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Drift-Diffusion Modeling of Accuracy and Reaction Times: A Deeper Insight Into Retrospective Attention

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Retrospective attention refers to the prioritization of contents held in working memory, a process investigated using the retro-cueing paradigm. This process is evidenced by the retro-cueing benefit, characterized by better performance for retrospectively cued trials. However, traditional statistical analyses fall short in distinguishing between decisional and nondecisional processes underlying this benefit. A pivotal contribution by Shepherdson et al. (2018) addressed this gap by applying drift-diffusion modeling which integrates both accuracy and reaction time measures to disentangle these processes. Their key contribution lies in demonstrating that retro-cues enhance the quality of working memory contents and enable their retrieval in advance of decision making—effects that occur independently of shifts in decision criteria. Building on Shepherdson et al.'s work, we encourage future drift-diffusion model-based retro-cueing studies to pursue precise, mutually exclusive hypothesis testing and to integrate behavioral and neural data to more clearly distinguish between competing explanations of the retro-cueing benefit.

Public Significance Statement

A pioneer study by Shepherdson et al. (2018) that implemented behavioral modeling—a significant advancement over traditional approaches that focus solely on reaction time or accuracy—showed that directing attention to items temporarily stored in memory strengthens their representation and speeds up their retrieval, independent of decision-making processes. To clarify the mechanisms underlying this effect, we advocate for future research to develop contrasting theoretical predictions and combine behavioral modeling with brain data.

Keywords: working memory, retrospective attention, retro-cue benefit, drift-diffusion modeling

To effectively carry out everyday tasks like grocery shopping without a list, we must rely on working memory (WM) to store and prioritize information. This prioritization is driven by retrospective attention—the ability to direct attention to items already held in WM. It is commonly studied using the retro-cueing paradigm (see Souza & Oberauer, 2016, for a review), in which a cue is presented between the disappearance of a memory array and the appearance of a probe. This approach has revealed the retro-cueing benefit (RCB; Griffin & Nobre, 2003; Landman et al., 2003), evidenced by increased accuracy and faster reaction times for valid retro-cue trials (i.e., when the cue and probe refer to the same item) compared to no-cue or neutral conditions (e.g., cues pointing to all items equally).

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The RCB provides compelling evidence that attention can selectively prioritize memory contents.

Four main hypotheses have been proposed to account for the RCB. The protection-from-interference hypothesis (Makovski et al., 2008) suggests that retrospective attention protects the cued item from interference from subsequent stimuli (e.g., test items or masks), independent of the memory load. In contrast, the strengthening hypothesis (Nobre et al., 2008) proposes that retro-cues boost the strength of WM representations and reduce competition among them, thereby decreasing the impact of memory load. A third explanation, the head-start retrieval hypothesis (Souza et al., 2014), argues that retro-cues allow for the earlier retrieval of the cued item before the test phase, which reduces interference from other, noncued representations. Finally, the removal hypothesis (Oberauer, 2001) claims that the RCB results from the elimination of noncued items from WM, thereby reducing WM load and improving performance.

This article emphasizes the pivotal contribution of Shepherdson et al. (2018), who modeled both accuracy and reaction times in retrocueing tasks using the drift-diffusion model (DDM; Ratcliff, 1978). DDM is especially well suited for investigating the cognitive mechanisms underlying behavior because it captures both accuracy and reaction time distributions. It models decision making as a process of accumulating noisy evidence toward one of two response boundaries. This framework allows for the separation of decision-related processes from those involved in memory retrieval, perception, and motor preparation (Ratcliff et al., 2016). Specifically, DDM estimates four key parameters with clear psychological interpretations (Farrell & Lewandowsky, 2018): drift rate (the speed of evidence accumulation), boundary separation (the decision threshold), nondecision time (encompassing encoding, retrieval, and motor processes), and bias (the initial starting point in the decision process).

In the context of retrospective attention, several studies have reported robust RCBs across multiple outcome measures—including reaction times, accuracy, and precision (e.g., Souza et al., 2014, 2016). However, DDM offers advantages over traditional analyses (Boag et al., 2023; Voss et al., 2013). First, DDM integrates all available data, enhancing sensitivity and reducing the risk of null effects that can arise when reaction times and accuracy reflect opposing influences (van Ede & Nobre, 2023). Second, DDMs differentiate decision-making effects from those related to other cognitive processes (e.g., memory retrieval). This is essential, since higher accuracy in valid trials could result from stricter decision criteria rather than better memory quality, and faster responses might reflect riskier decisions rather than more efficient retrieval. Third, using accuracy alone as a measure of memory strength is problematic because it conflates sensitivity with response bias (Brady et al., 2023). DDM avoids this issue by estimating drift rate and decision threshold separately, thereby distinguishing between improvements in WM quality and changes in response strategy. Finally, DDM enables more precise hypothesis testing and helps bridge the gap between behavior and neural processes by capturing latent cognitive dynamics (Forstmann et al., 2016).

