Effects of math structure and training on math and sentence processing: A cross-domain priming investigation

Kristen M. Tooley, Paul Christian Dawkins, and Christopher Soens
Texas State University

Syntactic/Structural priming research consistently demonstrates persistence of abstract structure within language (e.g., Mahowald et al., 2016; Tooley, 2023). Structural representations can also persist across domains, such as when the structure of a math expression affects how the structure of a target sentence stem is completed (Scheepers et al., 2011; Scheepers et al., 2019; Van de Cavey & Hartsuiker, 2016), supporting the existence of domain-general structural representations. Scheepers and colleagues suggest that incremental left-to-right structural extraction occurs in mathematical processing, which is inconsistent with recent findings from Zeng et al. (2021). Our study uses an eye-tracking while reading (cross-domain structural priming) paradigm to assess whether math processing displays a left-to-right processing bias, and whether the primed math structure affects later sentence reading measures, which has yet to be investigated. Math-to-language priming is sometimes weaker in those with lower math proficiency, so our sample included both math-related (MR) and non-math-related (NMR) majors. These groups allow us to investigate whether differences in mathematical training is associated with differences in math processing patterns and math-to-language priming effects.

Participants (N = 125; MR = 49, NMR = 76) solved 24 prime math expressions (from Scheepers et al., 2011) that had either Baseline (no grouping/solved left to right, e.g., 7 + 24 = ?), High Attachment (middle elements combined first, e.g., 7 + (28 − 4) × 2 = ?), or Low Attachment (final elements combined first, e.g., 7 + 28 – (4 × 2) = ?) structures. A globally ambiguous English target sentence followed each prime (e.g., *The reporter waited for the manager of the pop star who was always late*). Eye-tracking occurred during math and sentence processing. Participants then chose one of two answer options, which revealed their structural interpretation of the sentence (e.g., “the pop star was late” indicating low attachment or “the manager was late” indicating high attachment). Condition was counterbalanced across item lists, with at least two fillers of various structures between all yoked prime-target pairs. Targets following incorrectly solved primes (~11%) were removed before analysis.

To assess cross-domain priming, we ran a mixed-effects logistic model with target response structure as the outcome variable and prime condition, major, and their interaction as fixed effects (participant and item random intercepts). No fixed effects reached significance (see Figures 1a-b). However, additional models (n= 70/125 with cleaned eye-tracking data so far) of target first-pass and total fixation times as outcome variables revealed significant effects of Condition at the first noun phrase after the verb (*p’s* < .02). Participants spent longer reading this region (which attaches to the RC in high attachment) after a Low Attachment prime (see Figure 2), which may indicate disruption of high attachment processing after a low attachment prime. A non-significant, complementary trend was observed at the second noun (which attaches to the RC in low attachment), which was read slower after a high attachment prime.

To assess early math processing, first run fixation percentages were scaled based on the number of elements in the region and then estimated at regions 2 and 3 of the mathematical expressions (see Figure 3) in a linear mixed-effects model with the same fixed and random effects as before. We observed a significant effect of Condition at both regions (p’s < .001), but no effect of or interaction with major (See Figure 3). Participants had more initial fixations on the region containing the first operation to be solved, rather than a left-to-right processing bias.

Our findings do not replicate previous cross-domain priming effects observed on the target structure measure, but do reveal a novel effect of math structure on target sentence processing. These results also provide evidence corroborating Zeng et al.’s (2021) observation of operation-centric mathematical processing. Finally, we observed no interacting effects of mathematical training (indicated by a major coursework) with either cross-domain priming or mathematical processing.

Figure 1. Percentage of high and low attachment target completions following Baseline, High Attachment, and Low Attachment Conditions from a) 49 participants with math-related majors (left) and b) 76 participants with non-math-related majors (right). Error bars represent standard errors.

