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Paying attention to what is important in working memory

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Paying attention to what is important in working memory

Working memory is crucial but fallible. Indeed, it is typically defined in terms of its limited temporal and informational capacity, with forgetting owing to overloading of capacity, interference, and failures of attentional control. As such, it is a useful approach to focus these limited resources on encoding, holding, and retrieving information as efficiently as possible to optimise task performance. One way of achieving this might be to strategically focus attention on a subset of material that remains within capacity, rather than attempting to encode all information that is encountered and risk overwhelming available cognitive resources. Such an approach would be particularly useful if material that is of greater value, importance, or goal-relevance is prioritised. This review will describe recent experimental work designed to explore these issues.

The information we encounter in everyday life often varies along multiple dimensions including importance and goal-relevance. For example, when planning for an international trip, it is more important to remember our passport, tickets, and money, amongst a broader list of less crucial items. Similarly, when given a reasoning problem to solve, there will be aspects of the problem that are more or less critical to reaching a solution. This is not a factor that is often considered in memory research, however. Participants are typically presented with sets of items to encode and retain for a subsequent immediate or delayed test, and while we are very familiar with how factors such as list position (e.g. primacy vs. recency) and item characteristics (e.g. familiarity, emotional salience, meaning) can impact on memory, we tend to neglect the possibility that participants might not strategically approach every item in the same way. They may instead attempt to make the most of these resources by focusing attention on subsets of items, particularly in situations where a participant might feel their cognitive resources are being stretched. Indeed, this approach appears to benefit performance when memory load is increased (Atkinson, Baddeley, & Allen, 2018).

Recent work has begun to employ manipulations that harnass these effects, for the purposes of increasing understanding of memory function and of identfying ways in which memory performance can be made more efficient. It is well established that working memory and attention have a close, bidirectional, symbiotic relationship (e.g. Awh, Jonides, & Reuter-Lorenz, 1998; Chun, Golomb, & Turk-Browne, 2011; Gazzaley & Nobre, 2012; Oberauer, 2019); information held in working memory can influence attention (e.g. Downing, 2000), and the information to which we attend is more likely to be remembered (e.g. Schmidt et al., 2002). The latter appears to be determined both by automatic, perceptual attentional capture, and controlled, internally motivated attentional control (e.g. Chun et al., 2011; Hitch, Allen, & Baddeley, 2019; Hu et al., 2014). One method of directing attention to influence working memory is through the use of visual cues, presented before or after memory displays, that indicate which item is likely to be tested. A large body of work now exists showing that visual cueing of certain items leads to benefits for those items, alongside costs to uncued items (e.g. Griffin & Nobre, 2003; Souza & Oberauer, 2016). More recently, a different approach has been adopted, in which participants are encouraged to try and encode the whole memory set, but to strategically prioritise one or more of the items within this set, based on the reward or value that is assigned to it by the experimenter.

As with cueing work, this work on prioritisation has tended to focus on the visual domain in working memory. In the case of our group's work, the concept of a manipulation designed to direct strategic attention to certain items within a set emerged somewhat fortitously during an experiment exploring the impacts of a post-sequence interfering suffix on serial visual memory for feature bindings (Hu et al., 2014, Experiment 1). We observed the predicted effects overall, with a clear recency advantage for the final item in a 4-item sequence, and a disruptive suffix effect on these late-sequence items. However some participants produced a slightly different pattern, with improved recall for both the first and final item, and suffix effects on each; these participants appeared to be spontaneously prioritising the initial item in the sequence. We therefore followed this up with three subsequent experiments in which participants were encouraged to prioritise either the first or final item in the sequence, on the basis that they were allocated notional 'points' for the correct recall of these items if tested. Participants knew that these point values did not correct to any subsequent reward system, but were simply intended as a guide to identify which items they should treat as being more valuable.

