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The role of visual and verbal working memory in remembering the past and imagining the future

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ABSTRACT

This study examines how visual and verbal working memory contributes to episodic future thinking and whether their effects vary across temporal directions while controlling the effects of working memory capacity. Using a dual-task paradigm, participants recalled past and imagined future events under single- and dual-task conditions while performing visual or verbal 2-back tasks. Results showed that episodic future thinking requires more cognitive resources than episodic memory, evidenced by longer response times and reduced phenomenological richness. Performance under visual and verbal working memory loads was similar, indicating that overall working memory capacity contributes to episodic future thinking. However, past events were rated as less important and emotionally intense under a verbal working memory load, suggesting a crucial role for verbal working memory in episodic recall. These findings reveal the modality-specific and capacity-driven mechanisms shaping mental time travel, emphasizing the role of working memory in the representations of past and future events.

1. Introduction

The ability to pre-experience potential future events, referred to as episodic future thinking, is a remarkable cognitive skill that allows individuals to construct representations of what might happen in the future (Atance & O'Neill, 2001). Over the past decade, research on episodic future thinking has gained increasing attention as researchers have become aware of its fundamental role in human cognition. Studies have shown that simulating future events may support a number of cognitive, behavioral, and emotional processes, including constructing, planning, and monitoring goals (D'Argembeau & Demblon, 2012; Demblon & D'Argembeau, 2014), health-related decision-making (Segovia et al., 2020; Stein et al., 2018), and self-regulation (Salgado & Berntsen, 2020).

The constructive episodic simulation hypothesis is a prominent theoretical view explaining the formation of episodic future thinking (Schacter & Addis, 2007). Accordingly, episodic memory enables us to mentally simulate future events. Individuals can use their past experiences to remember and combine different elements, allowing them to imagine future events. Numerous studies showing parallels in individuals' subjective experiences while remembering the past and imagining the future have supported this approach. For instance, individuals with amnesia have difficulties with both episodic memory and episodic future thinking (Cole et al., 2016; Hassabis et al., 2007). Additionally, older participants generate fewer episodic details, such as event locations and timings, when remembering the past and imagining the future compared to younger participants (Schacter et al., 2013). Moreover, the underlying neural activations involved in episodic memory and future thinking largely overlap in the brain. Research points to the medial

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temporal lobe as a primary brain area for both episodic memory and episodic future thinking (Race et al., 2013; Szpunar et al., 2007). Despite these behavioral and neural similarities, there are also some differences. For instance, it has been suggested that episodic future thinking may demand more cognitive resources than episodic memory (Anderson et al., 2012; Hill & Emery, 2013; Wiebels et al., 2020; Zavagnin et al., 2016). The rationale behind this assumption is that constructing future events involves combining elements stored in episodic memory while deliberately inhibiting unnecessary information. This process is essential for the formulation of new, plausible events, and it inherently demands a significant expenditure of cognitive effort (Anderson & Dewhurst, 2009). Phenomenological findings, showing fewer sensory details and less vivid imagery when imagining the future compared to remembering the past support this assumption (Arnold et al., 2011; D'Argembeau & Van der Linden, 2004). Therefore, it is likely that constructing episodic future thoughts demands complex information processing within a dynamic memory system, such as working memory.

Working memory is a cognitive function that enables information storage, short-term retention, manipulation, and retrieval (Baddeley & Hitch, 1974; Cowan, 1988; Cowan et al., 2020). Given its effectiveness in information processing, theoretical accounts of episodic future thinking have identified working memory as the primary mental workspace for mental time travel (Dere et al., 2019; Marchetti, 2014; Suddendorf & Corballis, 2007). The view that working memory enables the retention and manipulation of information for the formation of episodic future thinking has gained support from empirical findings over the last 15 years (Addis et al., 2008; D'Argembeau et al., 2010; Hill & Emery, 2013; Zavagnin et al., 2016). For instance, Hill and Emery (2013) showed that working memory capacity promoted the formation of specific future-oriented events but did not significantly contribute to remembering specific past events to the same extent. Studies on older adults have also highlighted the role of working memory in episodic future thinking. For example, a study found that older people had more difficulty in constructing episodic future thoughts than younger people likely due to age-related declines in working memory performance (Zavagnin et al., 2016). Another study found a positive correlation between the episodic details in future events produced by older people and their performance in executive function tasks (Cole et al., 2013). D'Argembeau et al. (2010) also investigated cognitive processes involved in episodic future thinking, such as relational memory processing, executive functions, time perspective, self-consciousness, and visual-spatial processing. They found that executive functions predict various aspects of episodic future thinking. Notably, beyond executive processes, visual-spatial abilities uniquely contributed to the number of sensory details generated when imagining future events.

