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情緒在年齡相關語句閱讀預測歷程中的角色：來自腦電位的證據

The Role of Emotion in Age-Related Predictive Dynamics During Sentence Reading: Evidence from Brain Potentials

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摘要

本研究探討年輕與年長成人在語言理解過程中，預測性處理動態如何受到情緒的調節。實驗招募 27 位健康年輕成人（年齡介於 20–30 歲，平均為 24 歲）與 30 位年長臺灣華語母語者（年齡介於 60–77 歲，平均為 69 歲），在閱讀具情緒性或中性語句時記錄其事件相關電位（ERP）反應。語句在語意限制強度（constraint strength）上有所操弄，並以預期或不預期的情緒性或中性詞彙為結尾。

結果顯示，無論年齡組別，受試者對於出現在情緒性語境中的預期情緒詞，皆誘發較中性語境中更大的前額 P200 振幅，而該效應在年長組表現為較不前額的分佈，反映出情緒語境所驅動的早期注意力投入。此外，兩組皆在 N400 時間窗展現典型的預期效應：預期結尾相較於不預期結尾誘發較小的 N400 負波，且此效應不受語境情緒性的影響。特別是在中性語境中，來自語意限制性高的語句（Neu_SCE）的預期結尾，誘發較語意限制性低語句（Neu_WCE）為小的 N400 振幅，該效應在兩組中皆有顯現；然而，在情緒語境下，年輕組則未顯現類似的 N400 減弱。在前額 ERP 效應方面，兩組皆展現語境限制性調節的影響，但情緒調節的模式在年齡組別間有所不同。在中性語境中，兩組對於來自高限制性語境的預期結尾（Neu_SCE）皆呈現顯著較大的前額負波，相較於其他中性語句；此外，年長組對於低限制性語境中的不預期結尾（Neu_WCU）亦額外誘發一個前額正波。相對地，在情緒語境中，兩組的反應模式出現差異：年輕組對來自低限制性語境的預期結尾（Emo_WCE）表現出較大的前額負波，且未對不預期結尾產生正波；年長組則在高限制性語境

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的不預期結尾條件（Emo_SCU）中，顯現顯著的前額正波。這些結果說明，情緒對預測性語言處理的調節存在年齡差異，且表現出不同的電生理反應型態。在未進行情緒操弄的情況下，兩組皆能依據語句中的語意限制性建立語意整合，進而影響隨後詞彙的語境回溯處理。當給予足夠時間使情緒逐漸累積，情緒可能會在整個語境中增強語意訊息的整合與建構，進一步提升年輕人在高、低限制性語境中的再處理歷程。相對地，年長組僅在高限制性情緒語境中（而非中性語境）對不預期中性結尾詞產生前額正波（AP），此結果與先前研究一致，並指出情緒參與可能有助於提升年長者的預測性語言處理能力。整體而言，本研究強調了預測性語言處理在整個生命歷程中的適應性，並突顯了情緒如何在強語境限制下，透過不同的機制調節年輕與年長成人的語言理解歷程。

關鍵字：老化，語言，情緒，預測處理，閱讀理解

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Abstract & Keywords

Descriptors: Aging, Language, Emotion, Predictive processing, Reading comprehension

This study examined how predictive dynamics during language comprehension is modulated by emotion in young and older adults. Event-Related Potentials were recorded from 27 healthy young (aged 20–30 years, M=24) and 30 older Taiwan Mandarin natives (aged 60–77 years, M=69) as they read emotionally or neutrally framed sentences, varying in constraint strength and ending with expected or unexpected emotional or neutral words. Enhanced anterior P200 amplitudes to emotionally expected words in emotional relative to neutral contexts were observed in both young and older adults, with a less frontal distribution in older adults—suggesting early attentional engagement driven by emotional context. The results showed that expected endings elicited reduced N400 amplitudes compared to unexpected endings across context emotionality in both age groups. In particular, expected endings following strongly constraining neutral contexts (Neu_SCE) elicited less negative N400 amplitudes than those following weakly constraining neutral contexts (Neu_WCE) in both age groups, whereas

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this N400 reduction was not observed under emotional contexts in young adults. In addition, both age groups exhibited anterior constraint effects, but the pattern of emotional modulation under strong constraint differed between young and older adults. In neutral contexts, both age groups exhibited greater anterior negativity for expected endings following strongly constraining contexts (Neu_SCE) compared to the other neutral conditions. Older adults also showed an additional anterior positivity to unexpected endings in weakly constraining contexts (Neu_WCU). In emotional contexts, the pattern diverged: young adults showed enhanced anterior negativity for expected endings in weakly constraining contexts (Emo_WCE) but no anterior positivity for unexpected endings, whereas older adults exhibited a distinct anterior positivity to unexpected endings following strongly constraining contexts (Emo_SCU). These results indicate distinct patterns of emotional modulation in predictive dynamics during sentence comprehension. Without systematic emotional manipulation, both young and older adults were able to integrate semantic information based on strong contextual constraints, which in turn influenced context revisiting when reading upcoming words. With sufficient time for incrementing emotionality, emotion may globally amplify

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message-level consolidation throughout the context, enhancing revisiting processes not only in strongly but also in weakly constraining sentences for young adults. In contrast, for older adults, unexpected neutral words elicited an Anterior Positivity (AP) when ending an emotionally, strongly constraining contexts—a pattern absent in neutral contexts—replicating previous findings. In light of this, the observed AP effect may suggest that predictive processing during reading becomes more available for older adults when emotionally engaged. These findings underscore the malleability of predictive language processing across the lifespan and highlight age-related differences in how emotion modulates such mechanisms under strong contextual constraint.

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1 | Introduction

Grandson:

"Grandma, we're going on a school field trip to the beach tomorrow. I'm so excited to see the dinosaurs!"

Grandma:

"Alright, alright—I'll pack your swimsuit, swim trunks, sunglasses, and sunscreen. It's always super hot at the beach!"

Older Sister:

"Wait… did you say you're going to the beach to see dinosaurs? Who goes to the beach to see dinosaurs?... Oh—I see, you're going to the museum by the beach!"

Grandson:

"Yeah! We're going to the National Museum of Marine Science and Technology. They have a dinosaur fossil exhibit there!"

This provides a salient example of how young and older adults may differ in their interpretation of the same linguistic input.

Younger adults routinely engage in proactive, flexible predictive processing during conversation, allowing for efficient online comprehension and revision. They can

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quickly figure out what the speaker actually means because they're constantly flexibly updating their expectations based on contextual cues—they engage in active prediction throughout the conversation (explained more in sections below). This allows them to rapidly detect when something deviates from what they expect and to revise their understanding in real time. This ability reflects the routine use of predictive processing.

In contrast, while older adults retain broader world knowledge and an extended vocabulary—which tend to accumulate with age and remain relatively intact—age-related declines in executive function also make predictive language processing more effortful and reactive. One major factor is the decline in executive cognitive processes, such as inhibitory control, working memory updating, and task-switching. For instance, while older adults often possess an extensive vocabulary and a wealth of world knowledge accumulated through life experience—allowing for deeper and more sophisticated interpretation of words and sentences—prior research suggested they may nonetheless tend to be less proactive than young adults in language prediction. Specifically, they appear less likely to preactivate the semantic features of anticipated upcoming words before word onset, rendering their language prediction process more reactive—relying on semantic processing and integration only after word presentation, rather than actively generating predictions in advance. Furthermore, in line with this

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pattern, older adults appear to face greater challenges in rapidly extracting and integrating rich contextual cues, thereby reducing their likelihood of forming strong lexical expectations based on incoming linguistic input compared to younger adults (explained more in sections below). Age-related vulnerabilities in predictive language processing—such as reduced efficiency in extracting rich contextual cues and in preactivating semantic features of upcoming words—have been linked to cognitive resources, including executive function, processing speed, and working memory capacity. Older adults may have difficulty holding relevant contextual information in working memory, updating expectations when sentence endings shift unexpectedly, or inhibiting irrelevant information that may act as noise—functions that rely heavily on fluid cognitive abilities, which tend to decline with age. (Federmeier et al., 2007; Lai et al., 2024; Spreng & Turner, 2019; Wlotko et al., 2012; Wlotko & Federmeier, 2012a).

Building on prior findings that age-related challenges in language predictive processing are linked to declines in executive functioning, and that executive function is closely linked to emotional processing through structural and functional brain connections, it remains unclear whether and how emotion might modulate predictive language mechanisms in aging. (Ferdinand & Hilz, 2020; Huang et al., 2023; Mather, 2012, 2016; Mohanty, 2011; Tyng et al., 2017; Vogel et al., 2015). In view of this, our

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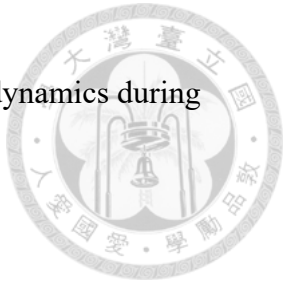
study seeks to examine the role of emotion in age-related predictive dynamics during sentence reading.



1.1 | Age-Related Strengths and Vulnerabilities in Language Predictive Processing

Age-related changes in language prediction involve both strengths and weaknesses across different stages of the language prediction process. Although older adults retain enriched vocabularies and extensive world knowledge, many studies have shown that cognitive functions essential for prediction—such as processing speed, working memory, and executive control—decline with age (Park & Reuter-Lorenz, 2009; Spreng & Turner, 2019). These declines may lead to reduced efficiency in integrating contextual information, generating predictions about upcoming words, and evaluating those predictions during sentence comprehension.

During sentence comprehension, once perceptually meaningful stimuli are encountered, their semantic representations are immediately activated from the semantic memory system, as indexed by the N400 (Kutas & Federmeier, 2011; Federmeier, 2021). As the comprehension process unfolds and more semantic information accumulates, the brain simultaneously accesses meaning from the current input and

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begins to integrate it with preceding contextual information. This ongoing integration is also reflected in N400 amplitude, with reduced N400 responses typically indicating reduced semantic processing demands due to contextual support. Building on this accumulated context, the brain may begin to generate predictions about upcoming words. As contextual support increases—that is, as sentence constraint becomes stronger—comprehenders are more likely to generate strong expectations for specific upcoming words. In contrast, when sentence constraint is weak and contextual cues are limited, readers tend to entertain multiple possible continuations, resulting in more diffuse or probabilistic predictions about the sentence ending. Upon encountering new input, the predicted outcomes are compared against the actual stimuli to evaluate whether such predictions match actual feedback. When reading strong constraint contexts that prompt us to generate specific expectations for upcoming words, violations of these predictions—encountering unexpected sentence-final words—often elicit an anterior positivity effect (AP) in young adults (Federmeier, 2007). This effect was suggested to reflect the effort involved in revising the preceding discourse representation to integrate new and unanticipated information. In the other way, when rich contextual information leads to multiple possible interpretations, the sentence meaning may remain underspecified or ambiguous. In such cases, readers must evaluate

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all contextually possible interpretations based on the available cues. The AN effect observed for highly expected words index the reader's engagement in processes that consolidate and affirm the overall message-level representation (Federmeier et al., 2007; Wlotko et al., 2012; Wlotko & Federmeier, 2012a).

Compared to younger adults, older adults exhibit reduced and delayed N400 responses to expected endings in strongly constraining contexts (Wlotko et al., 2012; Wlotko & Federmeier, 2012b), as well as the absence of anterior positivity to unexpected but plausible endings in such contexts (Federmeier et al., 2007). These findings suggest a diminished ability to extract and integrate rich contextual cues, making older adults show reduced engagement in proactively anticipating upcoming linguistic input. Together, these results highlight both age-related strengths and vulnerabilities that jointly influence predictive language processing, reflecting a shift from an active prediction mode to a more passive, reactive mode of comprehension in older adults, potentially reducing the overall efficiency of reading and language processing.

