Emotional State or Deviation? Emotion Deviations Consistently Predict Working Memory Performance in Daily Life

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Abstract

Previous studies have reported contradictory findings, showing that emotion can both enhance and interfere with working memory (WM). We propose that these inconsistencies partly arise from differences in how emotional effects are conceptually defined, rather than from emotional properties alone. Using a smartphone-based experience sampling method (ESM), we repeatedly assessed multidimensional emotional states and performance on two WM tasks over approximately three months in daily life. We conducted two analyses on the same dataset: one defining emotional effects based on emotional states at the measurement occasion, and another defining emotional effects as within-person deviations from each individual's typical emotional level using linear mixed-effects models. Analyses based on emotional states yielded mixed enhancement and interference effects depending on tasks and emotional dimensions. In contrast, emotional deviations from typical level were more consistently associated with interference effects on WM performance. Together, these findings demonstrate that how emotional effects are defined critically shapes their interpretation and consistency in emotion–WM research.

Keywords: Emotion; Working Memory (WM); Emotional Deviation; Within-Person Effects; Experience Sampling Method

Introduction

Emotion and WM: Enhancement or Interference

Emotion has been shown to influence a wide range of cognitive functions, including perception, attention, memory, learning, reasoning, and decision-making (Brosch et al., 2013; Okon-Singer et al., 2015). Among these functions, working memory (WM)—defined as the capacity-limited system that supports the temporary maintenance and manipulation of information—plays a central role in higher-order cognition. Due to its limited capacity and strong reliance on attentional control mechanisms, WM is especially sensitive to emotional influences, which can either enhance or interfere with ongoing cognitive processing (Baddeley, 2012; Barrett et al., 2004).

However, empirical findings on the effects of emotion on WM performance are mixed: prior studies have reported both enhancement and interference effects (Hou & Cai, 2022; Lautenbach, 2024; Schweizer et al., 2019). In a meta-analysis of 165 studies, Schweizer et al. (2019) demonstrated that although the overall magnitude of emotional effects is small to moderate, enhancement, interference, and null effects are all observed across studies. Furthermore, reviews and meta-analyses by Hou and Cai (2022) and Lautenbach (2024) demonstrated that findings vary substantially depending on emotional dimensions (e.g., valence and arousal) and task-related factors, suggesting that the emotion-WM relationship lacks a unified theoretical framework. Even after considering emotional and task-related characteristics, considerable variability remains, highlighting the need for alternative conceptual approaches to better explain emotion-WM interactions (Lautenbach, 2024; Schweizer et al., 2019).

Limitations of Previous Research

Inconsistencies in prior findings have often been attributed to differences in emotional dimensions (e.g., valence and arousal), as well as to methodological variations such as emotion induction procedures, task characteristics, and outcome measures (Hou & Cai, 2022; Lautenbach, 2024; Schweizer et al., 2019). Accordingly, prior research has emphasized these factors as key sources of context-dependent emotional effects on WM.

However, even after accounting for these factors, substantial variability across studies remains insufficiently explained. In the present study, we propose that such inconsistencies arise not only from differences in emotional properties or task conditions, but also from a more fundamental issue: the conceptual assumptions underlying how emotional effects on working memory have been defined and interpreted across studies.

Many studies have induced emotion in laboratory settings—such as by presenting positive, negative, or neutral stimuli, or by using mood induction procedures—and have examined associations between WM performance and momentary emotional states measured at the time of the task, treating these states as direct predictors of WM performance (e.g., Hou and Cai (2022), Lautenbach (2024), and Schweizer et al. (2019)). However, emotional states measured at a given moment are state-level measures that combine two distinct components: an individual's typical emotional level and temporary deviations from that level (e.g., Curran and Bauer, 2011; Enders and Tofighi, 2007). As a result, when emotional states are used directly to interpret emotional effects on WM, it becomes unclear whether observed effects reflect (i) changes in WM associated with higher overall emotional states at a given moment, or (ii) changes in WM associated with deviations from an individual's own typical emotional level.