Previous studies investigating the role of working memory on episodic future thinking have mainly focused on working memory capacity as a whole. However, the multi-component model of working memory identifies distinct yet interrelated components, including the phonological loop, visuospatial sketchpad, episodic buffer, and central executive (Baddeley, 2000). The model allows researchers to study the role of these components in various cognitive processes (e.g., episodic memory; Plancher et al., 2018; mind wandering; Choi et al., 2017; problem-solving; Raghubar et al., 2010; comprehension; Woolley, 2010). In the current study, by adopting a multi-component approach, we specifically focus on the role of the phonological loop and visuospatial sketchpad components of working memory in episodic future thinking. This multi-component approach posits that the phonological loop component allows the retention and manipulation of auditory and verbal information, while the visuospatial sketchpad allows visual and spatial processing such that an object's color, shape, size, or position can be held and manipulated.

There are only a few studies investigating the relationships between verbal working memory and episodic future thinking, with most of these studies focusing on the performance of children in working memory and future thinking tasks (Atance et al., 2019; Cuevas et al., 2015; Ferretti et al., 2018). For example, Ferretti et al. (2018) investigated children's ability to project themselves into the future and how verbal working memory performance could predict this ability. Their results revealed a positive correlation between verbal working memory and episodic future thinking performance, suggesting that improvements in verbal working memory can support the ability to describe future-oriented events among children. Consistent with these findings, studies have shown that receptive vocabulary skills contribute to episodic future thinking in children aged 3–6 years (Cuevas et al., 2015), and verbal fluency may support episodic foresight (Atance et al., 2019). However, it should be noted that these studies primarily examined children, so investigating the role of verbal working memory in episodic future thinking among young adults would be valuable.

The studies addressing the impact of visual processing on episodic future thinking have yet to explicitly focus on the influence of the visual component of working memory. Nevertheless, indirect findings suggest that visual working memory may play a part in episodic future thinking. For example, a recent study using a graph–theoretical analysis, a mathematical method to analyze brain networks, showed a strong connectome between the visual network and episodic future thinking (Hu et al., 2023). Additionally, Szpunar et al. (2007) demonstrated that the network activated when envisioning the future showed similarities with the networks involved in attention and spatial working memory tasks. In another study, D'Argembeau et al. (2010) revealed that visuospatial constructive abilities were crucial for episodic future thinking, even more than episodic memory.

In an experimental study testing the effects of visuospatial working memory load on episodic memory and episodic future thinking, de Vito et al. (2015) showed that performing voluntary eye movements concurrently with episodic future thinking tasks diminished the details about events, places, and emotions. In this study, participants simultaneously performed three types of secondary tasks (focusing on a moving dot, hand tapping, and free viewing) while engaging in remembering the past and imagining future events. The findings showed fewer episodic details when participants focused on a moving dot and engaged in a future thinking task than the control conditions. This may be due to the competition for cognitive resources between voluntary eye movements involving visuospatial information processing (de Vito et al., 2014; Postle et al., 2006) and episodic future thinking. One interesting finding from de Vito et al.'s (2015) study is that the visuospatial load did not affect the amount of details while remembering past events. This suggests that episodic future thinking and episodic memory may differ in their use of working memory, particularly visual working memory.

1.1. The present study

Working memory may be one of the most critical aspects of mental time traveling because the integration of personal experiences and semantic knowledge to create mental simulations of the past and the future is likely to require a mental workspace (Suddendorf & Corballis, 2007). Despite its significance and despite studies investigating the narrative and visual imagery aspects of mental time travel (Fivush, 2008; Fivush et al., 2006; Brewer, 1988; Conway, 2009; Rubin, 2005; 2006), very few experimental studies have directly examined the roles of visual and verbal working memory components. Understanding these roles is essential, as the visual and verbal subsystems of working memory may influence key features of mental time travel, such as vividness, visual imagery, verbal rehearsal, and narrative coherence. Investigating these components in the context of both remembering and imagining may also shed light on the shared and distinct processes underlying these abilities, providing a framework for testing the constructive episodic simulation hypothesis.

Previous studies have suggested a potential connection between working memory and mental time travel, proposing that working memory may serve as a mental workspace for recombining episodic details (Dere et al., 2019; Marchetti, 2014; Suddendorf & Corballis, 2007). Given that working memory plays a crucial role in visual imagery (Albers et al., 2013; Baddeley & Andrade, 2000; Borst et al., 2012), it is reasonable to expect that it also contributes to mental time travel, specifically episodic memory, which relies on visual imagery (Brewer, 1988; Conway, 2009; Rubin, 2005; 2006). If episodic details are represented visually, and if future-oriented simulations are constructed through the flexible recombination of episodic details stored in episodic memory, as proposed by the constructive episodic simulation hypothesis (Schacter & Addis, 2007), then visual working memory may contribute to episodic future thinking. This expectation is supported by studies indicating that visuospatial information may play a specific role in episodic future thinking (Hu et al., 2023; Szpunar et al., 2007; D'Argembeau et al., 2010). Studies further suggest that the visual modality might be more critical for episodic future thinking than episodic memory. For example, de Vito et al. (2015) found that people reported fewer episodic details during episodic future thinking under visual working memory load, while this load did not significantly impair episodic memory. This suggests that visual working memory may play a greater role in future-oriented simulations than in the recollection of past events.