Figure 1

An Active language prediction mode during online sentence comprehension

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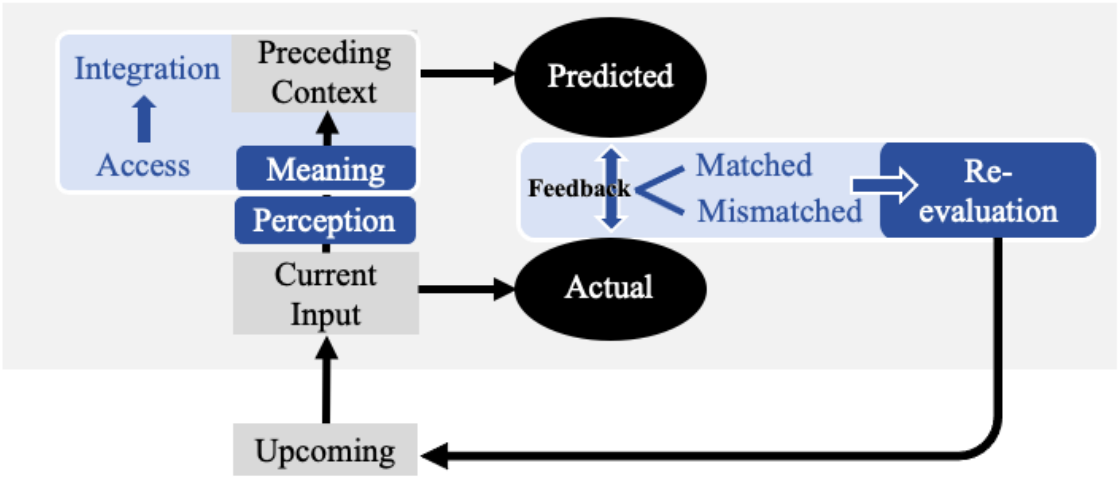

Note. This figure illustrates language predictive processing during online sentence comprehension. During language comprehension, once there is input of perceptually meaningful stimuli, the meaning representation is immediately activated from the semantic memory system (Federmeier, 2021). As more and more semantic representations build up, we then begin to integrate pieces of information from preceding contexts and to keep accessing meaning from current inputs simultaneously. Based on the integration from preceding context, predictions about upcoming words start to be generated. After which our brains will compare the previously predicted outcomes and actual encountering stimuli to evaluate whether such predictions match actual feedback.

1.1.1 | N400 (300-500 ms)

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The N400 is a widely studied ERP component linked to the retrieval of lexical-semantic information from long-term memory during language comprehension (Federmeier, 2021; Kutas & Federmeier, 2011; Wlotko et al., 2012; Wlotko & Federmeier, 2012a). These effects reflect the underlying mechanisms of active predictive language processing, including lexical-semantic access and integration with prior contextual information, as depicted in Figure 1.

The N400 reflects the effort our brains engage while trying to figure out how much new information should be activated in response to the word and how it fits into the sentence (Kutas & Federmeier, 2011). N400 to stimuli that are in weak contexts (such as at the end of a weakly constraining sentence), mismatch preceding contexts or out of contexts, is large since more new information is accessed from semantic memory. N400 amplitudes become smaller when semantic processing demands are reduced such as when stimuli are presented with a supportive sentential context (Federmeier, 2021; Wlotko et al., 2012; Wlotko & Federmeier, 2012a). The size of these N400 reduction is greater (more positive) when encountering words that strongly match preceding contexts compared to weaker matches (Wlotko et al., 2012; Wlotko & Federmeier, 2012a); this reflects the effort involved in context integration. For example, Federmeier et al. (2007) observed the typical expectancy effect, where expected words elicited

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reduced N400s in comparison to unexpected words; moreover, this effect has been found to be larger for expected endings with strongly versus weakly constraining contexts. Extending this line of research, Federmeier & Kutas (2005) demonstrated age-related differences in the use of contextual constraints during sentence processing. Specifically, older adults exhibited significantly smaller N400 reductions than younger adults in strongly constraining expected (SCE) contexts, while showing comparable N400 amplitudes in weakly constraining expected (WCE) conditions, suggesting that they may be less effective at extracting and utilizing rich semantic contextual information. Notably, delays in N400 responses in strongly constraining contexts have been linked to both chronological age and lower working memory capacity, underscoring the role of cognitive resources in predictive language processing. The richer contextual information in these sentences likely places greater demands on retrieval and integration processes required to construct or update the ongoing message-level representation. These increased demands may overburden the reduced executive and memory resources in older adults, leading to less efficient use of predictive mechanisms during comprehension.

Prior research has also shown that even when the final word in a sentence does not match the predicted word, the presence of a semantically related alternative can still

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facilitate processing, as reflected by a reduced N400 amplitude. This graded N400 response suggests that comprehenders engage in the preactivation of semantic features associated with expected continuations, thereby easing the retrieval process even for semantically related but unpredicted inputs (Federmeier, 2021). However, this semantic facilitation effect appears to be diminished or absent in older adults. Specifically, electrophysiological evidence from Federmeier (2021) demonstrates that while younger adults exhibit a graded N400 response across three levels of expectancy—expected exemplars, within-category violations (semantically related but incorrect), and between-category violations (semantically unrelated and incorrect)—older adults do not show this same sensitivity. In younger adults, N400 amplitude increases stepwise from expected to within-category to between-category violations, reflecting their ability to preactivate a semantic field of likely continuations. In contrast, older adults show similarly large N400 responses to both types of violations, indicating a lack of differential facilitation based on semantic relatedness.

These findings suggest that older adults are less likely to engage in proactive predictive processing during language comprehension. Instead of preactivating semantic features of upcoming input before word onset, their processing tends to be more reactive—initiating integration only upon encountering the actual word. This reduced

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engagement in anticipatory processing may contribute to their overall difficulty in leveraging predictive mechanisms to support efficient comprehension.

1.1.2 | Post-N400 Anterior Responses (600-900 ms)

Recent work has increasingly focused on event-related potential (ERP) patterns in the time window following the N400 to better understand the predictive dynamics of language comprehension—particularly in cases where predictions are either violated or precisely confirmed. Two major post-N400 ERP patterns have been consistently identified in predictive sentence processing: an anterior positivity (AP) and a frontal negativity (FN), each associated with different types of contextual outcomes. Among these post-N400 effects, two prominent patterns have been described: an anterior positivity, typically elicited by plausible yet unexpected words in strongly constraining contexts (i.e., prediction violations), and a frontal negativity, observed in response to highly expected words in similar predictive contexts.

This graded pattern has raised two possibilities over whether these ERP responses reflect a unitary predictive mechanism or distinct underlying cognitive processes. One is that these anterior post-N400 patterns reflect a single underlying mechanism that is graded in its sensitivity to expectancy or contextual fit; the other is

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that they instead reflect distinct cognitive processes that overlap in time and scalp distribution but differ in functional significance. When considered together, these effects seem to form a graded response continuum, with the most negative responses to highly expected words, intermediate responses to (expected or unexpected) words in weakly constraining contexts, and the most positive responses to prediction violations.

To date, evidence from individual and group-level variation has complicated the interpretation of these ERP patterns, highlighting the need for further clarification of their cognitive bases. While prior work has noted temporal and spatial similarities between the two, the field has yet to determine the extent to which they reflect separate comprehension processes or facets of a unified system.

Below, we discuss the two post-N400 anterior responses separately.

The anterior positivity (AP) is a post-N400 ERP component associated with prediction violation during sentence comprehension, typically elicited when readers encountering strongly constraining contexts lead to unexpected, yet plausible, outcomes. These effects reflect the engagement of predictive processes, including the detection of mismatches. While this effect has often been interpreted as reflecting prediction violation, recent studies suggested it also might reflect the cost of revising message-level representations, or the suppression of disconfirm predictions (Brothers et

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al., 2020; Federmeier et al., 2007). Notably, AP is reliably observed in young adults when they encounter unpredicted but plausible endings in strongly constraining sentences. Moreover, the anterior positivity appears to operate as an all-or-none mechanism—either fully engaged or not at all—rather than exhibiting a gradual sensitivity to variations in predictive effort. In other words, the AP does not vary in a graded manner with levels of engagement in prediction, but instead reflects a binary state of predictive commitment (Hubbard & Federmeier, 2021). Extending this, the presence of AP varies systematically across individuals and groups, suggesting that such violation-related processes in predictive processing—including detection, suppression, and revision—may not be uniformly engaged during comprehension. Older adults and individuals with lower literacy skills typically do not show AP responses to unexpected words following strong contextual information (Wlotko & Federmeier, 2012b, 2012a). This pattern aligns with prior N400 findings and suggests that these individuals are less likely to engage in proactive predictive processing. Rather than preactivating semantic features of upcoming input, they tend to adopt a more reactive strategy—initiating integration only once the word is encountered. As a result, prediction violations may perceived as less salient and thus insufficient to trigger the revision mechanisms reflected by the AP.

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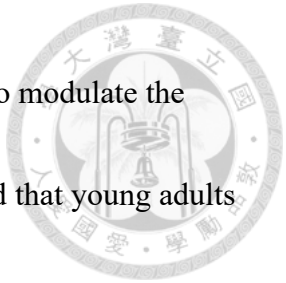

Moreover, task demands and stimulus characteristics appear to modulate the likelihood of AP elicitation. For example, Federmeier (2021) reported that young adults did not exhibit an AP when encountering unexpected words that were synonyms of the expected word—prediction violations without synonyms elicited a robust AP, whereas those with synonyms did not. This suggests that when the unexpected word does not disrupt the overall semantic interpretation of the sentence—such as when the word is semantically similar or related—the violation may not be salient enough to trigger revision processes reflected by the AP. In other words, AP may only arise when integrating unexpected input requires a meaningful update to the message-level representation. Findings from Lai et al. (2024) further highlight that the magnitude of AP is not necessarily modulated by prediction effort per se. In their study contrasting active and passive prediction conditions, both elicited comparable AP responses when prediction violations occurred, despite the active prediction condition involving greater intentional predictive engagement. This suggests that once prediction is engaged—regardless of whether it is voluntarily or implicitly triggered—the revision process indexed by the AP operates in a more categorical (i.e., all-or-none), rather than graded, manner. These findings underscore that the AP is not simply a graded index of prediction strength or effort, but instead reflects the necessity of revising the

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message-level representation when incoming input significantly disrupts the predicted meaning. The absence of AP for semantically related violations suggests that only violations requiring a meaningful reinterpretation of the discourse meaning are sufficient to trigger revision processes. Additionally, the comparable AP amplitudes across active and passive prediction conditions indicate that, once prediction is engaged, the AP response operates in a more categorical or all-or-none fashion, rather than scaling with the degree of predictive engagement.

The anterior negativity (AN), also known as the frontal negativity (FN), is a post-N400 ERP component associated with high predictability during sentence comprehension, typically elicited by highly expected words in moderately to strongly constraining contexts. AN often overlapping in both timing and scalp distribution with the anterior positivity (AP). It typically emerges around 400 ms and is most prominent over frontal electrode sites. It is reliably elicited by highly expected words presented in moderately to strongly constraining contexts (cloze probability ~75–90%) (Lai et al., 2024; Wlotko & Federmeier, 2012b).

Unlike the AP, which appears to reflect a binary prediction violation mechanism, the AN exhibited graded sensitivity to contextual predictability and could be modulated

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by task demands, suggesting it reflects a distinct and more flexible comprehension process. While the precise cognitive mechanisms underlying AN remain uncertain, previous studies have highlighted several of its characteristics. In contrast to the all-or-none nature of the AP, the AN appears to reflect a graded sensitivity to contextual factors—such as the strength of constraint and predictability—suggesting that it may be driven by a distinct comprehension mechanism (Wlotko & Federmeier, 2012b). Notably, Lai et al. (2024) demonstrated that task demands—especially when participants are explicitly instructed to predict—can further enhance the AN effect. This amplification is thought to arise from deeper semantic processing and consideration of multiple plausible interpretations, leading to greater engagement of integration-related processes.

Several interpretations have been proposed to explain the cognitive functions underlying the AN, ranging from ambiguity resolution to message-level representation formation. One possibility is that it reflects mechanisms akin to ambiguity resolution, wherein readers must evaluate and disambiguate competing interpretations to arrive at a coherent message-level representation (C. L. Lee & Federmeier, 2009). Another account proposes that the anterior negativity reflects processes involved in selecting and solidifying the message-level representation, especially when encountering the most

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globally probable word, thereby facilitating efficient semantic integration under high constraint.

In contrast to the AP, the AN is more robust across populations and predictive contexts, suggesting that it may support sentence comprehension even in the absence of top-down prediction. Notably, it is robustly elicited even in populations such as older adults and individuals with lower literacy, who typically do not show AP responses (Wlotko et al., 2012; Wlotko & Federmeier, 2012b). This pattern suggests that multiple interpretations of a sentence can still be constructed in the absence of active predictive processing. Importantly, whereas the AP often shows age-related decline, the anterior negativity is preserved—and in some cases enhanced—in older adults, and is elicited not only by sentences with moderately strong constraint but also across a wider range of cloze probabilities, including those with very high predictability (Wlotko et al., 2012; Wlotko & Federmeier, 2012b). This finding implies that although older adults may engage less in active prediction-based processing—which might be cognitively more demanding—they may compensate by adopting alternative comprehension strategies that require fewer top-down resources. For instance, they may rely more on deeper semantic processing and the stabilization of the message-level representation, which supports the consideration of multiple plausible interpretations and enhances integration

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efficiency. Through such mechanisms, older adults are still able to achieve effective language comprehension despite age-related cognitive vulnerabilities. Such a pattern may reflect a reading strategy shift toward bottom-up integration in the absence of efficient top-down prediction.