This distinction is particularly important given the nature of WM. Rather than being a fixed ability, WM is a state-dependent function supported by control processes such as attention, goal maintenance, and updating, and it varies as a function of contextual and internal-state changes (Braver, 2012; Miller & Cohen, 2001; Norman & Shallice, 1986). Accordingly, WM performance may be less sensitive to an individual's stable, everyday emotional level per se, and more sensitive to momentary internal states that deviate from one's typical condition.

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Related findings from emotion research suggest that emotional variability or instability may be more strongly associated with self-regulation and cognitive functioning than average emotional level (Brose et al., 2012; Kuppens et al., 2010). Together, these findings suggest that a proper understanding of emotion–WM relations requires considering not only the absolute level of emotional states at a given moment, but also the extent to which those states represent deviations from an individual's typical emotional level.

Based on this rationale, we propose that a key conceptual branching point for understanding inconsistencies in prior work lies in how emotional effects are defined—specifically, whether they are defined with reference to emotional states measured at the task occasion or to deviations from each individual's typical emotional state. Specifically, rather than re-examining whether emotion affects WM per se, the present study aims to clarify how the interpretation and consistency of emotion–WM relations change as a function of the reference point used to define emotional effects.

Here, "reference point"refers to the baseline against which an emotional effect is defined—such as the concurrent measured state or an individual's typical emotional level—which determines what the estimated effect should be interpreted.

To examine this conceptual issue, the Experience Sampling Method (ESM) offers a particularly well-suited methodological approach. ESM involves repeatedly measuring emotional states and cognitive performance within the same individuals, which allows emotional states at each assessment to be statistically decomposed using multilevel modeling into an individual's typical emotional level (person-level mean) and momentary deviations from that level (i.e., emotional fluctuations) (Bolger & Laurenceau, 2013; Csikszentmihalyi & Larson, 1983).

Notable repeated-measures studies on emotion and WM include a series of investigations by Brose and colleagues (Brose et al., 2012, 2014), which provided important evidence that WM performance varies within individuals on days when participants feel more emotional than usual. These studies played an important role in demonstrating the relevance of within-person emotion–cognition dynamics in daily life.

Building on this work, the present study addresses a distinct conceptual question: whether the interpretation and consistency of emotional effects on WM depend on how those effects are defined, specifically with reference to emotional states at the measurement occasion versus deviations from an individual's typical emotional level. Whereas prior work primarily focused on establishing the existence of within-person covariation, the present study explicitly contrasts these two reference points within the same dataset to examine how definition choice shapes the interpretation and consistency of emotional effects.

Furthermore, emotional measures in prior work were largely limited to broad positive and negative affect, and studies that simultaneously examine multidimensional emotional states and multiple types of WM tasks within the same naturalistic daily-life context remain scarce. Using multiple tasks allows us to test whether reference-point–dependent emotional effects generalize across different WM demands rather than being task-specific. Specifically, the 2-back task primarily taps continuous updating and monitoring processes, whereas the Mental Math task emphasizes information maintenance and manipulation under cognitive load.

Purpose of the Present Study

Building on these considerations, the purpose of the present study is to empirically examine how the reference point used to define emotional effects influences their direction, consistency, and interpretability. Rather than asking whether emotion affects WM in general, the present study asks how the same observed emotional state differs in its interpretation and its association with WM performance, depending on whether it is treated as an emotional state at the measurement occasion or an emotional deviation from an individual's typical level.

