Skilled Readers Engage More Proactive Attentional Control During a Working Memory Task

Malayka Mottarella, Brianna L. Yamasaki and Chantel Prat

July 12, 2020

Skilled Readers Engage More Proactive Attentional Control During a Working Memory Task

Malayka Mottarella[1], Brianna L. Yamasaki[2], and Chantel S. Prat[1,3]

[1]Department of Psychology, University of Washington

[2]Department of Psychology and Human Development, Vanderbilt University

[3]Institute for Learning and Brain Sciences, University of Washington

Author Note

The authors declare no conflicts of interest with respect to this preprint.

We thank Justin Abernethy and Andrea Stocco for their assistance with data curation and analysis script coding.

Correspondence should be addressed to Malayka Mottarella, University of Washington, Department of Psychology, Box 351525, WA 98195, United States. Email: mmottare@uw.edu

Abstract

This experiment employed a functional magnetic resonance imaging (fMRI) working memory task to examine how three sub-component processes: (1) Proactive Control, (2) Filtering, and (3) Disengagement contribute to a mechanistic explanation of the relation between working memory and reading skill. Results suggested that skilled readers deploy more prefrontal resources when cued proactively about task-relevant features than do less-skilled readers. In contrast, reading skill was not related to activation associated with attention-filtering or successful disengagement.

Keywords: working memory; proactive control; reading comprehension; individual differences

Skilled Readers Engage More Proactive Attentional Control During a Working Memory Task

Individual differences in working memory correlate with a range of reading-related processes; however, the mechanisms underlying this relation are still debated. One challenge of this research is that our understanding of the nature of individual differences in working memory has evolved over time. Most early theories focused on variability in the *capacity* of working memory, or the amount of information held in an active state for processing (Baddeley, 1992). More contemporary theories have suggested that a precursor of high working memory capacity is the ability to filter irrelevant information out (Vogel, McCullough, & Machizawa, 2005), or to disengage from information that is no longer relevant (Shipstead, Harrison, & Engle, 2016). These theories highlight different potential mechanisms linking individual differences in working memory to reading skill. Capacity-based theories suggest that skilled readers are better able to consider more information at once and execute processes in parallel when reading (Just & Carpenter, 1992). Filtering-based theories suggest that high working memory individuals are better readers because they can ignore irrelevant details and focus in on key information when they read (McVay & Kane, 2012). Finally, disengagement-based theories highlight the need for updating an individual's internal representation of meaning when new information is presented during reading (Martin, Shipstead, Harrison, Redick, Bunting, & Engle, 2019).

Critically, these contemporary conceptualizations of working memory require individuals to decide what information is relevant to a given task, and individuals vary in their ability to make these judgements. The construct of proactive control, or the ability to use proactive cues to predict what information will be relevant to an upcoming task, describes a mechanism for how individuals make these decisions (Braver, 2012). Individual differences in proactive control have been previously linked to working memory capacity (McNab & Klingberg, 2008), and behavioral research examining the relation between filtering mechanisms and working memory has suggested that working memory capacity *only* relates to filtering abilities when informative cues are presented (Robinson, Miller, & Unsworth, 2018). The current study employed a cued working memory task to investigate the hypothesis that individual differences in reading are related to differences in the ability to use proactive cues to guide attention and memory.

Methods

Participants

Sixty-seven right-handed, monolingual adults (44 female, 23 male, mean age = 21.46) participated in this study. Eight participants were excluded due to scanner (*n* = 5) or motion (*n* = 1) artifacts, or below chance accuracy (*n* = 2) on the functional magnetic resonance imaging (fMRI) task.

Procedure

Data used in this analysis were collected as part of a series of experiments investigating differences in complex skill learning. The fMRI task reported herein was embedded within a scan session that also included structural and resting-state measures.