To summarize, the findings from the three ERP components offer a comprehensive picture of age-related shifts and tendencies in predictive language processing during reading comprehension. Specifically, they illustrate the nuanced ways in which aging shapes the use of contextual information and predictive mechanisms. The key results are as follows:

(1) Older adults exhibited significantly smaller N400 reductions than younger adults in strongly constraining expected (SCE) contexts, while showing comparable N400 amplitudes in weakly constraining expected (WCE) conditions.

(2) Older adults did not exhibit a graded N400 response across varying levels of expectancy—expected exemplars, within-category violations, and between-category violations.

(3) Older adults typically did not show anterior positivity (AP) responses to unexpected words in strongly constraining contexts.

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(4) AN is robustly elicited even in populations such as older adults, who typically do not show AP responses.

These patterns suggest that the rich contextual support available in strongly constraining sentences may place greater demands on the reduced executive and working memory resources of older adults. This leads to less efficient extraction of informative cues and reduced engagement of proactive predictive mechanisms during comprehension. Instead of preactivating semantic content related to predicted outcomes, older adults seemed to rely more on a reactive, integrative processing style. This passive strategy results not only in a lack of differential facilitation based on semantic relatedness (as seen in N400 effects), but also in reduced sensitivity to prediction violations that would otherwise trigger revision processes (indexed by the AP) in younger adults. Because prediction violations may be perceived as less salient without prior anticipatory activation, they are less likely to prompt meaningful revisions to the message-level representation. However, this shift toward a reactive processing style may serve as a compensatory adaptation: by minimizing reliance on resource-demanding top-down mechanisms, older adults may stabilize discourse representations by integrating input as it arrives. This strategy, while less proactive, may

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support the consideration of multiple plausible interpretations and facilitate discourse integration in contexts where predictions are less certain or cognitively taxing.

1.2 | Emotion Processing in Aging: Impacts on Language and Prediction Mechanisms

Age-related vulnerabilities in language processing have been linked to declines in cognitive function, and emotion have been shown to structurally and functionally intertwin with cognitive function (Ferdinand & Hilz, 2020; Mather, 2012, 2016; Mohanty, 2011; Tyng et al., 2017; Vogel et al., 2015). Emotion and motivation play crucial roles in shaping human behavior, and their interaction with executive control functions can serve to influence cognitive performance, particularly under affectively or motivationally salient conditions. According to Pessoa (2009), both the affective and motivational significance influences competition at both perceptual and executive control levels. Elevated motivation, more effective orienting and reorienting of attention, might thereby enhance cognitive performance when the context is emotionally or motivationally relevant. Moreover, Pessoa (2008, 2009, 2017) indicated that emotion and cognition—particularly executive functions—are not separate modules in the brain but rather deeply integrated systems. He proposed the *emotion–cognition integration*

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framework, which suggested that emotional and cognitive processes are dynamically interactive and mutually influential. For instance, he highlighted that the prefrontal cortex (PFC) and anterior cingulate cortex (ACC) are involved not only in cognitive control functions such as working memory and attention regulation but also play critical roles in emotion regulation. He also showed that during cognitive task performance, the prefrontal regions simultaneously process emotional value—such as the threat relevance of stimuli—further supporting the idea that emotion and cognition operate in parallel and interactively. Moreover, he demonstrated that emotional content (e.g., negative images) can alter the functional connectivity between the prefrontal cortex and the amygdala during executive control tasks, suggesting that cognitive and emotional networks modulate each other in real time.

From a lifespan perspective, this supportive role of emotion becomes increasingly important in older adulthood. Socioemotional Selectivity Theory (SST) posits that older adults increasingly prioritize emotionally meaningful goals, which in turn strengthens their motivation to engage with affective information . Similarly, the Strength and Vulnerability Integration (SAVI) model highlights that emotion regulation and positive emotional engagement are essential for maintaining well-being in older adults (Charles, 2010). These frameworks suggest that emotional salience may increase

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motivational significance in older adults, prompting greater allocation of cognitive resources toward emotionally relevant information.

In language comprehension, many studies have demonstrated that emotion may facilitate language predictive processing during sentence reading. For instance, emotion has been shown to capture early perceptual processing and the allocation of attentional resources, as evidenced by larger P200 responses (Chou et al., 2020; Lin et al., 2024), and to support deeper reappraisal processes, reflected in greater late positive potential (LPP) amplitudes to emotionally salient compared to neutral stimuli (Schindler et al., 2022). The role of emotion in enhancing language predictive processing is particularly apparent in language-related ERP components.

Recent research has demonstrated that emotional context can enhance semantic integration as indexed by N400 modulation. Chou et al. (2020) showed that when neutral words appear in emotionally charged contexts, they elicit reduced N400 amplitudes, indicating facilitated semantic processing via contextual emotional bias—even when the words themselves are neutral. This effect highlights the role of emotion-driven predictive processing: as emotional attributes are pre-activated over the course of the sentence, semantic processing is facilitated, as reflected in reduced N400 amplitudes. Extending this view, Lin et al. (2024) suggests that emotional and semantic

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processing are deeply intertwined. It proposes that emotional processing supports semantic context integration: emotional features help allocate early attention resources and working memory toward relevant semantic features, thereby strengthening predictive mechanisms during N400 time windows. However, these facilitative effects of emotion on semantic processing have so far been observed only in younger adults, and their impact on language processing in older adults remains unknown.

Moreover, prior research found that while older adults often do not exhibit anterior positivity to neutral, unexpected but plausible sentence endings following neutral contexts(Federmeier et al., 2007), when unexpected endings were not only lexically unexpected but also emotionally incongruent with the context (e.g., a neutral word in an emotional context), the AP became enhanced in young adults—and surprisingly emerged in older adults as well (Huang et al., 2023). This frontally distributed post-N400 effect resembles the anterior positivity (AP) typically observed in young adults during disconfirmed strong prediction violations, suggesting that emotional information accumulated over the course of the emotional context may facilitate predictive processes during sentence comprehension in older adults. Together, these results indicates that emotional salience may bolster predictive engagement even in populations that typically show diminished AP. Together, these findings suggest that

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the AP is modulated by a complex interplay of factors—including expectancy, sentence constraint, emotional content, and task demand—that can vary both between and within age groups. Emotional context; in particular, appears to facilitate reallocation and integration of cognitive resources, thereby supporting language predictive mechanisms across the lifespan. However, since Huang et al. (2023) did not explicitly manipulate the strength of sentence constraint or the expectancy of sentence-final words—all sentences were moderately to strongly constraining and ended with unexpected words—it remains unclear whether the observed emotion-induced enhancement of anterior effects reflects an anterior positivity elicited by unexpected endings, a frontal negativity linked to expected completions, or a combination of both. This ambiguity highlights a key question that the present study aims to address.

1.3 | The Current Study

Prior findings have primarily used emotionally unexpected endings within moderately strong constraint conditions, making it difficult to determine whether the observed anterior effects truly reflect prediction-based processes. One possibility is that these effects arise from anterior negativity (AN) elicited by emotionally expected

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endings, compared to emotionally unexpected ones—a difference that may not yoked to predictions. Therefore, it is crucial to consider predictability—distinguishing expected items associated with AN from unexpected items linked to anterior positivity (AP)—in order to further elucidate the nature of this anterior effect and identify which stage of the language predictive processing mechanism is modulated by emotional facilitation. Moreover, the lack of rigorous manipulation of sentence constraint in previous work has resulted in the absence of a clear baseline condition, complicating efforts to disentangle the facilitative effects of constraint level and emotional context. Without a fully crossed design incorporating both constraint and expectancy, it remains unclear which stage of the predictive mechanism is modulated by emotion.

To comprehensively understand how emotion interacts with linguistic parameters such as expectancy and sentence constraint, especially in younger and older adults, a more complete design is needed. The present study adopts such a design by fully crossing emotional valence, constraint strength, and word predictability. This approach enables us to identify the distinct stages within the prediction mechanism that are modulated or enhanced by emotional context and clarify whether these effects vary by age. Given known differences in emotion regulation strategies and predictive learning mechanisms between age groups, this design also allows us to assess how each group

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uses emotion differently to support comprehension. Younger adults typically shift flexibly between prediction error–based learning and prediction confirmation learning, supported by greater fluid cognitive abilities (Carstensen et al., 2011; Samanez-Larkin & Knutson, 2015; Spreng & Turner, 2019). In contrast, older adults tend to adopt less effortful strategies that maintain stable emotional states, potentially relying more on semantic integration than on prediction per se (Eldesouky & English, 2018; Livingstone & Isaacowitz, 2021; Mather, 2012, 2016).

Based on these considerations, the present study initially aimed to verify several baseline effects as a reality check. Specifically, we sought to replicate the well-established effects of our expectancy and sentence constraint manipulations by examining the N400 component, associated with semantic access and contextual integration (Federmeier, 2021), and the post-N400 anterior positivity (AP), which has been linked to prediction violation (Federmeier et al., 2007; Moreno & Rivera, 2013). Sentences were constructed to vary in constraint (strong vs. weak) and expectancy (expected vs. unexpected), across both neutral and emotional contexts. Emotional sentential contexts were controlled for valence, arousal, and constraint, and sentence-final words were controlled for cloze probability, plausibility, and psycholinguistic variables. ERP responses were recorded while participants read the

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sentences and completed a recognition task. Post-EEG expectancy ratings confirmed that expectations aligned with the manipulations in both age groups.

We hypothesized that N400 amplitudes would validate both the expectancy and constraint manipulations. Specifically, unexpected words were expected to elicit the largest N400 responses, while expected words would produce reduced N400s. Moreover, we anticipated a graded reduction in N400 amplitude for expected words, with stronger reductions in strongly constraining sentences than in weakly constraining ones—a pattern reflecting graded semantic pre-activation driven by contextual constraint (Kutas & Federmeier, 2011).

In terms of post-N400 effects, we expected to replicate the anterior positivity effect observed in neutral contexts: unexpected endings in strongly constraining sentences should elicit greater anterior positivities than expected endings in the same condition, as well as greater than both expected and unexpected endings in weakly constraining sentences. Additionally, we aimed to replicate prior findings on emotion-related enhancement in young adults(Chou et al., 2020; Lin et al., 2024). In particular, target words that are both lexically and emotionally unexpected in emotionally strong constraining contexts were predicted to elicit larger N400 and anterior positivity

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responses compared to those that are only lexically unexpected in neutral strong constraining contexts.

Critically, we hypothesized that post-N400 ERP effects would differ across age groups. Given that younger adults are more likely to rely on effortful top-down predictive mechanisms, we expected them to exhibit a pronounced anterior positivity (AP) when encountering incongruent sentence endings within highly constraining contexts, particularly when the preceding content was emotionally salient (Chou et al., 2020; Huang et al., 2023; Lin et al., 2024). Older adults, by contrast, were predicted to show more pronounced anterior negativity (AN) effects to expected endings, particularly in strongly constraining contexts. This aligns with prior work showing that AN is preserved or even enhanced with age. Emotional contexts may amplify this pattern, not by strengthening prediction, but by recruiting compensatory mechanisms such as deeper semantic processing and message-level stabilization. Thus, rather than relying on cognitively demanding prediction, older adults may achieve effective comprehension by shifting toward a more bottom-up integration strategy—a shift that emotion may support or even enhance.

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2 | Methods

2.1 | Participants

33 young adults and 39 older adults from Taipei, Taiwan participated in this study. Six young adults and nine older adults were excluded from the analysis due to excessive EEG artifacts or failing to meet the MoCA cutoff. The final sample included 27 young adults (17 male; mean age = 24 years, range = 20–30) and 30 older adults (9 male; mean age = 69 years, range = 60–77). Eligibility criteria included being a native speaker of Mandarin Chinese, with no exposure (before age five) to non-Mandarin languages except Taiwanese, as assessed by a language background questionnaire and the Chinese version of the Exposure to Print Test (Cunningham & Stanovich, 1998). Participants were all right-handed, confirmed via the Edinburgh Handedness Inventory (Oldfield, 1971), and had normal or corrected-to-normal vision. Individuals with any history of neurological conditions, psychiatric illness, brain injury, or depression were excluded; depressive symptoms were screened using the Taiwanese Depression Questionnaire (Lee et al., 2000). All participants provided written informed consent prior to the study, and the study protocol received approval from the Institutional Review Board at National Taiwan University (202405163RINC).