Accordingly, the present study employed a smartphone-based ESM to repeatedly assess multidimensional emotional states and performance on two WM tasks (a 2-back task and a Mental Math task) in daily life over a period of approximately three months. We then conducted the following two analyses, in which emotional effects were defined with respect to different reference points:

1. Effects of Emotional State.
   Emotional states at the measurement occasion were used directly as predictors, and the association between momentary emotional state levels and WM performance was estimated. This analysis follows the analytic framework commonly adopted in prior emotion–WM research, which is based on comparisons across emotional conditions, and was intended to examine whether the inconsistency of emotional effects reported in previous studies could be replicated in the present dataset.
2. Effects of Emotional Deviation.
   Emotional states at the measurement occasion were person-mean centered to define emotional deviation as within-person departures from each individual's typical level. These emotional deviations were then used as predictors, and emotional effects were estimated as within-person covariation with WM performance using linear mixed-effects models.

Methods

Participants and Study Period

Participants were recruited through a survey company. A total of 106 adults residing in Japan who provided informed consent participated in the study (age: M = 42.82, SD = 8.44; 63 men, 37 women, and 6 participants who did not report their gender). The 2-back task and the Mental Math task were administered over a period of approximately three months for each participant between December 1, 2023, and April 21, 2024.

Procedure

The study consisted of an online preliminary survey and a three-month ESM phase (Figure 1).

Preliminary Survey

In the preliminary survey, participants were screened to confirm that they had no history of brain surgery and no prior diagnosis of psychiatric or neurological disorders. In addition, because emotion and WM performance are sensitive to individual characteristics such as depressive tendencies, stress,

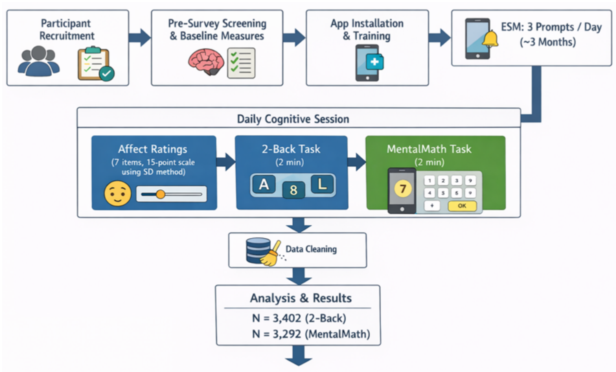

Figure 1: Experiment Procedure Steps

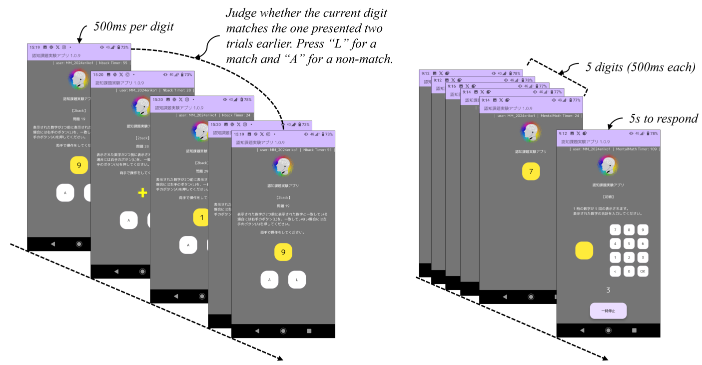

Figure 2: the 2-back task (L) and the Mental Math task (R)

and anxiety (Almarzouki, 2024; Zhang et al., 2022), participants completed questionnaires assessing depressive symptoms (Kessler et al., 2002), stress levels (Hayashi et al., 2023), and trait anxiety (Shimizu & Imae, 1981). These measures were used to assess participants'general mental health status in advance and to ensure that the sample did not exhibit pronounced levels of depression, stress, or anxiety.

ESM: Daily Emotion and Cognitive Assessment

During the ESM phase, participants used Cognitive Test, a research-use smartphone application for repeated emotion and cognitive assessments in daily life. Notifications were sent up to three times per day at random times between waking and bedtime, and participants were instructed to respond at least once per day. At each prompt, participants first reported their current emotional state and then completed one WM task, either the 2-back or Mental Math task, which was randomly selected by the application. Participants received instructions, precautions, and practice trials before the study, and research staff responded to reported technical problems.