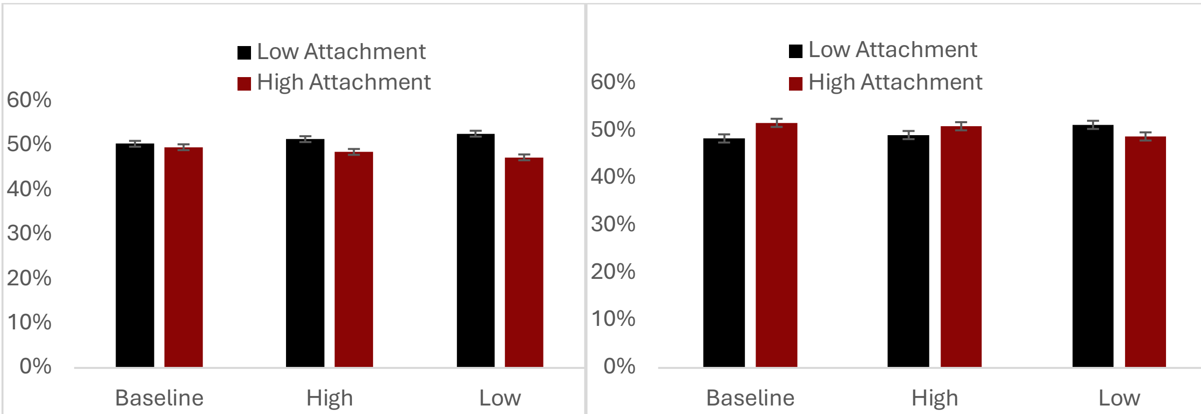


Figure 2. Mean first-pass reading time on the first (N1) and second (N2) nouns after the verb of the target sentences. Error bars represent standard errors.

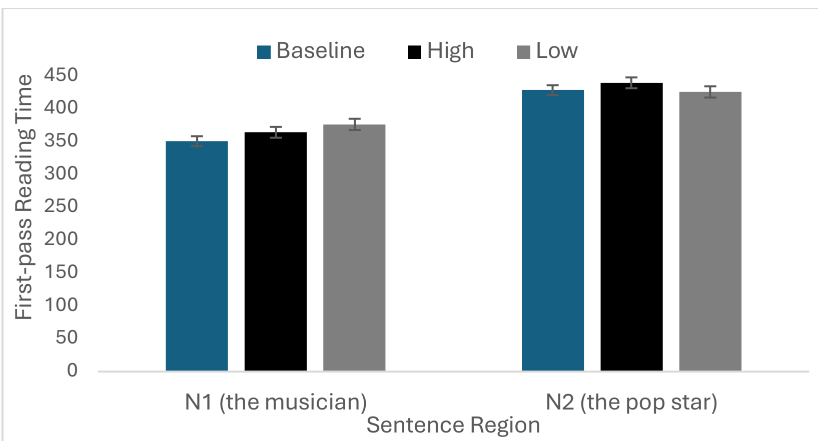
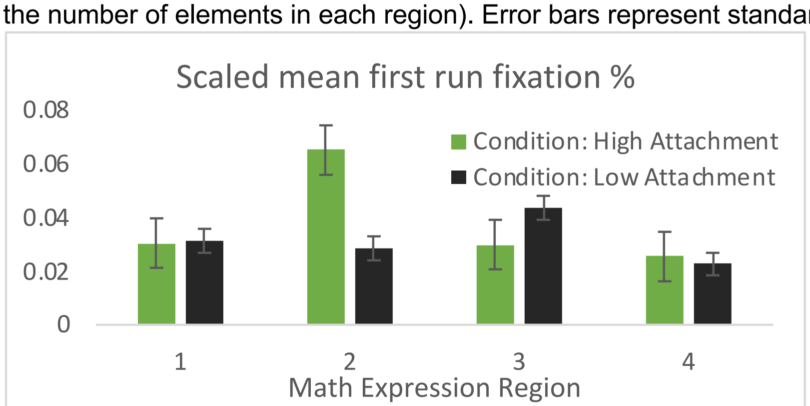


Figure 3. Mean first-run fixation percentage in the four mathematical expression regions (scaled based on the number of elements in each region). Error bars represent standard errors



Regions: **1 2 3 4**

High Attachment: |7 + |(28 − 4)| × 2 | = ? |

Low Attachment: |7 + | 28 – |(4 × 2)| = ? |