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2.2 | Materials

Three within-subjects factors–Sentence Constraint (strong vs. weak), Expectancy (expected vs. unexpected), and Context Emotionality (emotional vs. neutral) were fully crossed. Table 1 provides the examples. The experimental stimuli consisted of 224 sentences, half of which were strongly constraining and half of which were weakly constraining (as determined by cloze probability norming as described below). Within each sentence constraint, half of the frames ended with expected critical words, while the other half ended with unexpected yet plausible words (with a cloze probability near zero). All unexpected sentence-final words were neutral.

To determine the cloze probability of the endings in sentence frames, each sentence frame except the last word was first submitted for a cloze test where participants were required to fill in the word that first came to mind to complete the sentence, a task that has been widely used for quantifying semantic expectancy and sentence constraint (Federmeier et al., 2007). Sentence constraint was defined on the basis of cloze probability norming as the highest cloze probability among possible completions for a particular sentence, which measured how strongly a sentence frame prompted readers to anticipate a specific completion word. The word most frequently

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provided by participants in the sentence completion task was identified as the most expected ending, with the highest cloze probability for that sentence. The ending of the sentences served as the critical words, leading to four experimental conditions: expected endings in strong-constraining contexts (SCE), expected endings in weak-constraining contexts (WCE), unexpected endings in strong-constraining contexts (SCU), unexpected endings in weak-constraining contexts (WCU).

As mentioned, context emotionality (emotional vs. neutral) was also incorporated as a third factor in addition to the two experimental factors of sentence constraint (strong vs. weak) and expectancy (expected vs. unexpected). This resulted in a total of eight experimental conditions: expected endings in emotionally strong-constrained contexts (Emo_SCE), expected endings in emotionally weak-constrained contexts (Emo_WCE), unexpected endings in emotionally strong-constrained contexts (Emo_SCU), unexpected endings in emotionally weak-constrained contexts (Emo_WCU), expected endings in neutral strong-constrained contexts (Neu_SCE), expected endings in neutral weak-constrained contexts (Neu_WCE), unexpected endings in neutral strong-constrained contexts (Neu_SCU), and unexpected endings in neutral weak-constrained contexts (Neu_WCU).

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After the cloze test, a different group of participants rated the valence and arousal of all the sentence frames and completions elicited in the cloze test. For all variables, each item was rated by at least 15 individuals who did not participate in the ERP experiment. Valence for each sentence frame and ending was computed as the deviation from the midpoint (5) on a 1–9 scale (1 = most negative; 9 = most positive). Arousal was rated on the same 1–9 scale, with 1 indicating least arousing and 9 indicating most arousing. Based on these ratings, a final set of emotional and neutral contexts, as well as emotional and neutral endings, was selected. Emotional contexts and endings included both positive and negative scenarios, with an approximately balanced number of positive and negative items. In neutral contexts, unexpected endings were plausible and only violated lexical expectations. In emotional contexts, however, unexpected endings were emotionally neutral and thus incongruent with the emotionality of the context, making them both emotionally and lexically unexpected.

Plausibility was matched across context emotionality, but differed significantly in sentence constraint and expectancy ($p < .05$). Emotional and neutral sentence frames differed significantly in both valence and arousal ratings across context emotionality ($p < .001$). Similarly, emotional and neutral sentence-final target words differed significantly in valence and arousal across word emotionality ($p < .001$), while being

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strictly controlled for familiarity, concreteness, and word length. These properties are summarized in Table 2.

Participants completed 224 trials in the EEG task in which the sentence stimuli were pseudo-randomly arranged to avoid the sentences of the same condition appearing consecutively. During the EEG session, participants completed a sentence recognition task in a paper-and-pencil-like format using an iPad after every four blocks. Each sentence recognition task included 16 previously seen sentences, selected from the stimuli presented in the first half of the experiment—2 sentences from each of the 8 experimental conditions. In addition, 16 new, unseen sentences were included. These new items were selected from the original stimulus database but had not been used in the current experiment. They were strictly matched to the 8 conditions across key dimensions, including sentence constraint, context emotionality, and ending word expectancy.

Table 1

Example sentences

	Neu_SCE$_{neu}$ (Strongly Constraining, Expected neutral ending)
	兒童學習語言的過程中，環境是很重要的一個**因素**。 Environment is a crucial ***factor*** in children's language learning process.
	Neu_SCU$_{neu}$ (Strongly Constraining, Unexpected neutral ending)
	夜晚時應避免在屋內大聲吵鬧，以免吵到**保全**。 At night, loud noises should be avoided inside the house to prevent disturbing the ***security guards***.

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Neutral Sentence	**Neu_WCE$_{neu}$** (Weakly Constraining, Expected neutral ending)
	他前年把原本老師的工作辭掉，現在轉行當**家教**。 He quit his teaching job two years ago and switched to working as a ***private tutor*** since then.
	Neu_WCU$_{neu}$ (Weakly Constraining, Unexpected neutral ending)
	藉由這份問卷調查，可以了解夫妻生活是否符合**真實**。 Through this questionnaire, we can assess whether married life aligns with ***reality***.
Emotional Sentence	**Emo_SCE$_{emo}$** (Strongly Constraining, Expected emotional ending)
	PP (positive context + positive ending) 伴著燭光晚餐及美麗夜景，這次約會真**浪漫**。 With a candlelit dinner and a beautiful night view, this date is truly ***romantic***. --- NN (negative context + negative ending) 不滿官員暴利欺壓，憤怒的鄉民聚集凱道大聲**抗議**。 Dissatisfied with officials' profiteering and oppression, enraged villagers gathered on Ketagalan Boulevard to stage a loud ***protest***.
	Emo_SCU$_{neu}$ (Strongly Constraining, Unexpected neutral ending)
	PNeu (positive context + neutral ending) 男友偷偷從國外回來幫女友慶生，準備給她一個**包包**。 The boyfriend secretly come back from overseas to celebrate his girlfriend's birthday, planning to surprise her with a ***handbag***. --- NNeu (negative context + neutral ending) 發現老公竟是渣男屢次外遇，妻子一氣之下和他**辯論**。 After catching her husband having repeated affairs, the wife furiously confronted him and ***argued***.
	Emo_WCE$_{emo}$ (Weakly Constraining, Expected emotional ending)
	PP (positive context + positive ending) 年過五十的男神體態健美且熱愛運動，身體狀況很**健康**。 The heartthrob is over fifty years old, but maintains a fit physique, loves exercising, and is very ***healthy***. --- NN (negative context + negative ending)

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	母親昨晚半夜於醫院病逝，他今天上班非常**沮喪**。 He went to work today, feeling ***heartbroken*** after his mother passed away in the hospital late last night.
	Emo_WCU$_{neu}$ (Weakly Constraining, Unexpected neutral ending)
	PNeu (positive context + neutral ending) 夫妻倆關係親密無間且深深相愛，是因為彼此願意**經營**。 The couple shares a close and loving relationship, because both are willing to ***work on*** it. --- NNeu (negative context + neutral ending) 為了爭奪父母巨額遺產，大哥和二哥互相**聯手**。 To fight for their parents' vast inheritance, the eldest and second brothers ***teamed up*** with each other.

Note. Sentence final critical words are underlined. English translations are given below each Taiwan Mandarin example sentence.

Table 2

Mean values (with standard deviations in parentheses) of lexical and sentential features

Context valence / Semantic constraint / Ending word expectedness / Stimuli features	Emotional context				Neutral context			
	Strongly constraining		Weakly constraining		Strongly constraining		Weakly constraining	
	Exp (SCE)	Unexp (SCU)	Exp (SCE)	Unexp (SCU)	Exp (SCE)	Unexp (SCU)	Exp (SCE)	Unexp (SCU)

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Number of trials in each condition [P: positive; N: negative]			P	N	P	N	P	N	P	N	28	28	28	28
			16	12	16	12	16	12	16	12				
Sentence frame	**Semantic constraint** (%)		83% (8%)		84% (10%)		19% (4%)		21% (7%)		85% (6%)	86% (10%)	17% (4%)	23% (8%)
	Valence [1:most negative; 9: most positive]	**Raw score** [1: most negative; 9: most positive]	4.3 (2.3)		4.3 (2.1)		4.4 (2.2)		4.3 (2.1)		5.2 (0.4)	5.3 (0.5)	5.2 (0.5)	5.0 (0.5)
		Deviance from neutral [|Raw score – 5|; possible range: 0-4]	2.3 (0.5)		2.1 (0.4)		2.2 (0.4)		2.1 (0.5)		0.4 (0.2)	0.5 (0.3)	0.4 (0.3)	0.5 (0.3)
	Arousal [1: least arousing; 9: most arousing]		4.3 (0.7)		4.4 (0.9)		4.3 (1.0)		4.2 (0.8)		2.6 (0.6)	2.7 (0.7)	2.4 (0.5)	2.8 (1.0)
Critical word	**Cloze probability** (%)		83% (8%)		0% (1%)		19% (4%)		1% (2%)		85% (6%)	1% (2%)	17% (4%)	1% (2%)
	Plausibility [1: least plausible; 7: most plausible]		6.5 (0.3)		5.5 (0.7)		6.3 (0.3)		5.5 (0.8)		6.6 (0.2)	5.7 (0.7)	6.2 (0.4)	5.3 (0.8)
	Valence	**Raw score** [1: most negative; 9: most positive]	4.7 (2.2)		5.0 (0.4)		4.5 (2.1)		5.0 (0.5)		5.2 (0.3)	5.1 (0.5)	5.2 (0.5)	5.1 (0.4)
		Deviance from neutral [|Raw score - 5|;	2.1 (0.4)		0.3 (0.3)		2.1 (0.3)		0.4 (0.3)		0.3 (0.3)	0.4 (0.3)	0.4 (0.3)	0.4 (0.3)

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	possible range: 0-4]								
	Arousal [1: least arousing; 9: most arousing]	4.9 (0.9)	3.1 (0.9)	4.7 (0.9)	3.1 (1.0)	2.5 (0.5)	2.9 (0.6)	2.6 (0.6)	3.0 (0.9)
	Familiarity [1: least familiar; 7: most familiar]	5.0 (0.6)	5.0 (0.9)	5.1 (0.6)	4.9 (1.1)	5.8 (0.5)	5.2 (0.9)	5.2 (0.8)	5.0 (1.0)
	Concreteness [1: least concrete; 7: most concrete]	4.5 (1.1)	4.7 (1.3)	4.2 (0.6)	4.1 (1.0)	5.4 (1.1)	4.8 (1.4)	5.0 (1.1)	4.4 (1.2)
	Word length	2.0 (0)	2.1 (0.3)	2.0 (0)	2.0 (0)	2.0 (0)	2.0 (0.2)	2.0 (0)	2.0 (0.2)

Note. This table demonstrates mean values (with standard deviations in parentheses) of lexical and sentential features of the stimuli in each condition.

2.3 | Experimental Procedure

Participants were seated 100 cm in front of a computer monitor in a quiet, shielded room. Before the EEG task, participants received task instructions and completed a practice session with 3 trials to become familiar with the task and the experimental environment. In the EEG task, each trial began with a white fixation cross in the center of the screen for 500ms, followed by a black screen for 500ms. Then, a sentence was presented one word at a time in the center of the screen for 200ms, with a black screen shown between words for 300ms. After the sentence-final word, a 1300 ms black screen

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was displayed, followed by a prompt—"Next trial" ("Xià Yī Tí") shown in white. Participants were instructed to respond by pressing the spacebar on the keyboard. The prompt was displayed on the screen for 4000 ms or until a response was made, before the next trial began.

Participants were asked to minimize blinks, eye movements, and muscle movements while reading. They were instructed to read the sentence for comprehension while keeping in mind that they would be asked questions about what they had read after every 4 blocks. The EEG task comprised 8 blocks with short breaks in between, and a paper-and-pencil sentence recognition task was given with an iPad after every 4 blocks to encourage participants to engage in comprehending the message-level sentence as well. After the EEG session, participants completed an expectancy rating task using an Excel spreadsheet on the computer, which included all the stimulus sentences used in the experiment. Additionally, participants completed the Chinese version of the Empathy Questionnaire (Davis, 1980) and the verbal fluency task.

