is that providing a cue during the deepest part of the AB, has a facilitatory effect on the following T2 (Nieuwenstein et al. 2005) and no effect on T1 accuracy. According to TAC, encoding and selection can never co-occur, making it hard to explain how T2 can be successfully cued without aborting encoding of T1.

The second benchmark is the time course to initiate encoding during lag-1 sparing. The TAC has an intermediate buffer that allows T1 and T2 to be maintained in a purgatorial state, half-way to consciousness, where they persist until encoding is triggered by the occurrence of a non-target item. Enabling serial encoding of multiple targets through such a buffer is certainly an ingenious proposal and has precedent (Jolicoeur, et al. 2002; Taatgen et al. 2009), but the TAC account is contradicted by electroencephalogram (EEG) data.

TAC explains data at the level of neural mechanisms, which allows it to interface with EEG data reflecting the time course of cognitive processes. For example, the P3 component of the EEG is thought to reflect encoding into STM (Sergent, et al. 2005; Chennu et al. 2009; Martens et al. 2006).

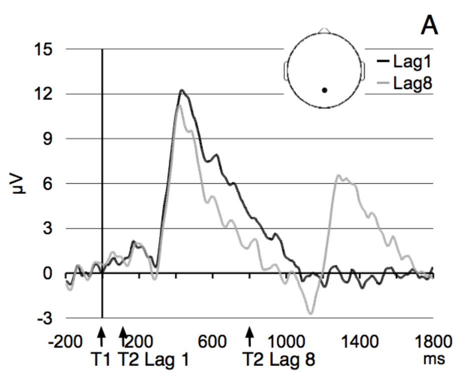

Figure 2. EEG data from the midline parietal (Pz) electrode in lag-1 vs lag-8 trials (Craston et al. 2009)

TAC assumes that T1 memory encoding is postponed when it is immediately followed by a T2. If true, then a lag-1 trial should produce a P3 onset that is delayed by 1 lag (e.g. about 100ms), and even longer when even more targets are placed in sequence. However, existing EEG data indicates that the onset of the P3 for two targets is not delayed at lag-1 when compared with lag-8 (See Figure 2).

Furthermore, this buffer imposes a restriction that conscious perception of a critically important stimulus would be delayed if it were followed by another important stimulus. This buffering of input until a period of "downtime", seems counterintuitive for a system with a requirement to process information as rapidly as possible.

In contrast to the TAC, other models (Bowman & Wyble 2007; Wyble, Bowman & Nieuwenstein 2009; Taatgen et al. 2009), posit that T1 encoding begins as soon as sufficient evidence has accumulated, without waiting for a non-target item and such models can simulate EEG data from lag-1 and lag-8 trials (Craston et. al 2009).

We conclude with what seems, to us, to be the essential conundrum of the AB and lag-1 sparing: What is the adaptive utility of suppressing attention during encoding?

Raffone et al. propose that such suppression prevents interference from "feature and proto-object representations". This seems an insufficient answer, because lag-1 *sparing* indicates that the system is capable of encoding multiple items in parallel, with relatively little apparent interference on measures of identification accuracy. Our modeling work suggests that the suppression of attention achieves a higher-order goal, viz enhancing the *episodic* information present in the stream of visual input. In other words, the visual system compiles information into temporal chunks, which are passed to STM as discrete episodes roughly equivalent to the duration of visual fixations (~200-300ms) (see also Reith & Vul 2012). Multiple items can be encoded in an episode, but at the cost of a loss of temporal information and a decreased ability to encode repetitions. This loss of episodic information is the price that is paid when stimuli are processed in parallel. We suggest further that such an episodic attentional system is a good solution to the problem of encoding information from a series of sequential eye fixations (Kamienkowski et al 2012).

References

Bowman, H., & Wyble, B. (2007). The simultaneous type, serial token model of temporal attention and working memory. *Psychological review*, *114*(1), 38.

Chennu, S., Craston, P., Wyble, B., & Bowman, H. (2009). Attention increases the temporal precision of conscious perception: verifying the neural-ST2 model. *PLoS computational biology*, *5*(11), e1000576.

Chun, M. M., & Potter, M. C. (1995). A two-stage model for multiple target detection in rapid serial visual presentation. *Journal of Experimental psychology: Human perception and performance*, *21*(1), 109.

Craston, P., Wyble, B., Chennu, S., & Bowman, H. (2009). The attentional blink reveals serial working memory encoding: Evidence from virtual and human event-related potentials. *Journal of cognitive neuroscience*, *21*(3), 550-566.

Dehaene, S., Sergent, C., & Changeux, J. P. (2003). A neuronal network model linking subjective reports and objective physiological data during conscious perception. *Proceedings of the National Academy of Sciences*, *100*(14), 8520-8525.

Jolicoeur, P., Tombu, M., Oriet, C., & Stevanovski, B. (2002). From perception to action: Making the connection. In W. Prinz, & B. Hommel (Eds.), *Attention and Performance XIX: Common mechanisms in perception and action* (pp. 558–586). Oxford: Oxford University Press

Kamienkowski, J. E., Navajas, J., & Sigman, M. (2012). Eye movements blink the attentional blink. *Journal of experimental psychology: human perception and performance*, *38*(3), 555.

Kawahara, J. I., Kumada, T., & Di Lollo, V. (2006). The attentional blink is governed by a temporary loss of control. *Psychonomic Bulletin & Review*, *13*(5), 886-890.

Martens, S., Munneke, J., Smid, H., & Johnson, A. (2006). Quick minds don't blink: Electrophysiological correlates of individual differences in attentional selection. *Journal of Cognitive Neuroscience*, *18*(9), 1423-1438.

Nieuwenstein, M. R., Chun, M. M., van der Lubbe, R. H., & Hooge, I. T. (2005). Delayed attentional engagement in the attentional blink. *Journal of Experimental Psychology: Human Perception and Performance*, 31(6), 1463.

Raffone, A., Srinivasan, N., & van Leeuwen, C. (2014). The interplay of attention and consciousness in visual search, attentional blink and working memory consolidation. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *369*(1641), 20130215.

Rieth CA, Vul E. 2012 Expectations about the temporal structure of the world result in the attentional blink and repetition blindness. In N. Miyake, D. Peebles, & R. P. Cooper (Eds.), *Proc. the 34th Annual Meetings of the Cognitive Science Society.* Austin, TX: Cognitive Science Society.

Sergent, C., Baillet, S., & Dehaene, S. (2005). Timing of the brain events underlying access to consciousness during the attentional blink. *Nature neuroscience*, *8*(10), 1391-1400.

Taatgen, N. A., Juvina, I., Schipper, M., Borst, J. P., & Martens, S. (2009). Too much control can hurt: A threaded cognition model of the attentional blink. *Cognitive psychology*, *59*(1), 1-29.

Wyble, B., Bowman, H., & Nieuwenstein, M. (2009). The attentional blink provides episodic distinctiveness: sparing at a cost. *Journal of Experimental Psychology: Human Perception and Performance*, *35*(3), 787.

Wyble, B., Potter, M. C., Bowman, H., & Nieuwenstein, M. (2011). Attentional episodes in visual perception. *Journal of Experimental Psychology: General*, *140*(3), 488.

Zylberberg, A., Slezak, D. F., Roelfsema, P. R., Dehaene, S., & Sigman, M. (2010). The brain's router: a cortical network model of serial processing in the primate brain. *PLoS computational biology*, *6*(4), e1000765.