To investigate the potential roles of visual and verbal working memory in mental time travel, we employed a dual-task paradigm in which episodic memory and future thinking tasks served as primary tasks while visual and verbal working memory tasks served as secondary tasks. In dual-task paradigms, when two tasks share the same information processing resource, performance is anticipated to decline in those tasks (Cocchini et al., 2002; Doherty & Logie, 2016; Duff & Logie, 2001; Fisk et al., 1986; Logie & Duff, 2007). Conversely, if they utilize different resources, performance would remain relatively unchanged in both tasks. Thus, for example, if episodic future thinking utilizes visual working memory resources, performing visual working memory and episodic future thinking tasks simultaneously would result in longer response times and lower phenomenological ratings than performing episodic future thinking and verbal working memory tasks simultaneously. Based on this rationale, our hypotheses are as follows:

H1: Performing episodic future thinking and visual working memory tasks simultaneously will result in higher response times (H1a) and poorer phenomenological evaluations (H1b) compared to performing episodic future thinking and verbal working memory tasks.

H2: Performing episodic future thinking and visual working memory tasks simultaneously will result in higher response times (H2a) and poorer phenomenological evaluations (H2b) compared to performing episodic memory and visual working memory tasks.

To better understand potential contributions of visual and verbal working memory to episodic future thinking and episodic memory, it is essential to control for individual differences in working memory capacity, as such variability could confound observed effects (Hill & Emery, 2013). We, therefore, added working memory capacity scores as a covariate in our statistical analyses. Additionally, for exploratory purposes, secondary task performance was assessed in terms of accuracy and response time. This analysis provided additional insight into the role of these components and complemented our confirmatory analyses.

2. Method

2.1. Participants

The sample size was determined using MorePower 6.0.4 software, which is appropriate for conducting power analysis based on our experimental design (Campbell & Thompson, 2012). The power analysis revealed that, for a mixed-design analysis of covariance (controlling for working memory capacity) with 2 (2-back group: visual, verbal) between-group variables × 2 (temporal direction: episodic future thinking, episodic memory) within-group variables × 2 (task type: single-task, dual-task) within-group variables, a minimum sample size of 168 was required to achieve a power of 0.90, with an alpha error of 0.05 and a medium effect size (Cohen's $f = 0.25$; Cohen, 1988).[1] To account for the potential attrition of participants arising from various factors, we aimed to recruit at least 15% more than the calculated maximum number. A total of 193 undergraduate students participated in the study in return for extra

[1] We also conducted a series of a posteriori power analyses using G*Power to determine the minimum sample sizes for each hypothesized effect in our mixed-design ANCOVA using the same parameters ($1\text{-}\beta = 0.90$, $\alpha = 0.05$, $f = 0.25$). The minimum sample sizes for each effect of interest were as follows: main effect of 2-back group: $n = 171$; main effect of temporal direction and task type: $n = 44$; temporal direction × task type: $n = 30$; 2-back group × temporal direction or task type: $n = 46$; three-way interaction; $n = 168$. Given that our final sample size was 188, our study was sufficiently powered to detect all hypothesized effects with at least moderate magnitude ($f = 0.25$).

course credit. All participants were native Turkish speakers and had normal or corrected-to-normal vision. We excluded data from 4 participants who could not complete the operation span task, and one participant who could not construct any events during the experiment, leaving us with data from 188 participants (166 women, 21 men, 1 not specified; M_{age} = 21.4 years, SD_{age} = 2.11).

2.2. Materials

2.2.1. 2-back task

The 2-back tasks were adopted from Jaeggi et al. (2010) and modified for use within the dual-task paradigm. In the visual version of the 2-back task, participants were presented with blue squares that appeared in eight different positions around a white fixation point on a black background on the computer screen. In the verbal version, participants heard a sequence of eight consonants (Y, N, P, K, F, R, C, and Z), spoken by a female voice and presented through headphones. For both versions, participants were asked to determine whether the current stimulus (either the letter or the position of the square) matched the stimulus presented two trials earlier. Participants were asked to respond only to correct trials by pressing the *H* key on the keyboard. We pseudorandomized each stimulus within a block and presented it in a predetermined order for 500 ms, with an inter-stimulus interval (ISI) of 2500 ms.

2.2.2. Episodic future thinking task

The episodic future thinking task was adapted from previous studies (e.g., D'Argembeau & Mathy, 2011; D'Argembeau & Van der Linden, 2006) and modified for use within the dual-task paradigm. The participants were provided with detailed written instructions explaining that these future-oriented events had to be specific (i.e., constructing a personal event taking place at a specific time and place). They were also instructed that these events can be pre-planned or imagined, and what is important is that they must be plausible events that could happen in the future (please see Appendix A).