On the basis of this notional point value manipulation, higher value items were subsequently recalled with higher rates of accuracy than lower value items in the sequence, while also showing a greater vulnerability to suffix interference (Hu et al., 2014; Experiments 2-4). We attributed these effects, and the ubiquitous recency advantage that continued to emerge regardless of value condition, as reflecting a privileged state in working memory (Olivers, Peters, Hoetkamp, & Roelfsema, 2011), with both higher value and most recent items being more likely to be held in the focus of attention, possibly synonymous with the episodic buffer (Hitch et al., in 2019). Higher value items achieve this state through strategic control, whereas the most recently encountered stimulus does so through automatic, perceptual input. Any item held within this state appears to be more easily accessed, but also more vulnerable to interference (caused, in our studies, by subsequent to-be-ignored suffix stimuli that contain potentially relevant features). More broadly, these developments illustrate the importance of considering the strategies that participants might be employing in a given task, from methodological and interpretative perspectives, but also as a way of identifying interesting new research questions.

We have subsequently replicated this value-based prioritisation effect across a range of studies. For example, Hitch, Hu, Allen, and Baddeley (2018) observed that any serial position in a sequence can be prioritised, with improved accuracy concomittant with increased suffix interference. Hitch et al. also found some tentative evidence that two items could be prioritised from within the same sequence. Within the same special issue of *Ann. N. Y.*

Acad. Sci. (connected to a workshop on working memory and attention organised by Alessandra Souza and Evie Vergauwe; Souza & Vergauwe, 2018), Atkinson et al. (2018) argued that strategic prioritisation effects are distinct from those of cue frequency (i.e. the increase in recall accuracy rates for items that participants knew durign encoding were more likely to be tested), with the implication that attention can be directed through a range of manipulations that may activate distinct underlying mechanisms. Care should therefore be taken when generalising across different task contexts.

The majority of our work has utilised serial presentation in order to explore how strategic control interacts with automatic perceptual input over time. Each trial typically involves presentation of a sequence of individual items, and participants are asked to encode all of them while particularly directing attention to, for example, the first in the series. Of course, it should also be possible to strategically prioritise items from within simultaneously encountered multi-object arrays. Allen and Ueno (2018) examined this question, presenting four objects on screen in each trial and indicating which of these was associated with a higher value before the trial commenced. Value-based prioritisation effects were duly observed and indeed, participants were able to prioritise multiple items within a single trial (Allen & Ueno, 2018). Furthermore, it was found that allocation of attentional resources could be graded across different items in response to varying associated values (i.e. items 'worth' 2 or 3 points were less well-remembered than those worth 4, but superior to 1-point items).

Central to the interpretation of these findings is that prioritisation reflects the operation of active attentional control processes, applied during encoding and maintenance. These processes may depend on the availability of sufficient general executive resources, with the prediction that when these are diminished, prioritisation boosts will reduce in magnitude. Although more work is required here, some initial evidence has emerged to support this view. Hu, Allen, Baddeley and Hitch (2016) manipulated the difficulty level of a concurrent verbal task performed during encoding of the visual sequence, and found that prioritisation effects were reduced or abolished as a result. In the same experiment, a substantial recency advantage for the final item remained, even when participants were performing a more difficult concurrent task and directing their attention to the first position in the sequence, thus supporting the proposed distinction between automatic and strategic effortful control.

The apparent reliance of strategic prioritisation on executive control would then suggest that population groups who do not have the same degree of attentional control resources may struggle to effectively prioritise one item over others. For example, it is well established that executive function and working memory develop from childhood to adulthood, and demonstrating at what age children can direct their attention to high value information is informative from both theoretical and educational perspectives. In three experiments with 6-9 year old children, Berry et al. found no evidence of the ability (or inclination) to prioritise the first or final items in three-item sequence of visual stimuli, alongside sizeable recency effects for the final item (Berry, Waterman, Baddeley, Hitch, & Allen, 2018). We have more recently followed this up, examining whether children from these age groups are more likely to show such effects when encouraged to engage with prioritisation instructions by embedding the task in a gamefied, child-friendly context, and developing the notional point value system into a more concrete, reward-oriented concept. This included the use of 'energy points', mid-task progress bars, an end-session game ostensibly tied to the energy points accrued during memory performance, and a friendly alien named Zorg (Atkinson, Waterman, & Allen, 2019). In this case, children do indeed produce a recall advantage for high value items, using both serial and simultaneous presentation of items, thus illustrating the importance of employing appropriately motivating task materials when working with developmental groups. It should be noted, however, that the observed effects were still relatively small when compared to those typically seen in adults, in line with the idea that immature executive control means prioritisation is not as effective as in young adults.