Emotion State Ratings Emotional states were assessed using seven bipolar semantic-differential items based on Russell's circumplex model (Russell, 1980): sad–happy, anxious–calm, afraid–relaxed, bored–excited, wistful–thrilled, angry–kind, and unpleasant–pleasant. Each item was rated on a 15-point slider, with higher values indicating stronger endorsement toward the positive pole.

2-back Task The 2-back task required participants to monitor a continuous sequence of digits presented on the screen and to judge whether the current digit matched the one presented two trials earlier. Participants were instructed to press the right button (labeled "L") as quickly as possible when the digits matched and the left button (labeled "A") when they did not. The task was administered for approximately 2 minutes, with match trials comprising 30% of all trials.

Each trial began with a fixation cross presented for 1,500 ms, followed by the presentation of a digit (0–9) for 500 ms. The 2-back task assesses WM processes involved in maintaining and updating information, comparing the current stimulus with prior representations, and executing a decision response (Figure 2).

Mental Math Task The Mental Math task required participants to remember multiple digits presented sequentially and to mentally calculate their sum, thereby assessing the ability to maintain and manipulate multiple items in WM (Figure 2). Specifically, five digits (0–9) were presented in a random sequence at 500-ms intervals, after which participants were instructed to enter the total sum as quickly as possible. The task was administered for approximately 2 minutes. The response input screen was displayed for 5 seconds, and if no response was entered within this time window, the task automatically advanced to the next trial.

Ethical Considerations This study was approved by the Ethics Committee for Human Research of National Institute of Information and Communications Technology (approval number: N230192300).

Results

On average, participants completed the tasks 32.1 times for the 2-back task and 31.7 times for the Mental Math task. For both reaction time and accuracy measures, observations exceeding ±3 SD from the overall mean were excluded as outliers. After this exclusion, 3,402 trials for the 2-back task and 3,292 trials for the Mental Math task were retained for analysis.

To examine the effects of emotional states on WM performance, we analyzed the data using linear mixed-effects models. To account for the trade-off between reaction time and accuracy, we used Inverse Efficiency (IE), calculated as reaction time divided by accuracy, as a composite measure of WM performance (Liesefeld & Janczyk, 2019). Because accuracy was relatively high and stable in the present study, we deemed IE to be an appropriate index that simultaneously captures response speed and accuracy. Lower IE values indicate better WM performance.

Intraclass Correlation Coefficient

We first fitted unconditional random-intercept models to estimate the proportion of variance in IE attributable to between-participant differences. The ICCs were .48 for the 2-back task and .52 for the Mental Math task, indicating substantial between-person variability and supporting the use of mixed-effects models.

Effects of Emotional State

To examine effects of emotional states at each measurement occasion, we fitted random-intercept linear mixed-effects models with emotional rating level as a categorical predictor and age and gender as covariates. The original 15-point emotional ratings were recoded into five levels—strongly negative, weakly negative, neutral, weakly positive, and strongly positive—to make this analysis comparable to prior studies contrasting negative, neutral, and positive emotional conditions while preserving weak versus strong endorsement. The neutral level served as the reference category, such that fixed effects captured differences from the neutral state. Analyses were conducted separately for each emotional dimension and task, and neutral-referenced contrasts were Bonferroni-adjusted. Because these analyses involved multiple emotional dimensions and tasks, emotion-specific effects were treated as exploratory; therefore, our interpretation focused on the overall pattern across dimensions and tasks rather than on isolated significant contrasts.