A total of 12 cue words were used to trigger the construction of future events (*bus, cat, cup, door, eyeglasses, glass, hat, paper, pizza, plant, shoes,* and *ticket*). All the words were concrete and neutral with similar ratings of imageability (Min. = 6.44, Max. = 6.87, M = 6.64; SD = 0.15) and concreteness (Min. = 6.64, Max. = 6.96, M = 6.85; SD = 0.10). These words were selected from a pool consisting of 800 Turkish words (Kurdoğlu-Ersoy & Tekcan, 2018). The cue words used in the practice phase were not used in the experimental phase. The cue words appeared in the center of the screen for 1000 ms (Anthony et al., 2023; Gatti et al., 2022). The font type, color, and size were Arial, white, and 40, respectively.

In this task, participants were shown a cue word and asked to construct a future event related or unrelated to the cue word in 15 s. We obtained response time data (in milliseconds) to measure the time taken to construct a future event. As soon as the participants came up with an event after seeing the cue word, they pressed the *spacebar*. The time interval between the onset of the cue word and the *spacebar* pressing was taken as the response time. Immediately after pressing the button, the participants were presented with a blank white screen for 5 s, during which they had to summarize the event very briefly, using 2 or 3 words. Participants' summaries were recorded by the software through a microphone. This allowed us to verify if the participant had indeed constructed an event. If they did not press the *spacebar* within 15 s following the cue word presentation, the remaining parts of the future thinking task were skipped. This duration was determined based on a pilot study in which five participants were asked to construct future events after seeing cue words. The time interval between cue word onset and the response was measured and averaged (M = 9.4, SD = 2.1), and was rounded up to 15 s to allow sufficient time for event construction. After participants summarized the event that came to their minds, they silently elaborated for 30 s. When the time was over, they answered phenomenological questions about the event. These questions were adopted from previous studies and allowed us to measure the participants' subjective experience of the event they described (Akdere & Ikier, 2024; D'Argembeau & Van der Linden, 2006; Özbek et al., 2017). Therefore, for example, participants evaluated how vivid the event was (1 = *not at all*, 7 = *to a very high degree*) or whether they felt like pre/re-experiencing the event when it was imagined (1 = *not at all*, 7 = *as clearly as if it were happening now*). Each question remained on the screen for a maximum of 20 s. Participants answered the questions by pressing the 1–7 keys on the top of the keyboard. There were a total of 13 questions about the vividness, sensory details, emotional valence, and other aspects of these events (please see Appendix B).

2.2.3. Episodic memory task

The episodic memory task was adapted from previous studies (e.g. Addis et al., 2007; D'Argembeau & Van der Linden, 2006) and modified for use within the dual-task paradigm. The procedure of this task was identical to the episodic future thinking task except for the instructions. In this task, the participants were asked to recall a personal event from the past related or unrelated to the cue word. As in the episodic future thinking task, the participants were instructed to construct a specific event that happened at a specific time and in a specific place. The phenomenological questions were also adjusted based on temporal directions.

2.2.4. Automated operation span task

We used the automated operation span task to control individual differences in the central executive component and general working memory capacity (Unsworth et al., 2005). In the task, the participants had to remember a series of letters (storage component) while concurrently engaging in a cognitive task (verifying the accuracy of math equations; processing component). After each decision on whether the math equation was correct, a letter was presented for 800 ms, and the participants had to memorize it for the following test. Each trial consisted of a set of three to seven processing-storage components, followed by a memory test. In the memory test, participants were presented with a 4 × 3 matrix containing all potential letters (i.e. F, H, J, K, L, N, P, Q, R, S, T, and Y), and they were instructed to select the letters in the correct sequential order by clicking on them. If participants could not recall the exact order, they could press the "blank" button to indicate a forgotten letter. The task consisted of three practice stages: 4 letter-remembering trials (only storage), 15 math equation verification trials (only processing), and 3 concomitant trials (both storage and processing). Participants then completed 15 experimental trials (varying from 3 to 7 set sizes per trial). Set sizes were presented in a random order for each participant. The score was calculated as the overall mean proportion of correct answers.

2.2.5. Demography and strategy Evaluation form

The demographic questionnaire includes questions about age, sex, and whether participants used any strategies during the experiment (please see Appendix C). The strategy questions specifically aimed to check whether they made a categorization or clustering while retaining the stimuli in the 2-back task, whether they constructed the episodic future thought or memory before seeing the cue word, and whether they continued to construct while answering the questionnaire question.