2.4 | EEG Recording and Data Analysis

The electroencephalogram (EEG) was recorded from 32 sintered Ag/AgCl electrodes positioned according to the 10-20 system (QuickCap, Neuromedical Supplies,

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Sterling, TX, USA). All scalp electrodes were online referenced to the left mastoid (TP9), and offline re-referenced to the average of the left and the right mastoid (TP9, TP10). Vertical eye movements were recorded by a pair of electrodes placed on the supraorbital and lateral to the outer canthus of the left eye, and horizontal eye movements were recorded by electrodes placed lateral to the outer canthus of both eyes. Electrode impedances of all electrodes were reduced below 5kΩ prior tothe EEG data collection. The continuous EEG was amplified with the actiCHamp Plus amplifier (Brain Products, GmbH) through a band-pass filter of 0.05-100 Hz and digitized at a sampling rate of 1,000 Hz.

Offline EEG data time-locked to the sentence-final words were analyzed using the EEGLAB (Delorme & Makeig, 2004) and ERPLAB (Lopez-Calderon & Luck, 2014) toolboxes for MATLAB (Natick, MA, USA). Epochs of EEG data were extracted from 200ms before and 1000ms after the stimulus onset, and digitally processed with a band-pass filter of 0.1-30 Hz to attenuate artifacts. Artifacts were first identified using algorithms in ERPLAB, including moving window peak-to-peak, the step functions applied to the eye channels for blinks and horizontal eye movements, and a simple voltage threshold function applied to all scalp channels to detect epochs with amplitudes exceeding ±100 μV. A second-pass manual artifact detection was conducted to ensure

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that all artifacts were properly identified. Trials contaminated by artifacts, including eye movements, muscle activity, signal drifting, or amplifier blocking, were eradicated offline before averaging. The average trial loss was 13.39% for young participants and 11.89% for older participants, respectively.

Artifact-free ERPs were averaged by stimulus type after subtraction of the 200ms pre-stimulus baseline. Following Chou et al. (2020), the time windows and electrodes of the ERP components used in the statistical analyses were determined in advance to minimize spatial and temporal overlap among effects, adhering to the conventional standards found in the literature (e.g., Anterior positivity/ Anterior negativity: (Chou et al., 2020; Federmeier & Kutas, 2005; Wlotko et al., 2012; Wlotko & Federmeier, 2012b)). The Green-Geisser adjustment to the degrees of freedom was applied to each analysis of variance (ANOVA) to correct the violations of sphericity associated with the repeated measures. Thus, the corrected *p* values were reported for all *F* tests with more than one degree of freedom in the numerator. Additionally, the false discovery rate (FDR) method was applied to the significance levels of the pairwise comparisons and the correlation analyses for multiple comparison adjustment, and the corrected *p* values were reported.

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3 | Results

3.1 | Stimuli Validation: Pre- and Post-EEG Expectancy Ratings Across Age Groups

Following Wlotko & Federmeier (2012b), who employed expectancy ratings to examine whether differences in sentence constraint and cloze probability were reflected in participants' perceived predictability, we included a post-EEG expectancy rating task to validate whether the interpretations of sentence expectancy by both younger and older adults aligned with our experimental manipulations of cloze probability and sentence constraint. In this task, a rating of 1 indicated that the ending was entirely unexpected and not at all anticipated, whereas a rating of 7 indicated that the ending fully matched the participant's expectation. A group of at least 15 undergraduate students, who did not participate in the EEG experiment, were asked to rate the expectancy of sentence-final words based on the preceding context. In addition, the same expectancy rating task was administered again after the EEG session to participants who had completed the online EEG experiment. Furthermore, we included both younger and older adults in the rating task to confirm that, although we did not collect normative ratings from older adults during stimulus development, their offline

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expectancy judgments followed patterns consistent with those of younger adults. This two-step procedure was designed to ensure that both young and older adults in the EEG study had similar expectations regarding the stimuli. By comparing ratings from non-EEG participants and EEG participants for both young and older adults, we confirmed that the experimental manipulation of expectancy was effective and comparable across age groups.

Table 3 shows the mean and standard deviations as a function of our experimental manipulation and participant groups. In addition, when comparing the pre-EEG expectancy ratings (provided by a separate group of young adults who had not seen the stimuli) with the post-EEG ratings (collected from both young and older adults after completing the EEG experiment), we observed that post-EEG ratings were generally higher among all conditions. This suggests that after reading all sentence stimuli during the EEG task, participants—regardless of age—tended to judge sentence-final words as more expected compared to those who had not previously encountered the stimuli. Furthermore, when compared with young adults, older adults tend to rate expected endings as less expected and unexpected endings as less unexpected.

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Despite the overall higher familiarity for post-young ratings and more conservative ratings from older adults, the patterns of expectancy ratings are quite similar between both age groups. Wlotko & Federmeier (2012b) found that when sentence-final words were all expected completions, sentences with higher constraint were perceived as more predictable or entirely sensical. A similar trend was discovered in our data. Across both emotional and neutral contexts, expected endings demonstrated a graded pattern, with higher ratings observed for expected endings in strongly constraining (SCE) contexts compared to weakly constraining contexts (WCE). For unexpected endings, in neutral contexts, the lowest ratings were given to WCU, followed by SCU. In contrast, following emotional contexts, SCU received the lowest expectancy ratings. This contrast suggests that expectancy violations in the SCU and WCU conditions may differ in their perceived intensity depending on the emotional valence of the context. These differences in rating patterns across emotional and neutral contexts will be further addressed in the Discussion.

Statistical analyses were conducted on the mean expectancy ratings for younger and older adults. These values were submitted to a mixed-design ANOVA with Group (younger vs. older adults) as a between-subjects factor, and Context Emotionality (emotional vs. neutral), Expectancy (expected vs. unexpected), and Sentence Constraint

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(strong vs. weak) as within-subjects factors. Results revealed no significant main effects of Age Group ($p = .688$) or Context Emotionality ($p = .218$). However, there was a significant interaction between Expectancy and Sentence Constraint ($p < .001$), which did not interact with Age Group ($p = .964$) or Context Emotionality ($p = .952$). Post hoc comparisons showed a significant Sentence Constraint effect for expected endings (SCE vs. WCE, $p < .001$), whereas no significant difference was found for unexpected endings (SCU vs. WCU, $p = .417$). These results are patterned with the cloze probability distribution and provide support that sentence manipulations in the intended experimental design were perceived similarly across contextual emotionality and age groups.

Interestingly, a significant interaction was found between Expectancy and Age Groups ($p < .001$). When compared with young adults, older adults showed lower expectancy ratings (less expected) for expected endings ($p < .01$) and higher expectancy ratings (less unexpected) for unexpected endings ($p < .001$). These results showed subtle differences between younger and older adults. For sentences with expected endings, younger adults consistently provided higher ratings than older adults, suggesting that they perceived these completions as more strongly aligned with their expectations. In contrast, for unexpected endings, older adults gave higher ratings than

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younger adults, indicating that they experienced less of a perceived violation when encountering less predictable sentence completions. Overall, older adults appeared to evaluate all endings in a more neutral or less polarized manner.

Table 3

Mean (SD) expectancy ratings collected pre- and post-EEG across young and older adults

			Pre-EEG	Post-EEG	
			Young adults	Young adults	Older adults
Condition	Emotional	SCE	6.43 (0.26)	6.68 (0.18)	6.46 (0.22)

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context	SCU	4.15 (1.07)	4.08 (1.09)	4.48 (0.71)
	WCE	5.86 (0.49)	6.18 (0.37)	5.57 (0.55)
	WCU	4.55 (1.17)	4.33 (1.17)	4.62 (0.71)
Neutral context	SCE	6.37 (0.33)	6.68 (0.23)	6.44 (0.32)
	SCU	4.52 (1.02)	4.46 (1.03)	4.90 (0.92)
	WCE	5.53 (0.75)	5.56 (0.81)	5.24 (0.63)
	WCU	4.02 (0.92)	4.18 (0.92)	4.47 (0.80)

Note.

SCE = Strong Constraining, Expected; SCU = Strong Constraining, Unexpected; WCE = Weak Constraining, Expected; WCU = Weak Constraining, Unexpected.

Across both emotional and neutral contexts, expected endings show a graded expectancy pattern, with higher ratings in strongly constrained contexts (SCE > WCE). For unexpected endings, the lowest ratings were observed for WCU followed by SCU in neutral contexts, whereas in emotional contexts, SCU received the lowest expectancy ratings.

Figure 2

Bar graph visualization of the mean (SD) expectancy ratings

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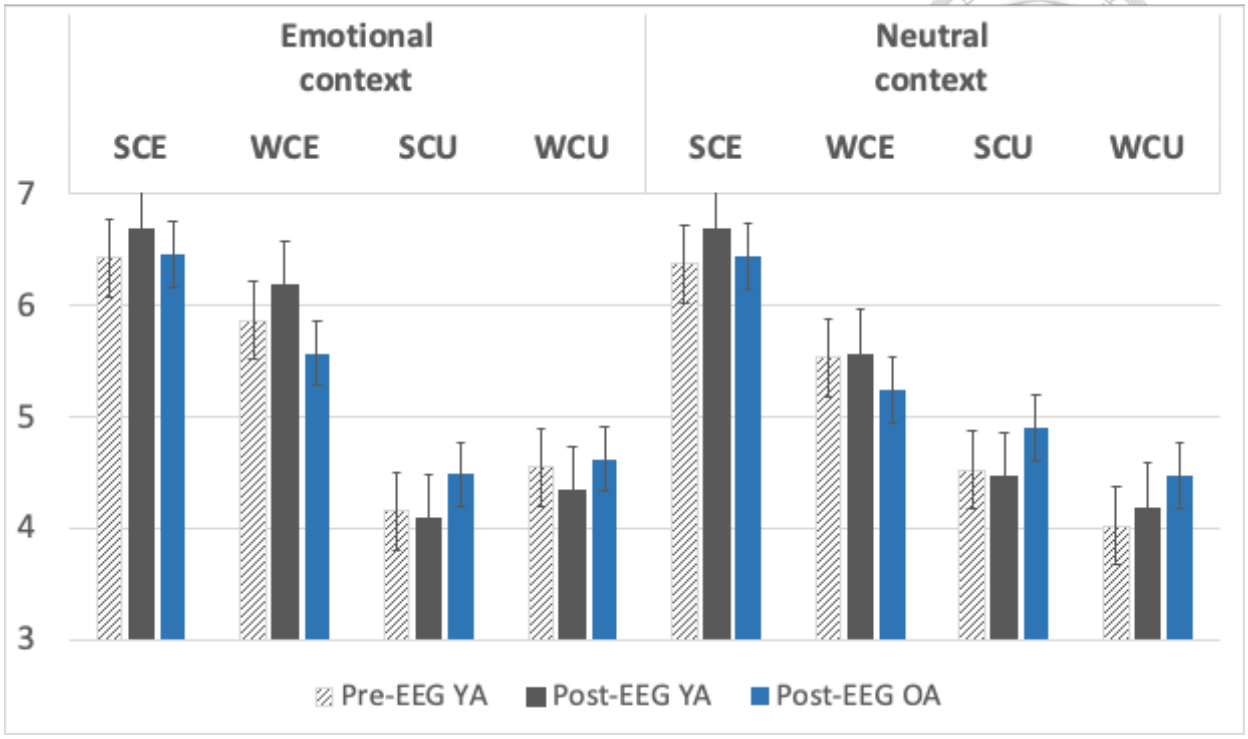

Note. This figure illustrates Bar graph visualization of the mean (SD) expectancy ratings presented in Table 3, respectively for emotional (left panel) and neutral (right panel) contexts, and for each age group (YA = Young Adults; OA = Older Adults). Conditions are further categorized by sentence constraint (strong vs. weak) and expectancy (expected vs. unexpected): SCE = Strong Constraining, Expected; SCU = Strong Constraining, Unexpected; WCE = Weak Constraining, Expected; WCU = Weak Constraining, Unexpected.)

3.2 | Behavioral Sentence Recognition Task

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In the recognition test that was given after every 4 blocks during EEG recording, young adults correctly recognized 78.2% of previously seen sentences and false alarmed to 20.3% of new sentences. In comparison, older adults showed a hit rate of 71.5% and a false alarm rate of 25.2%. The consistently higher rates of correct recognition for previously seen sentences over false alarms across all participants suggest that participants were attentive during sentence reading. Qualitative patterns further revealed that, across all eight conditions and in both age groups, Emo_WCU and Neu_WCU showed the lowest correct recognition rates, whereas Emo_SCE yielded the highest. When grouped by sentence emotionality, **e**motional contexts led to higher average correct recognition rates than neutral contexts. When comparing among conditions within each context emotionality, expected endings were better recognized than unexpected endings, and strong constraint sentences yielded higher recognition than weak constraint ones. Notably, regardless of context emotionality, WCU sentences consistently showed the lowest recognition performance. Figure 2 summarizes the correct recognition rate for both age groups.

