

## When effects appear before causes: an ERP study

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To build a coherent discourse model, comprehenders incrementally draw upon their stored real-world knowledge about causal relationships across events, resulting in facilitated semantic processing of predictable incoming words<sup>1,2</sup>. Crucially, however, the sequence in which causally related events unfold during language comprehension does not necessarily mirror their real-world sequence (where causes precede effects). Sometimes comprehenders receive explicit cues (e.g. discourse connectives), telling them whether to expect a canonical or non-canonical event sequence; at other times, they receive no such information. In two event-related potential (ERP) experiments, we asked whether and how two causal connectives, specifying either a canonical or non-canonical event sequence, influenced the load on working memory (WM), as indexed by a frontally-distributed sustained negativity<sup>3</sup>, and semantic facilitation, as indexed by the centroparietally-distributed N400<sup>4</sup>, as readers comprehended two-clause scenarios.

In **Experiment 1**, we manipulated the canonical sequence of events and their causal predictability. Methods: 32 participants read two-clause sentences, linked by a forward connective, “and so” (for canonical order; see 1a,c), or by a backward connective, “because” (for non-canonical order; 1b,d). A critical word (CW) in the second clause was either causally predictable (1a,b) or unpredictable and incoherent (1c,d), as operationalized by cloze norming. Sentences were presented word-by-word, randomized and counterbalanced across lists. Results & Discussion: The connective “because” evoked a larger widespread negativity between 350-500ms than “and so” ( $p < 0.03$ ). At left frontal sites, this negativity effect remained significant on the following word ( $p < 0.05$ ), suggesting an increased WM load as comprehenders prepared to process the second clause. We suggest that this WM load was incurred because the backward causal connective cued comprehenders to predict a non-canonical event sequence and retain the event representation of the first clause within WM in order to integrate it with the second clause. Additionally, at the critical word, the N400 was smaller to predictable than unpredictable/incoherent words ( $p < 0.001$ ). This N400 effect, however, was not influenced by the nature of the connective, suggesting that expectations about canonical sequencing did not influence causal predictions and semantic facilitation of incoming words.

**Experiment 2** was designed so that identical words followed “and so” and “because” in the second clause (examples, 2a,b). This allowed us to determine whether the WM load incurred after “because” was sustained over the words of the second clause. In addition, to determine whether the presence of causal connectives influenced either WM load or semantic facilitation, the same clauses were presented without connectives, separated only by a semicolon (2c,d). Methods: 30 different participants read a new set of two-clause coherent scenarios, again presented word-by-word, randomized and counterbalanced across lists. Results & Discussion: Replicating Experiment 1, the first word of the second clause evoked a larger frontal negativity following “because” than “and so”. Consistent with previous studies of non-canonical temporal connectives<sup>3</sup>, this larger frontal negativity was sustained across all the words in the second clause ( $ps < 0.05$ , **Figure 1**). A similar larger sustained frontal negativity was seen in the no-connective scenarios, relative to the “and so” scenarios. This suggests that readers incurred a sustained WM load both when they were uncertain about the causal or temporal relationship of upcoming events, and when they were explicitly cued to predict a non-canonical event sequence. Finally, the amplitude of the N400 on CWs was the same in the connective and no-connective scenarios, suggesting that the presence/absence of causal connectives did not influence semantic facilitation.

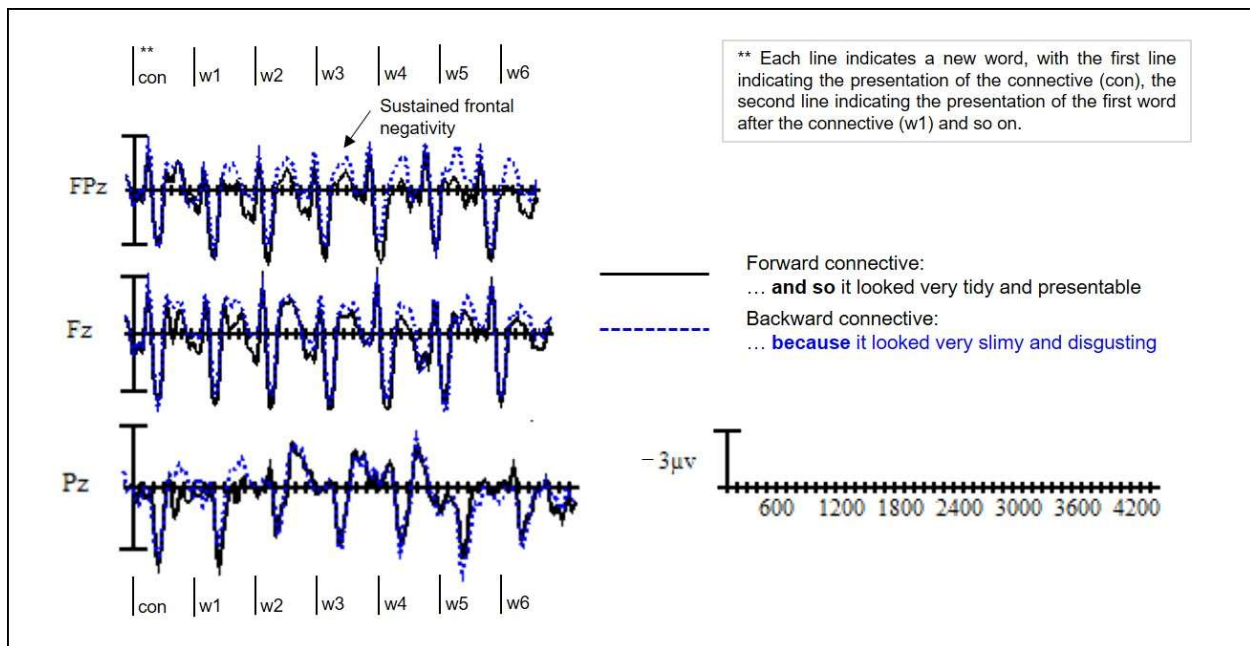
**Conclusion**: Together, these findings suggest that seeking causal coherence is essential to integrating meaning across events<sup>5,6</sup>, with readers anticipating and drawing upon their stored real-world knowledge to the same degree, regardless of the variable WM load associated with the presence or absence of causal connectives or the canonicity of the event sequence.

## Examples of stimuli:

Experiment 1		
1a	Forward connective, predictable CW	The river flooded <b>and so</b> the town was <u>destroyed</u> by the water.**
1b	Backward connective, predictable CW	The town was destroyed <b>because</b> the river <u>flooded</u> in the morning.
1c	Forward connective, unpredictable CW	The town was destroyed <b>and so</b> the river <u>flooded</u> in the morning.
1d	Backward connective, unpredictable CW	The river flooded <b>because</b> the town was <u>destroyed</u> by the water.
Experiment 2		
2a	Forward connective	The cleaners mopped the floor <b>and so</b> it looked very <u>tidy</u> and presentable
2b	Backward connective	The cleaners mopped the floor <b>because</b> it looked very <u>slimy</u> and disgusting
2c	No connective, Forward events	The cleaners mopped the floor; it looked very <u>tidy</u> and presentable
2d	No connective, Backward events	The cleaners mopped the floor; it looked very <u>slimy</u> and disgusting

\*\* Connectives are indicated in bold font and critical words are underlined.

**Figure 1: Experiment 2. Waveforms starting at the connective**



## References

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