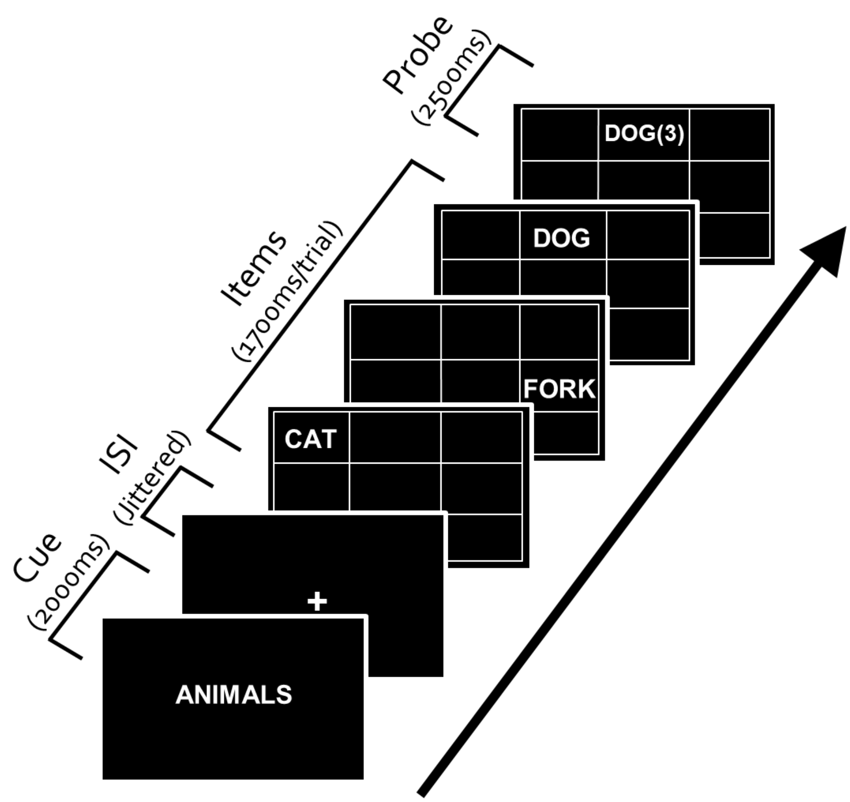
fMRI Task

In this task, to-be-remembered words were presented serially on a 3x3 grid in to-be-remembered locations (see Figure 1). Participants read cues at the beginning of each trial instructing them to either remember all presented words (No-Filter) or only words in a specific semantic category (Filter). At the end of each trial, participants were presented with one of the words and were asked to judge if it was in the correct location and had the correct order listed. Load (3 vs. 5 items) and filtering demands (Filter vs. No-Filter) varied orthogonally across trials.

Subcomponent processes were operationalized in the following way: (1) Proactive control: Greater activation for Filter than No-Filter cues; (2) Filtering: Greater activation for Filter compared to No-Filter trials; and (3) Disengagement: Smaller activation changes when distractors were added, as measured by comparing activation in Filter 5 trials (3 targets, 2 distractors) to No-Filter 3 trials (3 targets, 0 distractors).

Figure 1

Schematic of a Filter 3 Incorrect Trial.



fMRI Analysis

Group-level data were analyzed using a general-linear modeling approach. Activation associated with the proactive control and filtering contrasts were correlated with reading skill, measured using total percentile score on the Nelson-Denny Reading Test. To measure the dynamics associated with disengagement, the timecourses of activation from six regions-of-interest (ROIs; see Table 1), previously implicated in working memory (McNab & Klingberg, 2008), were extracted. Percent signal change from the first to the last scan of each trial was calculated and correlated with reading skill. The disengagement contrast was measured using percent signal change because it compared Filter 5 and No-Filter 3 trials, which, due to the serial nature of the paradigm, were different lengths and thus ill-suited to the general-liner modeling method.

Table 1

ROI Descriptions for Percent Signal Change Analysis

Region	MNI Coordinates	Radius (mm)
Left Basal Ganglia	-16, 16, 8	6
Left Prefrontal	-44, 30, 33	8
Left Parietal	-32, -70, 42	8
Right Basal Ganglia	16, 16, 8	6
Right Prefrontal	44, 30, 33	8
Right Parietal	32, -70, 42	8

Results

Proactive Control

Better readers recruited more proactive control mechanisms, as evidenced by greater activation in Brodmann's Area (BA) 10 (MNI: -14, 58, 22, cluster size = 125, $p < 0.001$, uncorrected), in the left anterior frontal lobe, when Filter compared to No-Filter cues were presented (see Figure 2). This result did not survive family-wise error (FWE) correction.