Level 1 (within-person level)

$$\begin{aligned} Y_{ij} &= \beta_{0j} + \beta_1\,\text{StrongNeg}_{ij} + \beta_2\,\text{WeakNeg}_{ij} \\ &\quad + \beta_3\,\text{WeakPos}_{ij} + \beta_4\,\text{StrongPos}_{ij} + e_{ij} \end{aligned} \tag{1}$$

Level 2 (between-person level)

$$\beta_{0j} = \beta_{00} + \beta_5\,\text{Gender}_j + \beta_6\,\text{Age}_j + u_{0j}$$

$$u_{0j} \sim N(0, \tau_{00}), \quad e_{ij} \sim N(0, \sigma^2)$$

Y_{ij} represents WM performance, indexed by IE scores, at assessment occasion i for individual j. The variables StrongNeg_{ij}, WeakNeg_{ij}, WeakPos_{ij}, and StrongPos_{ij} are categorical indicators of emotional rating level at the assessment occasion, with the neutral level treated as the reference category. The coefficients β_1–β_4 represent the effects of each rating level relative to the neutral level. The term β_{0j} represents the expected IE score for individual j in the neutral condition, conditional on covariates and the random intercept. At Level 2, this intercept was modeled as a function of gender (Gender_j) and age (Age_j). The parameter β_{00} represents the grand mean intercept, whereas β_5 and β_6 represent the effects of gender and age, respectively. The random intercept u_{0j} captures unobserved between-person variability. The residual term e_{ij} represents within-person error, with $u_{0j} \sim N(0, \tau_{00})$ and $e_{ij} \sim N(0, \sigma^2)$.

2-back Task To examine emotional interference effects in the 2-back task, we compared model-estimated marginal means across rating levels within each emotional dimension (Figure 3). Results showed that strongly positive rating levels were associated with significantly higher IE scores than the neutral level across multiple emotional dimensions (Bonferroni-corrected ps < .05). This effect was consistently observed across all emotional dimensions except the sad-happy dimension. In contrast, weakly positive rating levels showed significant differences from the neutral level only in a limited number of emotional dimensions, and no significant differences were observed for most dimensions.

Among negative emotional dimensions, only the strongly negative level on the bored–excited dimension showed significantly higher IE scores than the neutral level; no other negative-pole levels differed significantly from neutral.

Taken together, these findings indicate that, in the 2-back task, emotional interference effects were most evident at strongly positive emotional rating levels across several dimensions, except for the sad–happy dimension, whereas effects at negative-pole rating levels and weakly positive rating levels were limited.

Mental Math Task In the Mental Math task, we found no uniform effect of emotional rating level. Instead, the results revealed a mixed pattern of interference and facilitation effects depending on emotional dimension and rating level (Figure 4; Bonferroni-corrected ps < .05).

Based on analyses of model-estimated marginal means, within the positive emotional dimensions, the strongly positive level on the wistful–thrilled dimension was associated with significantly lower IE scores than the neutral level, indicating improved working memory performance.

Within the negative emotional dimensions, the strongly negative level on the afraid–relaxed dimension showed significantly higher IE scores than the neutral level, indicating increased interference. In contrast, the strongly negative levels on the angry–kind and unpleasant–pleasant dimensions were associated with significantly lower IE scores than the neutral level, indicating improved WM performance. No other emotional rating levels differed significantly from the neutral level across the remaining dimensions.

Taken together, these findings indicate that in the Mental Math task, WM performance can be either facilitated or impaired depending on emotional dimension and rating level, and no consistent emotional interference effect was observed.

Effects of Emotional Deviation

To examine the effects of within-person emotional deviations on WM performance, emotional ratings at each assessment occasion were person-mean centered for each participant, yielding deviations from the individual's typical level. These deviations were entered as the primary predictors in random-intercept linear mixed-effects models that included age and gender as covariates.[1]

For each bipolar emotional scale, deviations toward the two poles were modeled separately. For example, deviations toward anxiety and calmness may reflect different emotional states rather than simply opposite directions of the same underlying emotion. Because the emotional dimensions were likely correlated, these models were not intended to identify the unique causal effect of each specific emotion. Instead, they were used to assess whether a broader pattern of deviation-related WM impairment appeared across multiple emotional dimensions. Importantly, emotional deviation effects capture departures from each participant's typical emotional level, not objectively positive or negative emotional states.