2.3. Procedure

The experiment was programmed and conducted through E-Prime 2.0 Software. The tasks were completed on the computer in the Psychology Laboratory, and the participants were tested individually. The task was completed in approximately 45 min. All participants completed the informed consent form before being verbally briefed about the study and given written instructions for the experiment. Participants were randomly assigned to either the visual or verbal 2-back group. The visual 2-back group performed a visual working memory task as the secondary task, while the verbal 2-back group performed a verbal working memory task as the secondary task. All participants sat in front of a computer and wore a headset during the experiment. In the verbal 2-back group, participants heard the letters through headphones, whereas those in the visual 2-back group did not receive any auditory stimulation. The diagram that synthesizes the experimental design is illustrated in Fig. 1.

The participants completed both a practice and an experimental stage for each task. Once they completed the practice stage successfully, they proceeded to the experimental stage, where the actual measurements were taken. Initially, the participants completed single tasks before progressing to dual tasks. In both single and dual tasks, half of the participants started with the episodic future thinking task, while the other half began with the episodic memory task in order to prevent any potential effects that could have arisen from the order of temporal directions.

2.3.1. Single-task procedure

The single-task procedure started with the practice stage of the 2-back task. Both written and visual instructions were used to ensure a comprehensive understanding of the task. Subsequently, participants completed 15 trials of the 2-back (4 targets, 11 non-targets). Those who achieved an 80% success rate in the 2-back trials proceeded to the experimental stage, which involved 20 trials of the 2-back, including 5 targets and 15 non-targets. Participants who did not meet the 80% criterion repeated the practice set, receiving additional instruction before proceeding to the experimental stage. If participants were still unable to proceed with the task after receiving further instructions, we politely informed them that the experiment would end at that point, and we did not proceed with the remaining parts of the study.

After completing the 2-back trials, participants proceeded to the practice stage of either the episodic future thinking or episodic memory task. During this stage, participants received written instructions and were asked to confirm their understanding of the task. Those who required further clarification were provided with verbal instructions. The practice stage started with the appearance of a fixation point at the center of the screen, followed by the brief presentation of a cue word. Immediately after the cue word presentation, the fixation point reappeared, remaining on the screen until the participant came up with an event and pressed the specified key. Following the button pressing, the screen turned to a blank white screen and the participant briefly summarized the event out loud. The software recorded this summary through the microphone. Subsequently, participants were required to elaborate on the event in their minds. Following the completion of the elaboration stage, phenomenology questions were presented on the screen. Once these

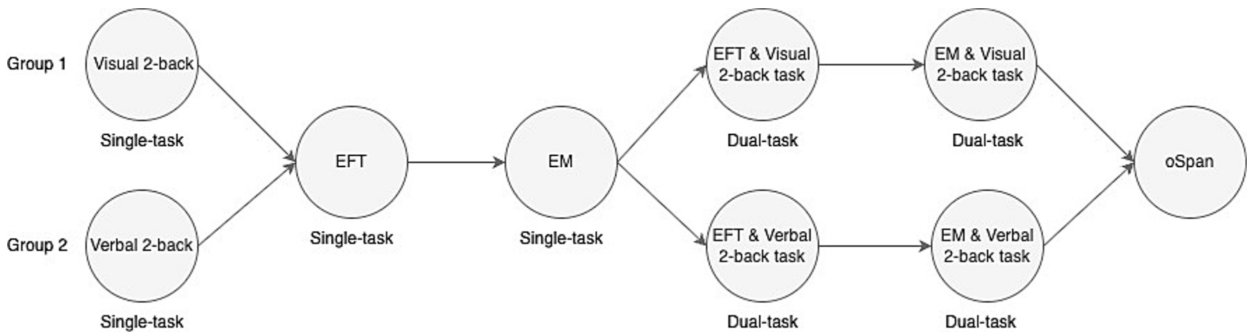

Fig. 1. Overview of the experimental procedure. The experiment began with single-task versions of visual and verbal 2-back tasks. Following this stage, all participants completed single-task versions of the episodic future thinking (EFT) and episodic memory (EM) tasks, presented in a counterbalanced order. Subsequently, participants performed the EFT or EM task (in the same order as the single-task condition) under dual-task conditions, which included a concurrent visual or verbal working memory load. The experiment concluded with the operation span task (oSpan) to assess participants' working memory capacity.

questions were answered, the experimental stage began, during which actual measurements were taken. The procedure for the experimental stage mirrored that of the practice stage. Upon completion of this stage, participants proceeded to practice for the other task, either the episodic future thinking or episodic memory task. This task was identical to the previous one, except for the instructions given to the participant. Following the single-task trials, participants commenced with the dual-task procedure.

2.3.2. Dual-task procedure

Participants initially engaged in dual-task practice involving either episodic memory or episodic future thinking. During this task, they simultaneously performed two tasks that they had learned (please see Fig. 2.) The practice stage began with 20 trials of the 2-back task. During the 2-back task, a cue word appeared on the screen, prompting participants to remember or imagine an event while maintaining their performance in the 2-back task. Upon constructing an event, participants pressed the *spacebar*, briefly pausing the 2-back task, and provided a brief summary of the event, which was recorded by E-prime software through the microphone. Participants were instructed to continue contemplating the event while monitoring the 2-back sequence. Subsequently, after the elaboration stage, they were presented with phenomenological questions on the screen. The practice stage concluded, and the experimental stage proceeded with the same procedure. Upon completion of the dual-task stages, participants were asked to fill out the Demography and Strategy Evaluation Form. Finally, they completed the automated operation task.