As mentioned earlier, strategic prioritisation and recency effects have been interpreted via the notion of priviledged storage within the focus of attention (FoA). This describes active, accessible retention of information in a form that is part of several influential theoretical approaches to working memory, including Cowan (e.g. 1995, 2005) and Oberauer (2002). The inclusion of the FoA within such approaches illustrates their origins in the attentional literature, while in contrast leading multi-component models of working memory (e.g. Baddeley, 2012; Baddeley, Allen, & Hitch, 2011; Baddeley & Hitch, 1974; Logie, 2014) do not explicitly incorporate such a feature. However, in line with broader recent developments in which different theoretical perspectives are starting to find common ground, the FoA might be appropriately mapped on to the episodic buffer component of the multi-component framework (e.g. Hitch et al., in press; Hu et al., 2014), in describing how different forms of information drawn from the environment and from LTM might be held in a highly accessible, consciously available format.

If we assume a locus of prioritisation effects within the FoA/episodic buffer, this gives rise to a number of additional interesting questions. Debate continues regarding whether one or more items can be held within the FoA concurrently. Cowan (1995, 2005) suggests that up to 3-4 objects or chunks might be maintained therein, depending on the type of information requiring storage, whereas Oberauer's view is that similarity-based interference renders any more than a one-item FoA unworkable, though again, this might vary under different conditions (Oberauer, 2018). Recent evidence indicates that multiple items can be concurrently active within working memory in a form that impacts on attentional search (e.g. Bahle, Beck, & Hollingworth, 2018; Chen & Du, 2017). Our own work suggests that more than one item can indeed be prioritised from within the same trial (Allen & Ueno, 2018; Hitch et al., 2018), and that different items can benefit from prioritisation and recency (e.g. Hu et al., 2014), though this has yet to be systemtically explored. Related to this, it will be useful to explore the modes of active maintenance that are typically employed to hold items in an accessible state, particularly when they are no longer present in the environment. Our work to date normally applies concurrent articulation tasks to prevent verbal rehearsal and focus instead on attentional direction, though it is likely that both verbal rehearsal and attentional refreshing (Camos, Lagner, & Barrouillet, 2009) can be used to support prioritisation (Hitch et al., 2019; Sandry et al., 2014). In the case of refreshing, this might vary with the number of items that participants are attempting to actively maintain. A single item might be continually visualised or refreshed, while multiple items might be repeatedly refreshed in turn, running them through the FoA to keep the active and accessible, akin to a plate-spinning act.

The FoA/episodic buffer are assumed to be modality-general, meaning that any type of information might be held there in an accessible state. While most work in this area has been carried out on non-verbal materials, work is starting to explore prioritisation effects on other forms of stimuli. Sandry, Schwark, and MacDonald (2014) for example, have found that visually presented words can be boosted through the assignation of higher value, and Atkinson and colleagues have recently extended this to auditory presentation using immediate serial recall of digit sequences (Atkinson, Allen, Baddeley, Hitch, & Waterman, under review). It remains to be seen whether any form of stimuli (e.g. visual, verbal, or multimodal materials), along with further feature dimensions such as touch, movement, or smell (e.g. Moss, Miles, Elsley, & Johnson, in press), might similarly benefit from value-directed remembering.

It should also be interesting to consider how research on value-directed prioritisation in working memory relates to the impressive existing literature using similar manipulations within long-term memory tasks. Episodic long-term memory, while not operating under the same constraints as working memory, is also prone to failure. Episodic memory processing also experiences processing bottlenecks at encoding and retrieval, and so understanding how it can be improved and made more efficient is again useful, both from theoretical and practical applied (e.g. educational, forensic, or legal) perspectives. For example, Castel and colleagues have carried out a number of studies showing that higher value items are better remembered than items associated with lower value, using for example word lists or visual objects (e.g. Castel, Benjamin, Craik, & Watkins, 2002; Hennessee, Knowlton, & Castel, 2018; Middlebrooks et al., 2017; Siegel & Castel, 2017, 2018). Such effects appear to survive concurrent attentional load manipulations, and emerge in both young and older adults. It would be informative to examine whether parallel patterns emerge in working and long-term memory, and how these might connect in terms of shared mechanisms. For example, Nguyen et al. (2019) have recently reported evidence using EEG that high- and low-value items are subject to different forms of attentional processing during encoding, and suggested that higher value information might be initially retained in the episodic buffer within working memory.