Figure 3

Mean correct recognition rates for both age groups

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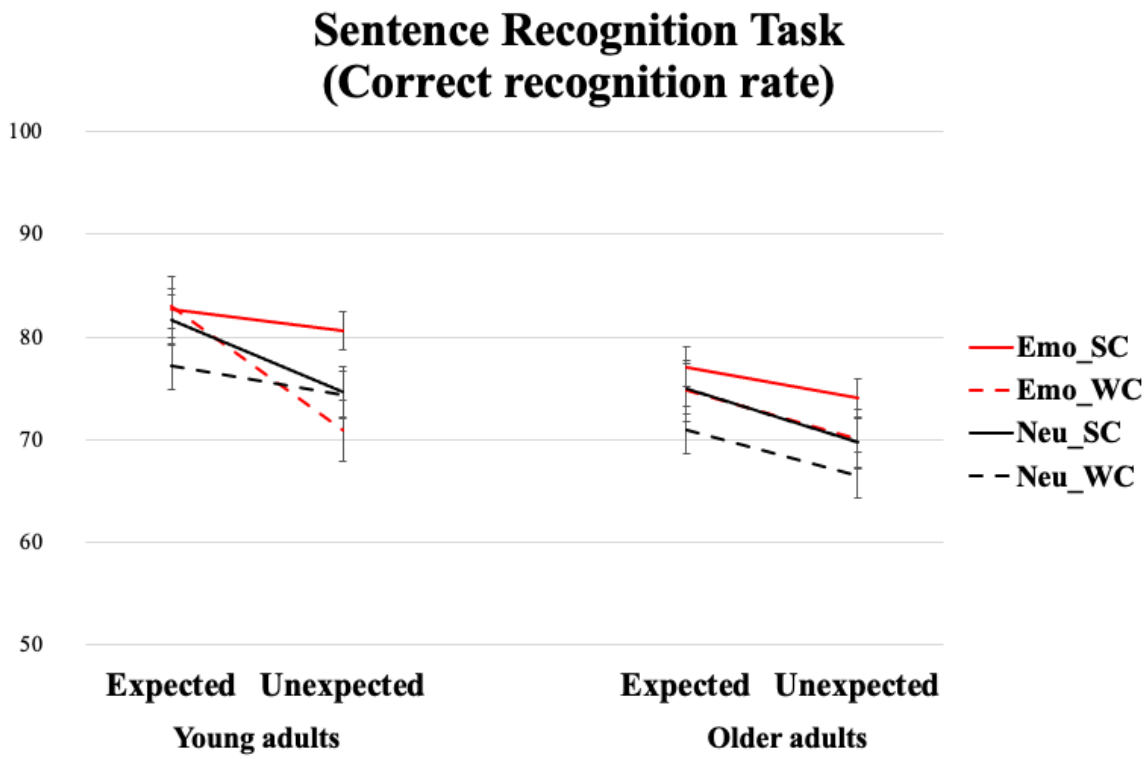

Note. Error bars depict standard errors. Context: Emo_SC = Emotional, Strong Constraining; Emo_WC = Emotional, Weak Constraining; Neu_SC = Neutral, Strong Constraining; Neu_WC = Neutral, Weak Constraining)

3.3 | ERP Results

Figure 4

Grand-average event-related potentials (ERPs) illustrating Expectancy effects

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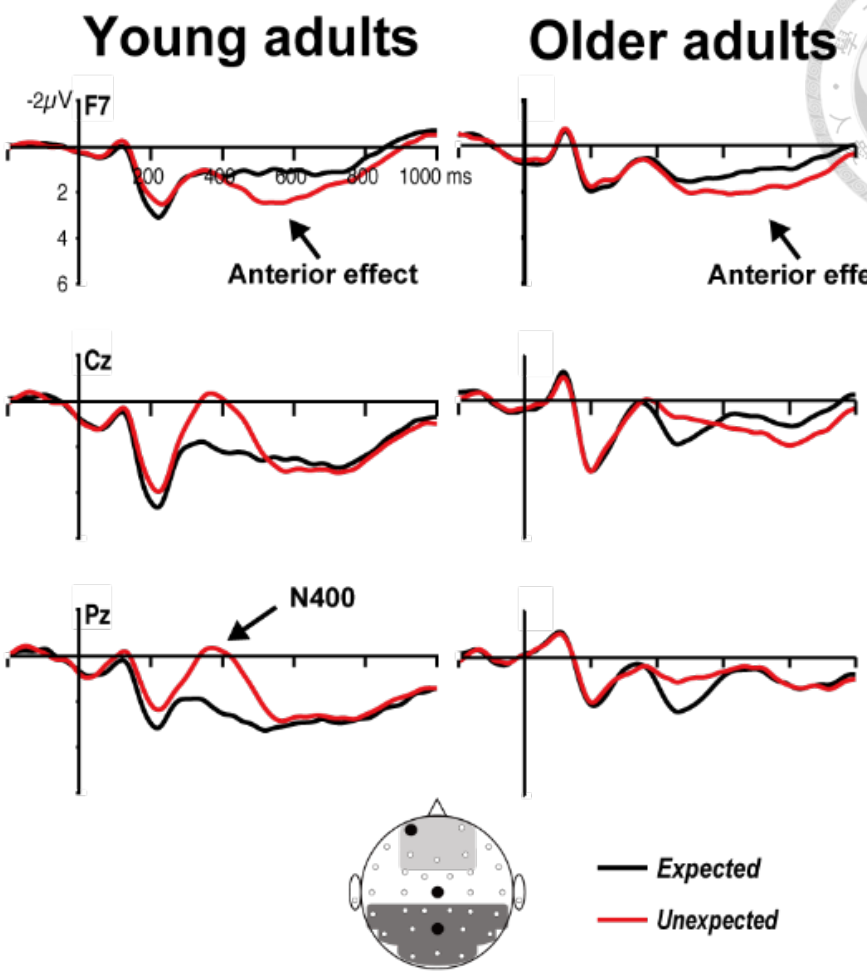

Note. This figure illustrates grand-average event-related potentials (ERPs) illustrating Expectancy effects at three representative electrode sites are displayed for all expected and unexpected sentence-final words, separately for younger adults (left column) and older adults (right column).

Fig. 4 plots the expectancy effect. As shown in Fig. 4, for both young and older adults, unexpected endings elicited a larger N400 over centro-posterior sites. Additionally, for both age groups, there are robust differences in the anterior response

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between the expected and unexpected endings. This pattern indicates that our expectancy manipulation successfully elicited anterior ERP effects, consistent with previous findings. However, expectancy effects are known to be modulated by multiple factors, including context emotionality and sentence constraint. Furthermore, in prior findings (e.g., Chou et al., 2020; Huang et al., 2023), it was not possible to disentangle whether the anterior expectancy effect was driven by negative-going responses to expected endings or more positive-going responses to unexpected endings. In view of these issues, the present study incorporated these variables to examine their interactive influences on the anterior expectancy-related effects. To our knowledge, this is one of the first studies to systematically investigate how these factors jointly influence the anterior effects of expectancy during sentence comprehension. The results are presented in Fig. 5.

Figure 5

Grand-average event-related potentials (ERPs) illustrating Emotion Expectancy effects

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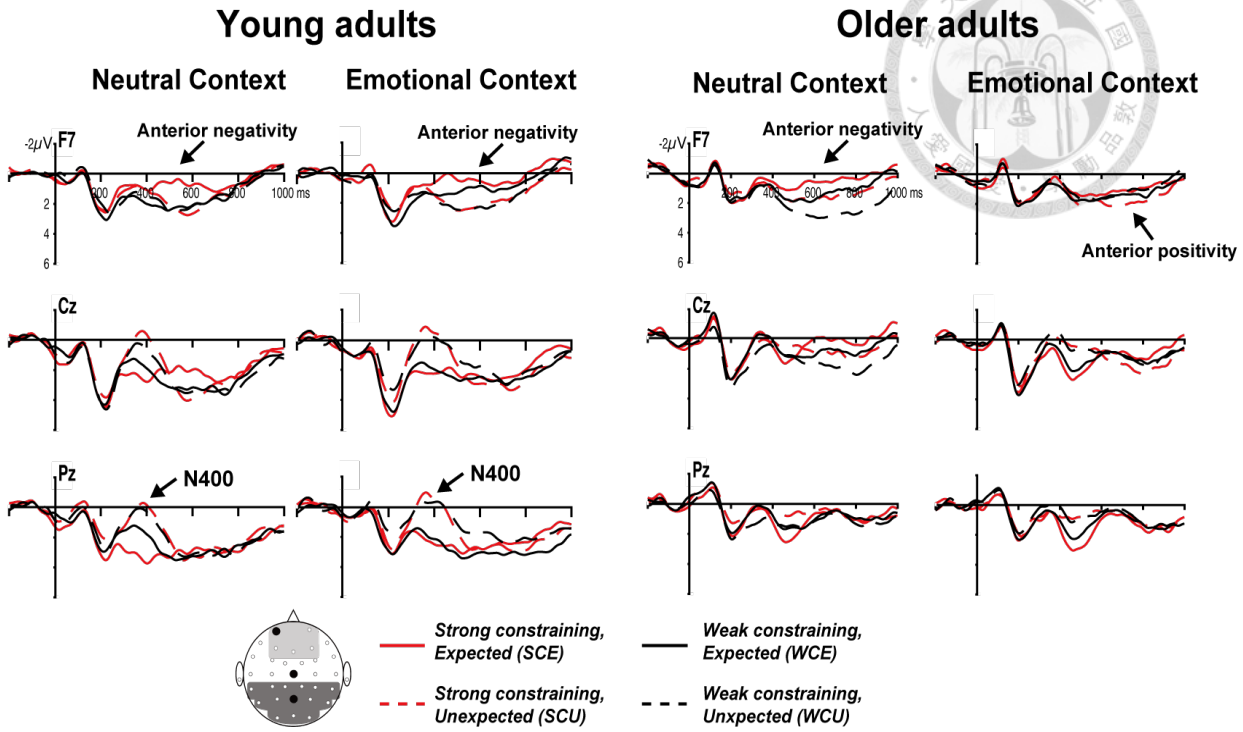

Note. This figure illustrates grand-average event-related potentials (ERPs) illustrating Emotion Expectancy effects at three representative electrode sites are displayed for all expected and unexpected sentence-final words, taking into account both context emotionality and sentence constraint. The figure presents ERP waveforms separately for younger adults (left panel) and older adults (right panel). For each age group, waveforms are arranged by context emotionality, with the left column showing responses to neutral contexts and the right column showing responses to emotional contexts. Three conditions were presented within each column for comparison: strong-constraining expected, strong-constraining unexpected, and weak-constraining expected.

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Fig. 5 plots the effects of expectancy and predictability in emotion and neutral contexts, separately for strong and weak constraint sentences, in young and older adults. As shown in Fig. 5, expected endings elicited reduced N400 amplitudes relative to unexpected endings across both context types in both age groups. Qualitatively, consistent with prior findings (Federmeier et al., 2007; Wlotko et al., 2012; Wlotko & Federmeier, 2012a), expected endings elicited less negative N400 amplitudes when preceded by strongly constraining neutral contexts (Neu_SCE) compared to weakly constraining neutral contexts (Neu_WCE) in both age groups. Younger adults exhibited reduced N400 amplitudes for expected endings following both strongly and weakly constraining emotional contexts (Emo_SCE, Emo_WCE), whereas such a reduction in N400 was only observed in the strongly constraining condition under neutral contexts.

In addition, both age groups exhibited anterior constraint effects, but the pattern of emotional modulation under strong constraint differed between young and older adults. In the neutral context, both younger and older adults exhibited greater anterior negativity in the Neu_SCE condition relative to the other three neutral conditions (Neu_WCE, Neu_SCU, Neu_WCU). Older adults additionally elicited an anterior

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positivity to Neu_WCU, which is surprising. In emotional contexts, however, the interaction between expectancy and sentence constraint showed a different pattern. With regard to anterior responses, younger adults showed relatively larger anterior negativity for expected endings following weakly constraining emotional contexts (Emo_WCE) and did not exhibit anterior positivity to unexpected endings. In contrast, older adults showed a distinct anterior positivity for unexpected endings following strongly constraining emotional contexts (Emo_SCU), relative to the other three emotional conditions (Emo_WCU, Emo_SCE, Emo_WCE). We quantify these findings next.