Leveraging these strengths, Shepherdson et al. (2018) analyzed four experiments to explore how the RCB maps onto DDM parameters. Participants performed retro-cueing tasks involving color stimuli, letters, and words, comparing valid retro-cue trials with no-cue trials across different memory loads and cue-to-probe intervals. Their findings confirmed that multiple mechanisms contribute to the RCB (Souza et al., 2014, 2016), and crucially, identified the DDM parameters associated with each. First, RCBs on drift rates (i.e., larger values for valid than for neutral trials) were observed irrespective of load effects, supporting the protection from interference account as the detrimental effect of high load was not remedied by retro-cues. Second, nondecision times were shorter for valid trials than for neutral ones, particularly under high-load and long cue-to-probe intervals. This supports the head-start retrieval hypothesis, indicating that retro-cues allow earlier access to the cued representation, reducing interference from nontarget items. Therefore, Shepherdson et al. concluded that retro-cues primarily act by enhancing information quality (via increased drift rate) and by enabling early retrieval (via reduced nondecision time), without affecting decision criteria. Importantly, while shorter nondecision times are also consistent with the removal account, the fact that drift rates still varied with load casts doubt on this explanation alone. If retro-cues fully removed irrelevant items, load effects on drift rates would have disappeared. Similarly, the strengthening hypothesis predicts reduced load effects on both drift rate and nondecision time—yet this was not the case.

Subsequent research has built upon these insights (Cipriani et al., 2024; Fuentes-Guerra et al., 2025; Shepherdson, 2020; Souza & Frischkorn, 2023), reaffirming that retro-cues improve WM content quality and retrieval speed, independently of shifts in decision boundaries. Nonetheless, unresolved questions remain. In particular, the protection and strengthening hypotheses both predict RCBs in drift rate, but whether the strengthening account should also yield reduced load effects remains unclear. Additionally, the head-start retrieval and removal accounts may not be mutually exclusive. Removing noncued items might facilitate the retrieval of cued ones (Souza et al., 2016), supporting the plausibility of a removal mechanism. An effective way to examine this is by analyzing retro-cueing costs—specifically, comparing performance in invalid trials (where cue and probe mismatch) with that in neutral conditions (e.g., Cipriani et al., 2024).

To disentangle these overlapping accounts, we propose two complementary strategies. First, future research should derive mutually exclusive predictions about how each hypothesis maps onto DDM parameters, identifying contexts where one mechanism operates independently of the others. For example, the strengthening account may predict larger RCBs when retro-cue-to-probe intervals are longer, while this prediction does not follow clearly from the protection account (Shepherdson et al., 2018). Second, integrating behavioral modeling with neural data—particularly electroencephalography—could refine mechanistic interpretations (Nunez et al., 2024). For example, contralateral delay activity, a neural marker of WM storage, has been linked to the removal of noncued items (Günseli et al., 2019). By jointly modeling behavioral data and contralateral delay activity measures, researchers could test whether retro-cueing costs in nondecision time correlate with neural signatures of item removal, thus favoring one interpretation over another.

In conclusion, Shepherdson et al. (2018) showed how DDMs clarify retrospective attention by linking the RCB to cognitively meaningful parameters. Their work showed that retro-cues enhance both the quality of WM representations and the speed of accessing them, without altering decision thresholds. While the protection and head-start retrieval accounts are well supported, the strengthening and removal accounts remain only partially validated. Moving forward, researchers should formulate mutually exclusive predictions for each mechanism within the DDM framework and consider combining behavioral and neural data to further clarify how attention modulates WM representations.

References

Boag, R. J., Strickland, L., Heathcote, A., Neal, A., Palada, H., & Loft, S. (2023). Evidence accumulation modelling in the wild: Understanding safety-critical decisions. *Trends in Cognitive Sciences*, *27*(2), 175–188. https://doi.org/10.1016/j.tics.2022.11.009

Brady, T. F., Robinson, M. M., Williams, J. R., & Wixted, J. T. (2023). Measuring memory is harder than you think: How to avoid problematic measurement practices in memory research. *Psychonomic Bulletin & Review*, *30*(2), 421–449. https://doi.org/10.3758/s13423-022-02179-w

Cipriani, G. A., González-García, C., Martín-Arévalo, E., Lupiáñez, J., & Botta, F. (2024). Competing working memory contents: Perceptual over semantic prioritization and voluntary retrieval following retro-cueing. *Visual Cognition*, *32*(4), 342–361. https://doi.org/10.1080/13506285.2024.2435652

Farrell, S., & Lewandowsky, S. (2018). *Computational modeling of cognition and behavior*. Cambridge University Press.