Level 1 (within-person level)

$$Y_{ij} = \beta_{0j} + \beta_1 EmoDev_{ij} + e_{ij} \tag{2}$$

Level 2 (between-person level)

$$\beta_{0j} = \beta_{00} + \beta_2 Gender_j + \beta_3 Age_j + u_{0j}$$

$$u_{0j} \sim N(0, \tau_{00}), \quad e_{ij} \sim N(0, \sigma^2)$$

[1]Although individual differences in emotion-deviation effects are theoretically plausible, random-slope models frequently resulted in convergence problems or singular fits, likely due to unequal numbers of repeated observations across participants and missingness. We therefore used random-intercept models to estimate population-average within-person associations between emotional deviations and WM performance.

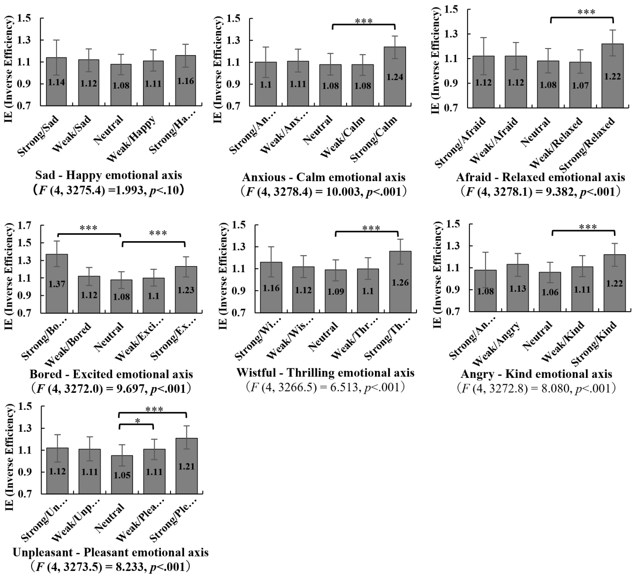

Figure 3: Effects of emotional rating level on 2-back WM Performance. Error bars represent 95% confidence intervals of model-estimated marginal means derived from linear mixed-effects models. Asterisks indicate significant differences from the neutral level based on Bonferroni-corrected pairwise comparisons (***$p < .001$, **$p < .01$, *$p < .05$), and daggers indicate marginal differences (†$p < .10$).

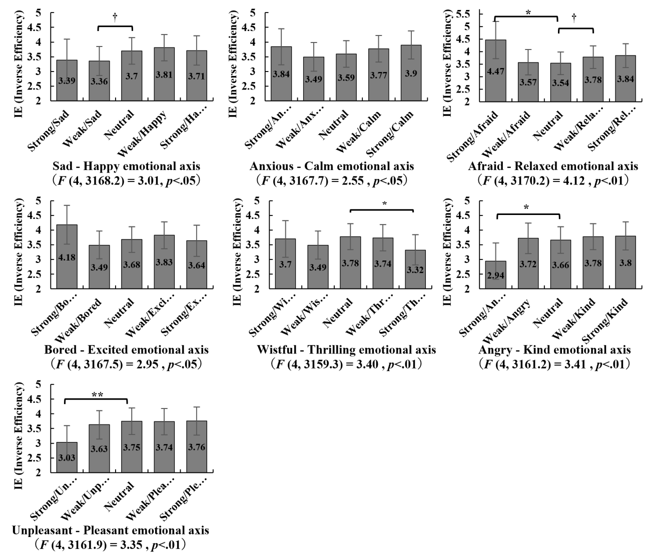

Figure 4: Effects of emotional rating level on Mental Math WM Performance. Error bars and significance markers follow the same conventions as in Figure 3.

$EmoDev_{ij}$ represents the magnitude of emotional deviation computed by person-mean centering emotional states at each assessment occasion, and is a continuous variable indicating deviations from an individual's typical level. The coefficient β_1 represents a fixed effect indicating the extent to which WM performance changes when an individual's emotional state deviates from their typical level.

2-back Task In the 2-back task, within-person emotional deviations from an individual's typical level were significantly associated with WM performance across multiple emotional dimensions (Table 1).