3.3.1 | N400 (300-500 ms)

—— Expected endings elicited reduced N400 amplitudes relative to unexpected endings for both emotional and neutral sentences in both age groups

We examined N400 responses as a function of Expectancy (expected vs. unexpected endings), Sentence Constraint (strong vs. weak), and Context Emotionality (emotional vs. neutral). Specifically, we compared N400 amplitudes to expected words that were both semantically and emotionally expected with the preceding context–emotional expected words following emotionally strong or weak contexts

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(Emo_SCE, Emo_WCE) and neutral expected words following neutral strong or weak contexts (Neu_SCE, Neu_WCE) with those to unexpected words that were semantically and/or emotionally expected– neutral unexpected words following emotional or neutral contexts of varying sentence constraint (Emo_SCU, Emo_WCU, Neu_SCU, Neu_WCU). Mean amplitudes were submitted for analyses for variance (ANOVAs) for responses recorded over central-posterior channels (CP1, CP2, CP5, CP6, Pz, P3, P4, P7, P8, Oz, O1, O2).

There was a significant main effect of Expectancy [$F(1, 55) = 64.17$, $p < .001$, $ges = 0.106$], that was separately modulated by Constraint [$F(1, 55) = 8.60$, $p < .001$, $ges = 0.054$] and Age Group [$F(1, 55) = 19.20$, $p < .001$, $ges = 0.034$]. In line with past findings, follow-up pairwise comparisons with expected endings following strong constraints elicited significantly less negative N400 responses compared to all other conditions (all $p < .001$), while no significant difference was found between strongly and weakly constrained unexpected endings. For both younger and older adults, expected endings elicited significantly less negative N400s than did unexpected endings; however, the effect was more robust in the younger adults [young: $t(55) = 8.69$, $p < .001$, $d = 0.88$; older: $t(55) = 2.80$, $p = .01$, $d = 0.27$]. The effect of Expectancy also interacted with Context Emotionality [$F(1, 55) = 10.85$, $p < .01$, $ges = 0.014$], with

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significant effects with both context types [emotional: $t(56) = 7.79$, $p < .001$, $d = 0.67$; neutral $t(56) = 5.92$, $p < .001$, $d = 0.61$]. In addition, the effect of Context Emotionality [$F(1, 55) = 1.35$, $p = .250$, $ges = 0.002$] was not significant. However, the effect of Context Emotionality interacted with Age Group [$F(1, 55) = 8.39$, $p < .01$, $ges = 0.009$]. Follow-up comparisons showed that only younger adults exhibited significantly less negative N400 amplitudes in emotional relative to neutral contexts [$t[55] = -2.90$, $p = .032$, $d = 0.22$]. There was no significant main effect of Group [$F(1, 55) = 0.75$, $p = .390$, $ges = 0.007$] or Group × Constraint [$F(1, 55) = 0.05$, $p = .817$, $ges < .001$] or Context Emotionality × Constraint interactions [$F(1, 55) = 0.01$, $p = .919$, $ges < .001$].

3.3.2 | Anterior Positivity and Anterior Negativity (600-900 ms)

——Both Age Groups Exhibit Anterior Expectancy Effects, with Distinct Patterns of Emotional Modulation

Based on past literature (Lai et al., 2024), we did not expect any response differences over anterior regions. However, unexpectedly, WCU responses deviated from WCE responses for both young and older adults under different conditions (Fig. 6). To address our original questions, we first used the WCE condition as a control to

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clarify the expectancy effect in the strong constraint context. We then returned to examine the effect of the WCU condition.

To examine the primary focus of this study–the nature of the anterior difference between SCE and SCU, mean amplitudes of the post-N400 anterior responses recorded over frontal electrodes (FP1, FP2, Fz, F3, F4, F7, F8) were computed over SCE, SCU and WCE conditions for emotional and neutral contexts for each age group. We first conducted a 3-way mixed ANOVA with Age Group (young vs. older), Context Emotionality (emotional vs. neutral), and Expectancy Type (SCE, SCU, WCE) as factors. The results showed a main effect of Expectancy type [$F(2, 110) = 10.91$, $p < .001$, $ges = 0.03$] that was modulated by Context Emotionality [$F(2, 110) = 4.65$, $p = .01$, $ges = 0.009$]. Notably, this interaction did not further interact with Age.

To further examine whether the observed interaction patterns held across age groups, we conducted separate analyses for each group. In young adults, the main effect of Expectancy Type approached marginal significance, [$F(1.56, 40.55) = 3.36$, $p = .056$, $ges = 0.020$]. Neither the main effect of Emotional Context ($ps = .93$) nor the interaction between Emotional Context and Expectancy Type ($ps = .23$) reached significance. To further examine the effect of Expectancy Type, we conducted pairwise comparisons

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collapsed across emotional context. The results revealed significantly more negative responses for strongly constrained expected endings (SCE) compared to weakly constrained expected endings (WCE) [$F(1, 26) = 5.16$, $p = .032$, ges = 0.021]. In contrast, no significant difference was found between strongly constrained unexpected endings (SCU) and WCE (ps = .95).

For older adults, the results of the ANOVA with factors of Context Emotionality (emotional vs. neutral), and Expectancy Type (SCE, SCU, WCE) showed a significant Expectancy Type and Context Emotionality interaction [$F(2, 58) = 3.86$, $p < .05$, ges = 0.016]. Motivated by these interactions. We then compared SCE and SCU with WCE within each Context Emotionality. For older adults, results showed more negative responses for strongly constrained expected endings (SCE) relative to weakly constrained expected endings (WCE) in the neutral context [$t(29) = -4.89$, $p < .001$] and more positive responses for SCU relative to WCE in the emotional context [$t(29) = 2.34$, $p < .05$]. No other significant results were found (ps = .48 and .23).

We then examined the expectancy effect in weak constraint sentences. To do so, an ANOVA was conducted on the mean amplitudes of post-N400 anterior responses to the WCE and WCU conditions, measured over frontal electrodes (FP1, FP2, Fz, F3, F4,

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F7, F8), across emotional and neutral contexts and age groups. The results showed a main effect of Expectancy [F(1, 55) = 9.89, p < .005, ges = 0.013] and Context Emotionality [F(1, 55) = 9.19, p < .005, ges = 0.013]. These two effects did not interact with each other or with the Age group (*p*s ≥ 0.2). To determine whether these effects were consistent across age groups, we conducted follow-up analyses within each group separately. In young adults, neither the main effect of Emotional Context (ps = .26) nor the main effect of Expectancy (p = .19) reached significance, and the interaction between these two factors was also non-significant (ps = .76). In older adults, the results showed a main effect of Expectancy [F(1, 29) = 8.66, p = .006, ges = .029] and Context Emotionality [F(1, 29) = 10.01, p = .004, ges = .028], with no significant interaction (p = .10).

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4 | Discussion

4.1 | Summary of this Study

This study was designed to explore the nature of anterior ERP effects in emotional contexts and to clarify how emotional information interacts with language processing, particularly in shaping predictive mechanisms in both younger and older adults. We anticipated that the validity of our expectancy and constraint manipulations would be confirmed through N400 responses—specifically, that unexpected words would elicit the largest N400 amplitudes, with expected words showed graded reductions in negativity more so when following strongly constraining frames than weakly constraining ones. Regarding anterior positivity effects under neutral conditions, we expected that unexpected words followed by strongly constraining contexts would exhibit more pronounced anterior positivities compared to their expected counterparts, along with whether expected or unexpected in weakly constraining contexts. The central focus of our analysis was to determine how emotional features embedded within the sentence context may modulates these anterior ERP patterns. This approach allowed us to investigate the combined influence of emotional salience and linguistic constraints on predictive processing across different stages of adulthood.

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To summarize, both young and older adults exhibited similar overall patterns in response to expectancy: across both emotional and neutral contexts, unpredicted words elicited significantly larger N400 amplitudes and a subsequent post-N400 anterior positivity; expected endings elicited reduced N400 amplitudes under strong contextual constraint. Additionally, in neutral contexts, expected endings in strongly constraining sentences elicited greater anterior negativity. The age-related differences were primarily observed in anterior responses under emotional contexts. Young adults showed the greatest anterior negativity to expected endings in strongly constraining emotional contexts (i.e., emotionally and semantically expected), with a trend toward enhanced negativity even in weakly constraining emotional contexts. In contrast, older adults did not exhibit anterior negativity but instead showed enhanced anterior positivity to unexpected endings in strongly constraining emotional contexts.

However, one point worth noting when discussing the emotion effect and why it might be somewhat limited in replicating previous findings in our results is that our study may have had difficulty clearly disentangling emotion effects. This is because only two conditions (Emo_SCE and Emo_WCE) ended with emotional word endings, whereas all other six conditions (Emo_SCU, Emo_WCU, Neu_SCE, Neu_SCU, Neu_WCE, and Neu_WCU) ended with neutral words. Such an asymmetry may have

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constrained our ability to clearly compare the relative contributions of word-level versus context-level emotionality.

4.2 | Emotional Contexts Facilitate Semantic Integration

In this study, both young and older adults showed a typical expectancy effect in the N400 response, with unexpected endings eliciting larger N400 amplitudes than expected ones, replicating previous findings. Emotional contexts elicited reduced N400 amplitudes compared to neutral contexts in older adults, suggesting facilitated semantic processing. In addition, expected endings following emotional contexts elicited greater N400 reductions compared to those following neutral contexts in both young and older adults. Previous findings suggested that older adults did not use the context to pre-activate semantic features of likely upcoming words; ERPs to the anomalous endings related to strongly expected endings were not reduced in their N400 amplitudes as they were for younger adults. While older adults rely more heavily on contextual cues to support degraded bottom-up processing, they are less effective at leveraging these cues to facilitate real-time sentence comprehension. (Wlotko et al., 2012; Wlotko & Federmeier, 2012b). Our findings suggest that this emotionally driven facilitation appears to support more effective use of contextual cues, potentially helping older

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adults better integrate semantic information throughout the sentence, particularly when relying on a more reactive, integrative, bottom-up processing mode during comprehension.

In both young and older adults, expected endings following emotional contexts elicited greater N400 reductions compared to neutral contexts, suggesting facilitated meaning integration potentially driven by emotional features accumulated throughout the sentence. This pattern indicates that N400 reduction for emotional expected words in emotionally biased contexts may reflect enhanced semantic processing through the pre-activation of relevant emotional attributes, supporting findings from Chou et al (2020). Nevertheless, emotional contextual bias—relative to neutral contexts—appeared to diminish the disparity in constraint-driven N400 modulation between strongly and weakly constraining sentences in young adults.

Our findings suggest that emotional contexts may enhance the facilitation of semantic processing for predictable words as shown by less negative N400 amplitudes in emotional contexts in both young and older adults. On the other hand, emotional contexts may help older adults more effectively extract meaning from ongoing input when they rely on a bottom-up processing mode. In turn, this support may facilitate the pre-activation of likely upcoming word meanings and enhance the integration of

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preceding semantic information during online reading comprehension. However, it may also attenuate the brain's sensitivity to constraint-based prediction mostly in young adults as evidenced by the reduced N400 amplitudes for Neu_SCE relative to Neu_WCE, a pattern that was not observed under emotional contexts in young adults. In other words, emotional contexts might promote more global, less contextually tuned semantic facilitation, thereby diminishing the modulatory effect of contextual constraint strength on semantic processing.

4.3 | Emotional Modulation of Anterior Expectancy Effects under Strong Constraint

The aim of this study was to examine how emotional context and sentence constraint influence predictive language processing. Our findings suggest that emotional contextual semantic processing engages distinct mechanisms in young and older adults, highlighting age-related differences in how emotional information modulates ongoing predictive processing during comprehension. Specifically, while young adults showed enhanced semantic anticipation even under emotionally weak constraints, older adults appeared to rely more on strongly emotional contextual cues to support predictive processing during sentence comprehension.

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Unexpected words elicited a significant post-N400 anterior positivity (AP) in both young and older adults, irrespective of contextual emotionality or sentence constraint, consistent with previous findings. In both age groups, the contrast between neutral-strong constraining sentences (Neu_SC) and neutral-weak constraining sentences (Neu_WC) was significant. However, the anterior differences between emotional strong- and weak-constraint conditions (Emo_SC vs. Emo_WC) was not significant in either age group, indicating that emotional context may diminish the influence of contextual constraint in predictive processing. Consistent with the N400 findings, emotional contextual bias may broadly amplify anterior expectancy effects, while potentially attenuating the impact of contextual constraint strength.