2.4. Design and analyses

We employed a mixed design with 2 (2-back groups: visual, verbal) between-group × 2 (temporal direction: episodic future thinking, episodic memory) within-group × 2 (task type: single-task, dual-task) within-group variables. The dependent variables were the response time to cue words and phenomenological ratings, with working memory capacity used as a covariate. To control individual differences, temporal direction and task type parameters were treated as within-subject factors while the 2-back task type was treated as a between-subjects factor to enhance experimental feasibility. We conducted a three-way mixed ANCOVA to examine the impact of visual and verbal secondary tasks on response time to cue words and phenomenological ratings while controlling for the effect of working memory capacity. All analyses were performed using IBM SPSS Statistics 21. We reported confidence intervals for effect sizes using MBESS package in R (Kelley, 2007). The data for this study are publicly available in the Open Science Framework (OSF) at https://osf.io/3gkhw/?view_only=4f0c73a8b3cc43ddbe29a65678ac8312.

Prior to the analyses, we excluded some cases to ensure the reliability of our measures. We replaced one participant because s/he was unable to proceed to the 2-back practice stage after receiving further instructions. We also removed cases where participants failed to report any event after pressing the button (28 cases), and cases where participants reported events before pressing the button (7 cases). Missing values and excluded cases in response time and phenomenological ratings were addressed using the multiple imputation technique, with imputation conducted for each variable employing the multiple chained equations (MICE) technique five times. For single- and dual-task conditions, approximately 50 and 30 values were imputed, respectively. Considering the presence of missing values and the lack of a priori justification, we did not remove any outliers.

3. Results

3.1. Do visual and verbal working memory loads affect the construction latencies of past and future events differently?

We hypothesized that a visual working memory load would impair the construction latencies of episodic future thinking more than a verbal working memory load (H1a), and that visual load would hinder the construction of future events more than past events (H2a). To test these hypotheses, we conducted a 2 (2-back groups: visual, verbal; between-subjects) × 2 (temporal direction: episodic future thinking, episodic memory; within-subjects) × 2 (task type: single-task, dual-task; within-subjects) ANCOVA on response times, with working memory capacity included as a covariate. Before performing ANCOVA, we centered the covariate as our experiment consists of a within-subject factor (Delaney & Maxwell, 1981; Schneider et al., 2015). Preliminary assumption testing was conducted for each dependent variable to check for normality, linearity, and homogeneity of variances. To assess normality, skewness and kurtosis values were calculated for all variables (see Appendix E). The skewness values ranged from 2.03 to 0.65, and kurtosis values from –1.59 to 3.76, which are within the recommended thresholds for approximate normality (West, Finch & Curran, 1995). Visual inspection of histograms and Q–Q plots corroborated these results. Levene's test results were not significant for each dependent variable, indicating no violation of homogeneity of variances (all Fs < 2.8, ps > 0.05). Descriptive statistics are presented in Table 1.

The results revealed a main effect of temporal direction, $F(1, 186) = 7.76$, $p = 0.006$, $\eta_p^2 = 0.040$, 95% C.I. [.003, 0.108]. Participants took longer imagining future events ($M = 5903.2$ $SD = 183.6$) than remembering past events ($M = 5422.2$ $SD = 169.9$). There was also a significant main effect of the task type, $F(1, 186) = 23.59$, $p < 0.001$, $\eta_p^2 = 0.113$, 95% C.I. [.041, 0.201]. Construction of events in the single-task condition ($M = 6232.1$, $SD = 198.3$) took longer than in the dual-task condition ($M = 5093.3$, $SD = 189.3$). There were no two-way or three-way interactions (all ps > 0.05).

3.2. Do visual and verbal working memory loads affect the phenomenological characteristics of past and future events differently?

We hypothesized that a visual working memory load would impair the phenomenological characteristics of episodic future thinking more than a verbal working memory load (H1b), and that visual load would hinder the characteristics of future events more than past events (H2b). To test these hypotheses, we conducted a 2 (2-back groups: visual, verbal; between-subjects) × 2 (temporal direction:

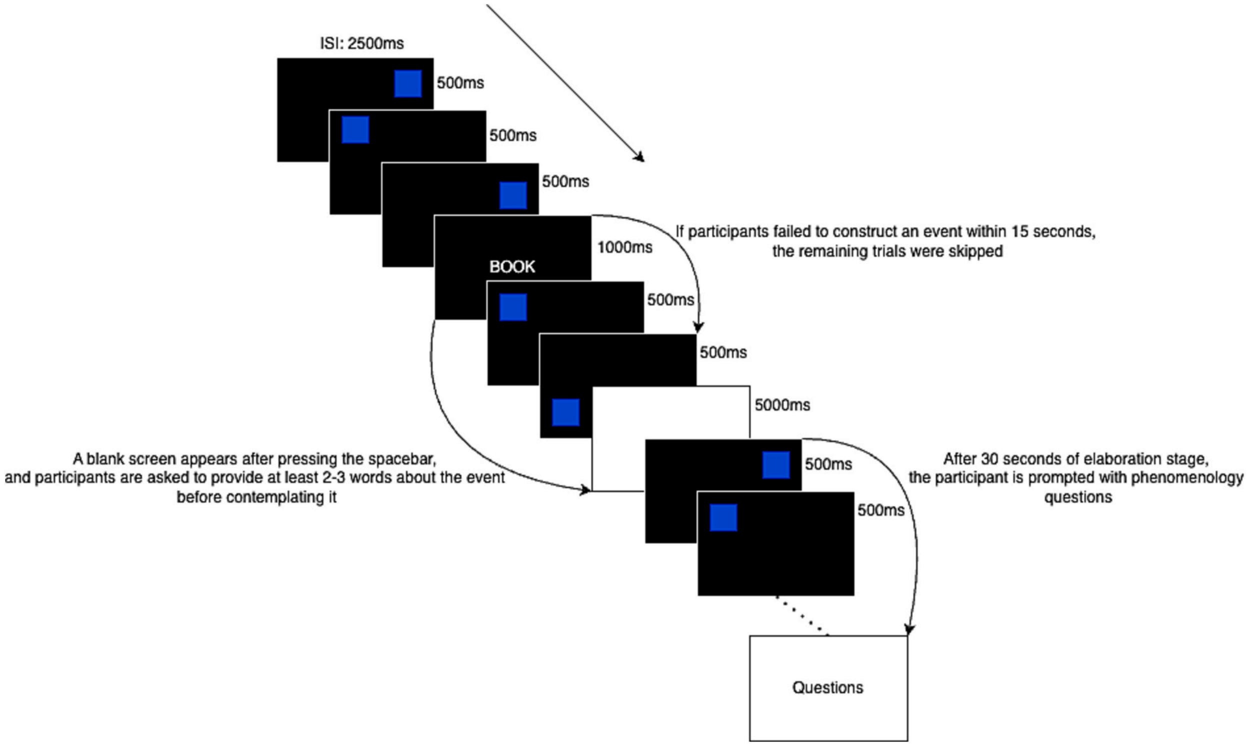

Fig. 2. The dual-task procedure of the visual 2-back group.

Table 1
Descriptive statistics of response times in milliseconds ($M \pm SD$).

	Past events		Future Events	
	Visual 2-back Group	Verbal 2-back Group	Visual 2-back Group	Verbal 2-back Group
Single Task	6211.1 ± 3097.1	5850 ± 2934.1	6592 ± 3508.1	6276.5 ± 3279.5
Dual Task	4914.5 ± 3044.2	4717.1 ± 2894	5488.4 ± 3134.6	5258.2 ± 3053.3

episodic future thinking, episodic memory; within-subjects) × 2 (task type: single-task, dual-task; within-subjects) ANCOVA on phenomenological characteristics (e.g., vividness, visual imagery, etc.) with working memory capacity included as a covariate. Preliminary assumption testing was conducted for each dependent variable to check for normality, linearity, and homogeneity of variances. Normality and linearity assumption checks were conducted by checking histograms, Q-Q plots, and skewness and kurtosis values (see Appendix E). No violation was observed. Levene's test for equality of variances was conducted for each dependent variable.[2] The internal consistency of each scale was assessed using Cronbach's alpha.[3] The covariate was centered before running the analyses. The descriptive statistics are summarized in Table 2.

3.2.1. The main effects

We observed a significant main effect of temporal direction in pre-experiencing, specificity, and spatial imagery, with lower ratings for future events compared to past events (all $ps < 0.05$; see Table 3 for complete statistics and confidence intervals). There was also a

[2] The results indicated unequal variances in some variables (e.g. vividness of past events in the single-task condition, $F(1, 186) = 4.6$, $p < 0.03$. Furthermore, we observed non-normality in the specificity of past events in the single-task condition. However, the standard deviations were similar across conditions for these variables, and sample sizes were equal, suggesting that the violations were not severe (Stevens, 1996, p. 249).

[3] Phenomenological measures showed acceptable internal consistency for each condition (in the single-task of episodic memory ($\alpha = 0.74$); in the single-task of episodic future thinking ($\alpha = 0.73$); in the dual-task of episodic memory ($\alpha = 0.73$), and in the dual-task of episodic future thinking ($\alpha = 0.75$). We assessed the internal consistency of the oSpan scores following the procedure described by Unsworth et al. (2005). In this method, internal reliability is estimated by computing Cronbach's alpha across multiple administrations of each set size. In our version, each set size was presented three times, and we created three separate scores: one based on the first presentation of each set size, one based on the second, and one based on the third. Cronbach's alpha was then calculated across these three scores to estimate the internal consistency of the task. The results indicated acceptable reliability for the oSpan task ($\alpha = 0.70$), which is comparable to those reported by Unsworth et al. (2005; $\alpha = 0.78$).