Filtering

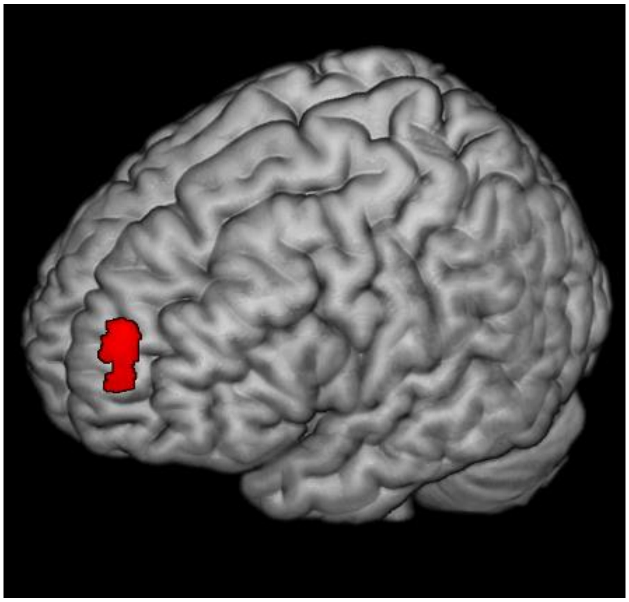
No significant correlation was observed between reading skill and filtering mechanisms ($p > 0.001$, uncorrected).

Disengagement

No significant correlation was observed between reading skill and disengagement mechanisms in any of the prespecified ROIs ($p > 0.05$).

Figure 2

Correlation between Nelson Denny Reading Test and Proactive Control in Left Anterior Frontal Lobe (BA10).



Discussion

The results reported herein demonstrate that skilled readers more strongly engage proactive control mechanisms in a complex working memory task. The region in which reading skill correlated with proactive-control-related brain activation, BA10, has been previously associated with goal maintenance and attention allocation mechanisms (Ramnani & Own, 2004). To follow up on this finding, we conducted a post-hoc analysis on the subset of our participants (n = 28) who also completed the AX Continuous Performance Task (AXCPT), a behavioral measure of proactive control. In this task, participants are instructed to press a button when they see an “X” that is preceded by an “A” (“AX” trials) but not when they see an X that is preceded by any other letter (“BX” trials) or when they see any other letter that is preceded by an A (“AY” trials). Participants who engage more proactive control, and thus better attend to and utilize the cues, tend to perform worse on “AY” trials compared to “BX” trials. Consistent with the hypothesis tested herein, better readers displayed greater proactive control as indexed by a negative correlation between “AY” – “BX” accuracy and reading skill [$r(27) = -0.428$, $p = 0.023$].

The lack of a relation between reading and filtering or disengagement mechanisms in the current study, is inconsistent with previous behavioral research, but may reflect methodological limitations. Due to the nature of the fMRI task we were unable to capture activity changes between the cue and task and this may have limited our ability to capture variance associated specifically with task performance. Despite this limitation, the results reported herein provide novel behavioral and neural evidence that proactive control plays an important role in reading. This conclusion is in line with contemporary theories of text comprehension, which suggest that reading outcomes are dependent on specific task goals (McCrudden & Schraw, 2007).

References

Baddeley, A. (1992). Working memory, *Science*, *255*(5044), 556-559.

Vogel, E.K, McCullough, A. w., & Machizawa, M. G. (2005). Neural measures reveal individual differences in controlling access to working memory. *Nature*, *438*, 500-503.

Shipstead, Z., Harrison, T. L., & Engle, R. W. (2016). Working memory and fluid intelligence: Maintenance and disengagement. *Perspectives on Psychological Science*, *11*(6), 771-799.

Just, M. A., & Carpenter, P. A. (1992). A capacity theory of comprehension: Individual differences in working memory. *Psychological Review*, *99*(1), 122-149.

McVay, J. C., & Kane, M. J. (2012). Why does working memory predict variability in reading comprehension? On the influence of mind wandering and executive attention. *Journal of Experimental Psychology: General*, *141*(2), 302-320.

Martin, J. D., Shipstead, Z., Harrison, T. L., Redick, T. S., Bunting, M., & Engle, R. W. (2019). The role of maintenance and disengagement in predicting reading comprehension and vocabulary learning. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *46*(1), 140-154.

Braver, T. S. (2012). The variable nature of cognitive control: A dual mechanisms framework. *Trends in Cognitive Sciences*, *16*(2), 106-113.

McNab, F. & Klingberg, T. (2008). Prefrontal cortex and basal ganglia control access to working memory. *Nature Neuroscience*, *11*(1), 103-107.

Robinson, M. K., Miller, A. L., & Unsworth, N. (2018). Individual differences in working memory capacity and filtering. *Journal of Experimental Psychology: Human Perception and Performance*, *44*(7), 1038-1053.

Ramnani, N., & Owen, A. M. (2004). Anterior prefrontal cortex: Insights into the function from anatomy and neuroimaging. *Nature Neuroscience Reviews*, *5*, 184-194.

McCrudden, M. T., & Schraw, G. (2007). Relevance and goal-focusing in text processing. *Educational Psychology Review*, *19*, 113-139.