To summarise, it is now clear from a range of studies that (at the risk of sounding like a motivational poster) we should pay attention to what is important. The constraints under which our cognitive systems operate mean that the limited processing and storage resources at our disposal should, wherever appropriate, be oriented towards information that is more valuable and/or goal-relevant,. This would fit broadly with the view that memory is useful in supporting adaptive behaviour (e.g. Klein, Cosmides, Tooby, & Chance, 2002; Nairne & Pandeirada, 2016), in this case through the flexible and strategic allocation of attention to whatever stimuli or mental representation is deemed most useful for the task in hand. It remains to be seen what mechanisms underlie strategic prioritisation across different task contexts, and how these might vary with, for example, age or cognitive ability. It will also interesting to explore how such methods of directing attention might be employed in practical contexts such as the classroom, to try and optimise cognitive performance and learning progress in the face of distracting environments.

References

Allen, R. J., & Ueno, T. (2018). Multiple high-reward items can be prioritized in working memory but with greater vulnerability to interference. *Attention, Perception, & Psychophysics*, *80*(7), 1731-1743.

Atkinson, A. L., Allen, R. J., Baddeley, A. D., Hitch, G. J., & Waterman, A.H. (under review). Can valuable information be prioritized in verbal working memory?

Atkinson, A. L., Baddeley, A. D., & Allen, R. J. (2018). Remember some or remember all? Ageing and strategy effects in visual working memory. *The Quarterly Journal of Experimental Psychology*, *71(7),* 1561-1573.

Atkinson, A. L., Berry, E. D., Waterman, A. H., Baddeley, A. D., Hitch, G. J., & Allen, R. J. (2018). Are there multiple ways to direct attention in working memory? *Annals of the New York Academy of Sciences*, *1424*(1), 115-126.

Atkinson, A. L., Waterman, A. H., & Allen, R. J. (2019). Can children prioritize more valuable information in working memory? An exploration into the effects of motivation and memory load. *Developmental Psychology, 55(5),* 967-980.

Awh, E., Jonides, J., & Reuter-Lorenz, P. A. (1998). Rehearsal in spatial working memory. *Journal of Experimental Psychology: Human Perception and Performance*, *24*(3), 780-790.

Baddeley, A. (2012). Working memory: Theories, models, and controversies. *Annual Review of Psychology*, *63*, 1-29.

Baddeley, A. D., & Hitch, G. (1974). Working memory. In *Psychology of learning and motivation* (Vol. 8, pp. 47-89). Academic press.

Baddeley, A. D., Allen, R. J., & Hitch, G. J. (2011). Binding in visual working memory: The role of the episodic buffer. *Neuropsychologia*, *49*(6), 1393-1400.

Bahle, B., Beck, V. M., & Hollingworth, A. (2018). The architecture of interaction between visual working memory and visual attention. *Journal of Experimental Psychology: Human Perception and Performance*, *44*(7), 992-1011.

Berry, E. D., Waterman, A. H., Baddeley, A. D., Hitch, G. J., & Allen, R. J. (2018). The limits of visual working memory in children: Exploring prioritization and recency effects with sequential presentation. *Developmental Psychology*, *54*(2), 240-253.

Camos, V., Lagner, P., & Barrouillet, P. (2009). Two maintenance mechanisms of verbal information in working memory. *Journal of Memory and Language*, *61*(3), 457-469.

Castel, A. D., Benjamin, A. S., Craik, F. I. M., & Watkins, M. J. (2002). The effects of aging on selectivity and control in short-term recall. *Memory & Cognition, 30,* 1078–1085. http://dx.doi.org/10.3758/BF0 3194325.

Chen, Y., & Du, F. (2017). Two visual working memory representations simultaneously control attention. *Scientific Reports*, *7*.

Chun, M. M., Golomb, J. D., & Turk-Browne, N. B. (2011). A taxonomy of external and internal attention. *Annual Review of Psychology*, *62*, 73-101.

Cowan, N. (2005). Essays in cognitive psychology: Working memory capacity. New York, NY, US.