For negative emotional dimensions, greater emotional deviations from the typical level were associated with significantly higher IE scores—indicating reduced WM performance—for the anxiety, fear, and boredom dimensions. In contrast, no significant associations between emotional deviations and WM performance were observed for the sadness, wistfulness, anger, or unpleasantness dimensions.

For positive emotional dimensions, greater emotional deviations from the typical level were consistently associated with significantly higher IE scores across all dimensions, indicating reduced WM performance.

Taken together, in the 2-back task, emotional deviations from the typical level were associated with a consistent interference effect on WM performance, particularly within the positive emotional dimensions.

Mental Math Task In the Mental Math task, significant associations between within-person emotional deviations from an individual's typical level and WM performance were observed for a subset of emotional dimensions (Table 2).

For negative emotional dimensions, greater emotional deviations from the typical level were associated with significantly higher IE scores—indicating reduced WM performance—for the anxiety, boredom, wistfulness, and anger dimensions. In contrast, no significant associations were observed for the sadness, fear, or unpleasantness dimensions.

For positive emotional dimensions, greater emotional deviations from the typical level were positively associated with IE scores for the joy, calm, relaxed, kindness, and pleasantness dimensions, whereas no significant associations were observed for the excited or thrilled dimensions.

Taken together, in the Mental Math task, the association between emotional deviations and WM performance depended on the type of emotion, with interference effects observed for specific emotional dimensions.

Discussion

The present study examined the effects of emotion on working memory (WM) in daily life from two perspectives: emotional states at the measurement occasion and emotional deviations from an individual's typical level. The results showed that effects based on emotional states were inconsistent across tasks and emotional dimensions, whereas effects defined with respect to emotional deviations were more consistently associated with reduced WM performance, particularly in the 2-back task, and showed weaker but directionally similar effects in the Mental Math task, despite variability across emotion types.

These findings suggest that the conceptualization of emotional effects—specifically, the reference point used to define them—is a critical factor influencing the consistency and interpretability of the emotion–WM relationship. The emotional-state and emotional-deviation analyses should be viewed as complementary rather than competing approaches. The former asks whether WM performance differs as a function of emotional levels at the measurement occasion, whereas the latter asks whether WM performance changes when an individual departs from their own typical emotional level. Thus, the two sets of results should not be compared as direct estimates of the same effect; rather, they should be compared in terms of how different reference points change the consistency

Table 1: Results of linear mixed-effects models predicting 2-back performance from within-person emotion deviation

Negative-pole EmoDev			**Positive-pole EmoDev**		
Predictor	β	t	Predictor	β	t
Sad	.0005	.067	Happy	**.0531**	**4.931*****
Anxious	**.0179**	**2.388***	Calm	**.0651**	**7.336*****
Afraid	**.0182**	**2.376***	Relaxed	**.0757**	**8.127*****
Bored	**.0248**	**3.128****	Excited	**.0205**	**2.108***
Wistful	.0083	1.097	Thrilled	**.0325**	**3.308*****
Angry	.0042	.571	Kind	**.0689**	**6.534*****
Unpleasant	-.0028	-.478	Pleasant	**.0467**	**4.764*****

Note. Emotional deviation (EmoDev) represents within-person deviation in emotional state computed via person-mean centering. **Negative-pole and positive-pole EmoDev** indicate deviations toward the negative and positive poles of each bipolar emotional scale, respectively. Age and gender were included as covariates in all models. t values are based on Satterthwaite-approximated degrees of freedom (lmerTest).$^{*}p < .05$, $^{**}p < .01$, $^{***}p < .001$.