Forstmann, B. U., Ratcliff, R., & Wagenmakers, E. J. (2016). Sequential sampling models in cognitive neuroscience: Advantages, applications, and extensions. *Annual Review of Psychology*, *67*(1), 641–666. https://doi.org/10.1146/annurev-psych-122414-033645

Fuentes-Guerra, Á., Botta, F., Lupiáñez, J., Talavera, P., Martín-Arévalo, E., & González-García, C. (2025). Exogenous spatial attention selects associated novel bindings in working memory. *Journal of Memory and Language*, *140*, Article 104571. https://doi.org/10.1016/j.jml.2024.104571

Griffin, I. C., & Nobre, A. C. (2003). Orienting attention to locations in internal representations. *Journal of Cognitive Neuroscience*, *15*(8), 1176–1194. https://doi.org/10.1162/089892903322598139

Günseli, E., Fahrenfort, J. J., van Moorselaar, D., Daoultzis, K. C., Meeter, M., & Olivers, C. N. (2019). EEG Dynamics reveal a dissociation between storage and selective attention within working memory. *Scientific Reports*, *9*(1), Article 13499. https://doi.org/10.1038/s41598-019-49577-0

Landman, R., Spekreijse, H., & Lamme, V. A. (2003). Large capacity storage of integrated objects before change blindness. *Vision Research*, *43*(2), 149–164. https://doi.org/10.1016/S0042-6989(02)00402-9

Makovski, T., Sussman, R., & Jiang, Y. V. (2008). Orienting attention in visual working memory reduces interference from memory probes. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *34*(2), 369–380. https://doi.org/10.1037/0278-7393.34.2.369

Nobre, A. C., Griffin, I. C., & Rao, A. (2008). Spatial attention can bias search in visual short-term memory. *Frontiers in Human Neuroscience*, *2*, Article 4. https://doi.org/10.3389/neuro.09.004.2007

Nunez, M. D., Fernandez, K., Srinivasan, R., & Vandekerckhove, J. (2024). A tutorial on fitting joint models of M/EEG and behavior to understand cognition. *Behavior Research Methods*, *56*(6), 6020–6050. https://doi.org/10.3758/s13428-023-02331-x

Oberauer, K. (2001). Removing irrelevant information from working memory: A cognitive aging study with the modified Sternberg task. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *27*(4), 948–957. https://doi.org/10.1037/0278-7393.27.4.948

Ratcliff, R. (1978). A theory of memory retrieval. *Psychological Review*, *85*(2), 59–108. https://doi.org/10.1037/0033-295X.85.2.59

Ratcliff, R., Smith, P. L., Brown, S. D., & McKoon, G. (2016). Diffusion decision model: Current issues and history. *Trends in Cognitive Sciences*, *20*(4), 260–281. https://doi.org/10.1016/j.tics.2016.01.007

Shepherdson, P. (2020). Select, then decide: Further evidence for separable selection and decision processes in short-term visual recognition. *Visual Cognition*, *28*(2), 119–134. https://doi.org/10.1080/13506285.2020.1733155

Shepherdson, P., Oberauer, K., & Souza, A. S. (2018). Working memory load and the retro-cue effect: A diffusion model account. *Journal of Experimental Psychology: Human Perception and Performance*, *44*(2), 286–310. https://doi.org/10.1037/xhp0000448

Souza, A. S., & Frischkorn, G. T. (2023). A diffusion model analysis of age and individual differences in the retro-cue benefit. *Scientific Reports*, *13*(1), Article 17356. https://doi.org/10.1038/s41598-023-44080-z

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. https://doi.org/10.3758/s13414-016-1108-5

Souza, A. S., Rerko, L., & Oberauer, K. (2014). Unloading and reloading working memory: Attending to one item frees capacity. *Journal of Experimental Psychology: Human Perception and Performance*, *40*(3), 1237–1256. https://doi.org/10.1037/a0036331

Souza, A. S., Rerko, L., & Oberauer, K. (2016). Getting more from visual working memory: Retro-cues enhance retrieval and protect from visual interference. *Journal of Experimental Psychology: Human Perception and Performance*, *42*(6), 890–910. https://doi.org/10.1037/xhp0000192

van Ede, F., & Nobre, A. C. (2023). Turning attention inside out: How working memory serves behavior. *Annual Review of Psychology*, *74*(1), 137–165. https://doi.org/10.1146/annurev-psych-021422-041757

Voss, A., Nagler, M., & Lerche, V. (2013). Diffusion models in experimental psychology. *Experimental Psychology*, *60*(6), 385–402. https://doi.org/10.1027/1618-3169/a000218

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