Downing, P. E. (2000). Interactions between visual working memory and selective attention. *Psychological Science*, *11*(6), 467-473.

Gazzaley, A., & Nobre, A. C. (2012). Top-down modulation: bridging selective attention and working memory. *Trends in Cognitive Sciences*, *16*(2), 129-135.

Griffin, I. C., & Nobre, A. C. (2003). Orienting attention to locations in internal representations. *Journal of Cognitive Neuroscience*, *15*(8), 1176-1194.

Hennessee, J. P., Knowlton, B. J., & Castel, A. D. (2018). The effects of value on context-item associative memory in younger and older adults. *Psychology and Aging*, *33*(1), 46-56.

Hitch, G.J., Allen, R.J., & Baddeley, A.D. (2019). Attention and binding in visual working memory: Two forms of attention and two kinds of buffer storage. *Attention, Perception, & Psychophysics.*

Hitch, G. J., Hu, Y., Allen, R. J., & Baddeley, A. D. (2018). Competition for the focus of attention in visual working memory: perceptual recency versus executive control. *Annals of the New York Academy of Sciences*, *1424*(1), 64-75.

Hu, Y., Allen, R. J., Baddeley, A. D., & Hitch, G. J. (2016). Executive control of stimulus-driven and goal-directed attention in visual working memory. *Attention, Perception, & Psychophysics*, *78*(7), 2164-2175.

Hu, Y., Hitch, G. J., Baddeley, A. D., Zhang, M., & Allen, R. J. (2014). Executive and perceptual attention play different roles in visual working memory: Evidence from suffix and strategy effects. *Journal of Experimental Psychology: Human Perception and Performance*, *40*(4), 1665-1678.

Logie, R. H. (2014). *Visuo-spatial working memory*. Psychology Press.

Middlebrooks, C. D., Kerr, T., & Castel, A. D. (2017). Selectively distracted: Divided attention and memory for important information. *Psychological science*, *28*(8), 1103-1115.

Moss, A., Miles, C., Elsley, J., & Johnson, A. (in press). Olfactory working memory: Exploring the differences in n-back memory for high and low verbalisable odorants. *Memory.*

Nairne, J. S., & Pandeirada, J. N. (2016). Adaptive memory: The evolutionary significance of survival processing. *Perspectives on Psychological Science*, *11*(4), 496-511.

Nguyen, L. T., Marini, F., Zacharczuk, L., Llano, D. A., & Mudar, R. A. (2019). Theta and alpha band oscillations during value-directed strategic processing. *Behavioural Brain Research*, *367*, 210-214.

Oberauer, K. (2002). Access to information in working memory: exploring the focus of attention. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *28*(3), 411-421.

Oberauer, K. (2018). Removal of irrelevant information from working memory: sometimes fast, sometimes slow, and sometimes not at all. *Annals of the New York Academy of Sciences*, *1424*(1), 239-255.

Oberauer, K, (2019). Working memory and attention: A conceptual review and analysis. *Journal of Cognition, 2(1),* 36*.*

Olivers, C. N., Peters, J., Houtkamp, R., & Roelfsema, P. R. (2011). Different states in visual working memory: When it guides attention and when it does not. *Trends in Cognitive Sciences*, *15*(7), 327-334.

Sandry, J., Schwark, J. D., & MacDonald, J. (2014). Flexibility within working memory and the focus of attention for sequential verbal information does not depend on active maintenance. *Memory & Cognition*, *42*(7), 1130-1142.

Schmidt, B. K., Vogel, E. K., Woodman, G. F., & Luck, S. J. (2002). Voluntary and automatic attentional control of visual working memory. *Perception & psychophysics*, *64*(5), 754-763.

Siegel, A. L., & Castel, A. D. (2018). Memory for important item-location associations in younger and older adults. *Psychology and aging*, *33*(1), 30-45.

Souza, A. S., & Oberauer, K. (2016). In search of the focus of attention in working memory: 13 years of the retro-cue effect. *Attention, Perception, & Psychophysics*, *78*(7), 1839-1860.

Souza, A. S., & Vergauwe, E. (2018). Unravelling the intersections between consolidation, refreshing, and removal. *Annals of the New York Academy of Sciences*, *1424*(1), 5-7.