Table 2: Results of linear mixed-effects models predicting Mental Math performance from within-person emotion deviation

Negative-pole EmoDev			**Positive-pole EmoDev**		
Predictor	β	t	Predictor	β	t
Sad	.0188	.55	Happy	**.1674**	**3.31*****
Anxious	**.1120**	**3.38*****	Calm	**.1096**	**2.70****
Afraid	.0323	.92	Relaxed	**.1255**	**2.80****
Bored	**.0868**	**2.36***	Excited	.0624	1.32
Wistful	**.1245**	**3.45*****	Thrilled	.0184	.39
Angry	**.0735**	**2.45***	Kind	**.1652**	**3.10****
Unpleasant	.0361	1.22	Pleasant	**.0966**	**2.37***

Note. Same as Table 1.

and interpretation of emotion–WM associations. Importantly, the present study does not suggest that deviations are always more important than emotional states or that prior inconsistencies are resolved; rather, it demonstrates that reference point choice represents one meaningful source of variability in how emotional effects are interpreted and compared across studies.

Furthermore, the present findings suggest that cognitive performance may be particularly vulnerable to deviations from an individual's typical internal state, which has potential implications for the design of supportive artificial intelligence systems and adaptive interfaces in human-in-the-loop environments.

Rather than attributing emotional effects on cognitive processing to emotional rating level per se, the present findings suggest that within-person emotional deviations may be better interpreted as increased non-stationarity of internal states. Large emotional deviations reflect not merely strong emotions, but moments in which an individual's internal state departs from their typical baseline; from a cognitive-control perspective, such departures can be characterized as transient non-stationary states. Under these conditions, emotional processing is likely to place additional demands on cognitive processes such as attention and executive control, which may in turn make the stable maintenance and control of working memory more difficult. This interpretation is consistent with cognitive control frameworks proposing that emotion alters the efficiency and stability of top-down control processes rather than directly reducing processing capacity (Eysenck et al., 2007; Kuppens et al., 2010; Pessoa, 2009).

Although emotional deviations were associated with reduced WM performance in both tasks, the manner in which these effects emerged differed depending on task demands. In the 2-back task, associations between emotional deviations and reduced WM performance were observed consistently across multiple emotional dimensions, whereas in the Mental Math task, such associations were evident only for a limited subset of emotional dimensions.

These task differences may be related to differences in the cognitive processes required by each task. The 2-back task requires continuous updating and monitoring of goal-relevant information, such that fluctuations in attentional allocation and cognitive control states are more likely to be directly reflected in performance, making the task potentially more sensitive to internal-state variability (Braver, 2012; Miller & Cohen, 2001). In contrast, the Mental Math task consists of independent calculation problems and allows the use of multiple problem-solving strategies, which may enable strategic compensation when emotional deviations occur and thereby attenuate their consistent impact on overall task performance (Ashcraft, 2002; Beilock & Carr, 2005; Klingberg, 2010). Accordingly, although emotional deviations were associated with WM performance across tasks with different processing demands, the manner in which these effects manifested appears to vary as a function of the cognitive requirements imposed by the task.

Several limitations should be noted. First, the present study relied on self-reported measures of emotion. Thus, the emotional states assessed here reflect participants'subjective reports rather than objective physiological or behavioral indicators of emotion. Future studies should combine ESM with physiological measures to more directly assess emotional processes. Second, emotional deviation effects should be interpreted as departures from each participant's own typical emotional level, not as indicators of objectively positive or negative emotional states. For example, a deviation toward calmness for a participant who is generally high in anxiety may still correspond to an anxious state in absolute terms. Third, because the emotional dimensions were analyzed separately but are likely correlated, the results should be interpreted as broader patterns across related dimensions rather than unique causal effects of individual emotions. Fourth, the demanding WM tasks may have introduced selective responding, as participants may have been less likely to respond when fatigued, unmotivated, busy, or under high situational demand. Unmodeled contextual factors such as time of day, practice, and daily workload may also have influenced the observed associations. Finally, because the study was observational, it does not provide direct evidence regarding causal direction. Future studies should model these contextual factors directly and adopt longitudinal or intervention-based designs that combine ESM with experimental manipulations and physiological measures to clarify how within-person emotional deviations influence cognitive stability and WM control.

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