In young adults, expected words following neutral strong-constraining contexts (Neu_SCE) elicited a larger anterior negativity onsetting at around 500 ms and sustained through 700 ms. This negative-going deflection became even more pronounced when preceded by emotional contexts. While there were no systematic differences between expected endings in neutral and emotional strongly constraining sentences, emotionally expected words following emotional weak-constraining contexts (Emo_WCE) showed a trend toward increased anterior negativity, with the waveform approaching that elicited by the emotional strong-constraining condition (Emo_SCE).

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Based on previous studies, this late frontal negativity has been hypothesized to reflect processes engaged during the revisiting of contextual information, particularly when multiple interpretations of a sentence are possible. This negative-going brain response tends to occur for items with moderate to strong constraint (Wlotko et al., 2012; Wlotko & Federmeier, 2012b). Notably, it emerged specifically in sentences that participants judged to be exact matches with their prior predictions. Our results suggest that emotional context may promote this revisiting process. Consistent with previous findings (Huang et al., 2023), emotional contexts appeared to enhance overall semantic facilitation for expected endings and may have encouraged young adults to engage in deeper sentence processing, resulting in stronger effects and the consideration of multiple interpretations. However, because emotional contexts diminished the differences in anterior negativities to expected endings following strong versus weak constraints, it seems that the influence of contextualized emotion may have overridden the effect of sentence constraint. It is also possible that emotional contexts—along with the recruitment of additional attentional resources and the pre-activation of emotional attributes during earlier time windows—may have jointly amplified the subsequent re-interpretation processes. This could have led to deeper sentence processing and, in turn, an enhanced constraint-related anterior negativity effect. Unlike previous findings,

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which reported anterior positivity to unexpected endings following neutral strongly constraining contexts in young adults (Federmeier et al., 2007), as well as enhanced anterior positivity to emotionally and semantically incongruent endings following emotional strong-constraining contexts in both young and older adults (Huang et al., 2023; Lin et al., 2024), we did not observe a clear anterior positivity in response to unexpected words following either neutral or emotional contexts in young adults, indicating that the typical expectancy-related modulation may have been attenuated or overridden.

In older adults, expected words in strongly constraining neutral contexts (Neu_SCE) elicited a comparable anterior negativity (AN) to that observed in young adults, but with a longer duration—emerging around 500 ms and persisting through 900 ms. These results are aligned with previous findings (Lai et al., 2024; Wlotko et al., 2012; Wlotko & Federmeier, 2012b), showing that expected endings with fewer alternative completions elicited larger negativities. In contrast, unexpected words in weakly constraining contexts (Neu_WCU) elicited a pronounced post-N400 positivity over frontal channels in older adults. This pattern deviated from our initial predictions. Based on prior literature (Federmeier et al., 2007), we expected that young adults would show an anterior positivity (AP) in response to unexpected words in strongly

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constraining neutral contexts (Neu_SCU), whereas older adults would not. However, the anterior positivity effect was not observed in the neutral unexpected conditions for either age group in our data. We speculate that this discrepancy may stem from the characteristics of our stimulus materials. (This point is further elaborated in the next section.)

Importantly, when preceded by emotional contexts, unexpected words in strongly constraining contexts (Emo_SCU) elicited a robust anterior positivity in older adults. Consistent with prior findings (Huang et al., 2023; Moreno & Rivera, 2013; Moreno & Vázquez, 2011; Pan & Lee, 2018), unexpected emotional continuations elicited a larger anterior positivity than expected emotional endings. This suggests that the affective and motivational salience of emotional content may recruit additional cognitive resources to enhance perceptual and executive control processes. Emotional stimuli are known to capture more attention than neutral stimuli due to their motivational relevance. The pre-activation of emotion-related semantic features may thus support bottom-up processing in older adults by enhancing attentional engagement. In this view, emotionally rich contexts may help older adults construct more precise semantic representations, allowing for more proactive processing during comprehension. Consequently, when the actual sentence-final word strongly violates emotionally biased

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predictions and shares little semantic overlap with expected continuations, greater effort may be required for integration—leading to more pronounced prediction violation effects (Huang et al., 2023; Lin et al., 2024; Pessoa, 2009). Our findings suggest that emotional information, when integrated across the sentence, can facilitate top-down processes in older adults. This facilitation may enhance the availability of predictive mechanisms, as reflected by the anterior positivity observed in response to emotional prediction violations. These findings align with the broader view that attention and executive control functions during language processing may benefit from emotionally salient input. One potential neural mechanism underlying this facilitation is the role of the prefrontal cortex (PFC), which integrates cognitive and emotional information by linking cortical and subcortical systems (Pessoa, 2008). Such enhanced connectivity may help compensate for age-related functional declines, enabling stronger top-down processing of emotionally salient language.

To understand why our study did not replicate a typical AP response to unexpected words in strongly constraining neutral contexts (Neu_SCU) among young adults (Federmeier et al., 2007), we considered several methodological and cultural factors. A key factor may lie in the nature of our sentence-final words. While labeled "unexpected" based on cloze probabilities, many of these endings were semantically

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related or even synonymous with the expected completions. This semantic overlap likely reduced the perceived unexpectedness, weakening the prediction violation and thereby attenuating the anterior positivity. Previous work (Federmeier, 2021) has shown that semantic similarity between predicted and actual words can modulate neural responses. When unexpected endings are semantically similar or synonymous, the AP is often reduced or absent. In our study, many "unexpected" completions, although less probable, were semantically close to participants' most expected completions—possibly reducing the strength of the prediction error. However, we did not explicitly quantify the semantic relatedness between unexpected and expected words in our norming task. Thus, it remains unclear whether the absence or reduction of AP occurs equally across neutral and emotional contexts. Future work is needed to systematically examine how semantic similarity modulates the likelihood of AP across emotional settings. Given that our unexpected endings were often semantically related to the expected ones, the violations may have been perceived as relatively mild. This aligns with previous findings (Federmeier, 2021) showing that young adults did not exhibit an AP when encountering unexpected words that were synonyms of the expected word. Our results suggested when violations did not alter the underlying semantic interpretation of the

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sentence, it was insufficient to trigger the AP effect in our study, the brain might not treat the input as a strong violation.

In our study, the anterior negativity (AN) was more prominent than the AP in both age groups under neutral conditions. Young adults did not exhibit an AP in neutral contexts, and older adults instead showed robust AN responses to expected completions—consistent with previous studies (Federmeier et al., 2007). These findings suggest that older adults may be less likely to engage in proactive prediction and may rely more on reactive, integrative strategies that are less cognitively demanding. Older adults appear to prioritize semantic integration and message-level coherence over specific lexical prediction, consistent with the age-related decline in executive resources. This strategy may support comprehension through deeper processing and stabilization of plausible interpretations. However, this pattern shifts when emotional contexts are introduced. Extending prior findings, we observed that emotional contexts altered ERP responses differently in the two age groups. Young adults showed enhanced AN responses to emotionally expected endings, while older adults exhibited a robust AP to emotionally unexpected endings—particularly in the Emo_SCU condition. Notably, older adults showed clear AP responses when unexpected endings violated both lexical and emotional predictions. Given the semantic characteristics of our unexpected endings,

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the observed AP in older adults may have been primarily driven by violations of emotional, rather than lexical, expectations.

These findings highlight the supportive role of emotional salience in mitigating diminished predictive efficiency in aging. Our results replicate previous patterns and further underscore how emotional content can enhance ERP responses to prediction violations in older adults. This facilitative effect appears to involve multiple mechanisms: increased attentional allocation, improved executive control, heightened affective significance, and stronger motivational engagement. Even when unexpected endings were semantically related to expected ones—possibly reducing lexical prediction violation—the robust AP observed in the Emo_SCU condition may reflect sensitivity to emotional expectancy violation. Such findings suggest that emotion-related executive control plays a central role in older adults' engagement with prediction. As executive resources for language decline with age, emotional contexts may trigger a reallocation of remaining resources to maintain predictive comprehension. Together, these findings point to the importance of emotional salience in sustaining top-down predictive processes in aging. They also emphasize how emotional modulation can differentially affect language processing across the lifespan, providing

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critical insight into age-specific mechanisms for maintaining comprehension in naturalistic contexts.

4.4 | Cultural Orientations Shape Predictive Processing

Another possible explanation for the reduced prominence of prediction violation responses indexed by AP in this study may be attributed to differences in cultural orientation, as suggested by Cho et al. (2025). Their findings indicate that younger Americans tend to prioritize novelty, whereas younger Taiwanese place greater emphasis on familiarity when making memory decisions. This divergence is reflected in the activation patterns of the left inferior frontal gyrus (LIFG), a region implicated in interference resolution during memory retrieval. Specifically, young American adults showed greater LIFG activation when successfully rejecting new items compared to recognizing old ones. This pattern suggests a stronger engagement of the LIFG when processing novelty, possibly to inhibit interference from previously encoded information. In contrast, young Taiwanese adults exhibited greater LIFG activation when recognizing old items than when rejecting new ones, reflecting a familiarity-driven retrieval strategy supported by LIFG involvement. Among older adults, however, these cultural differences in LIFG activation were no longer observed.

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Both American and Taiwanese older adults showed similar neural patterns regardless of whether the item was novel or familiar. This convergence suggests that aging may attenuate culturally shaped retrieval strategies, leading to a more uniform neural profile in later life. In sum, these findings highlight distinct cultural patterns in younger adults that parallel the patterns we observed in emotion-elicited anterior responses. Young Americans, who exhibit an orientation bias toward novelty, show stronger neural responses when rejecting unfamiliar new information—a pattern consistent with prior research linking anterior positivity (AP) to unexpected endings in strongly constraining contexts. In contrast, young Taiwanese, who show a bias toward familiarity, appear to rely more on familiarity-based retrieval strategies. This may correspond with the more robust anterior negativity (AN) elicited by expected endings in our data, rather than the AP typically associated with prediction violations. Notably, these culturally shaped differences were not evident in older adults. In our study, consistent with previous findings, neither American nor Taiwanese older adults showed an AP effect in response to unexpected endings following neutral strongly constraining contexts. This further supports the idea that aging may reduce the influence of culturally distinct cognitive orientations, resulting in a more convergent pattern of neural responses across cultures in later adulthood.

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5 | Conclusion

To our knowledge, this is one of the first studies to systematically investigate how emotion, strength of sentence constraint, expectancy and age jointly influence the predictive dynamics during sentence comprehension. Our findings underscore that predictive language processing is a dynamically interactive system shaped by multiple factors across the lifespan and highlight age-related differences in how emotion modulates such mechanisms under strong contextual constraints.

Emotion may enhance overall semantic processing as exhibited by less negative N400 amplitudes in emotional contexts. However, it may also attenuate the brain's sensitivity to constraint-based prediction mostly in young adults as indexed by the reduced N400 amplitudes for Neu_SCE relative to Neu_WCE, a pattern that was not observed under emotional contexts in young adults. In other words, emotional contexts might promote more global, less contextually tuned semantic facilitation, thereby diminishing the modulatory effect of contextual constraint strength on semantic processing. In the presence of unexpected form information that did not signal a corresponding change in sentence meaning (near-synonyms or semantically related words), young adults did not elicit the AP to the prediction violations. Moreover, this study exhibited age-related emotional modulation of anterior expectancy effects under

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strong constraint. Expected endings in neutral, strongly constraining contexts promote context revisiting and strengthen message-level representations across age groups as indexed by enhanced AN to expected endings following strong constraining contexts in young and older adults. With sufficient time for incrementing emotionality, emotion may globally amplify message-level consolidation throughout the context, enhancing revisiting processes not only in strongly but also in weakly constraining sentences for young adults as indexed by enhanced AN to expected endings following emotionally weak constraining context; in contrast, the observed AP effect which was absent in neutral contexts in older adults may suggest that predictive processing during reading becomes more available for older adults when emotionally engaged as indexed by a robust AP to unexpected endings following emotionally strong constraining contexts.

These findings underscore the malleability of predictive language processing across the lifespan, highlighting how emotional salience facilitates or compensates for prediction-based language comprehensions, and cultural orientation differences in predictive strategies. In sum, our results contribute to a growing understanding of how emotional and linguistic processes interact to shape language comprehension in aging, emphasizing the critical role of emotion in modulating early perceptual processing,

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semantic context integration, and subsequent revisiting mechanisms, which together enhance emotional language prediction processing.

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