Table 2
Descriptive statistics of phenomenological ratings ($M \pm SD$).

	Past Events				Future Events			
	Visual 2-back Group		Verbal 2-back Group		Visual 2-back Group		Verbal 2-back Group	
	Single Task	Dual Task	Single Task	Dual Task	Single Task	Dual Task	Single Task	Dual Task
Vividness	5.5 ± 1.5	5.5 ± 1.5	5.8 ± 1.2	5.3 ± 1.6	5.5 ± 1.3	5.4 ± 1.5	5.6 ± 1.5	5.5 ± 1.5
Pre-re/experiencing	5.3 ± 1.5	5.0 ± 1.6	5.3 ± 1.5	4.9 ± 1.7	4.9 ± 1.7	4.6 ± 1.7	5.2 ± 1.6	4.7 ± 1.8
Visual Imagery	6.0 ± 1.1	5.6 ± 1.3	5.9 ± 1.1	5.7 ± 1.3	5.9 ± 1.2	5.6 ± 1.3	5.8 ± 1.2	5.6 ± 1.5
Auditory Imagery	5.2 ± 1.7	4.7 ± 1.9	5.3 ± 1.6	4.7 ± 1.9	5.1 ± 1.6	4.7 ± 1.9	4.9 ± 1.7	5.0 ± 1.8
Spatial Imagery	6.0 ± 1.5	5.3 ± 1.5	5.7 ± 1.3	5.3 ± 1.6	5.3 ± 1.5	4.9 ± 1.7	5.2 ± 1.5	5.2 ± 1.6
Emotional Intensity	4.8 ± 1.7	4.6 ± 1.7	4.7 ± 1.8	4.5 ± 1.7	4.4 ± 1.7	4.4 ± 1.7	5.0 ± 1.7	4.8 ± 1.8
Valence	4.8 ± 2.0	4.5 ± 2.1	4.4 ± 2.0	4.4 ± 2.0	4.9 ± 1.7	4.9 ± 1.9	5.1 ± 1.9	5.0 ± 1.9
Personal Importance	4.2 ± 2.0	3.7 ± 1.9	4.0 ± 1.8	3.6 ± 2.0	3.8 ± 1.9	3.8 ± 1.9	4.6 ± 2.0	4.1 ± 1.9
Voluntary Rehearsal	3.8 ± 1.8	3.4 ± 1.9	3.9 ± 1.9	3.4 ± 1.8	3.3 ± 1.9	3.3 ± 1.8	3.9 ± 2.1	3.9 ± 2.2
Involuntary Rehearsal	4.4 ± 1.9	4.5 ± 1.9	4.7 ± 1.9	4.3 ± 1.8	4.1 ± 1.8	4.1 ± 1.8	4.4 ± 2.0	4.8 ± 1.8
Ease of Imagining/Remembering	5.7 ± 1.4	5.1 ± 1.7	5.8 ± 1.3	5.2 ± 1.7	5.5 ± 1.2	5.2 ± 1.6	5.8 ± 1.3	5.3 ± 1.7
Imagery Perspective	3.3 ± 2.2	3.3 ± 2.4	3.3 ± 2.3	3.1 ± 2.3	2.4 ± 3.7	3.4 ± 2.3	3.5 ± 2.4	3.0 ± 2.3
Specificity	6.0 ± 1.5	5.7 ± 1.8	6.1 ± 1.4	6.1 ± 1.2	5.7 ± 1.8	5.6 ± 1.6	5.8 ± 1.4	5.7 ± 1.5

Table 3
The main effects of temporal direction and task type on phenomenological characteristics.

	df	F	p	η_p^2	95% C.I. for η_p^2
The main effect of temporal direction					
Pre-re/experiencing	1, 184	10.33	< 0.01	0.053	[.008, 0.127]
Specificity	1, 185	6.28	< 0.05	0.033	[.001, 0.097]
Spatial Imagery	1, 185	12.03	< 0.001	0.061	[.011, 0.137]
Valence	1, 185	11.63	= 0.001	0.059	[.011, 0.134]
The main effect of task type					
Vividness	1, 185	4.78	< 0.05	0.025	[.000, 0.085]
Visual Imagery	1, 185	10.42	= 0.001	0.053	[.008, 0.127]
Auditory Imagery	1, 185	14.24	< 0.001	0.072	[.017, 0.151]
Spatial Imagery	1, 185	12.03	= 0.001	0.061	[.011, 0.137]
Pre-re/experiencing	1, 184	10.33	< 0.01	0.053	[.008, 0.127]
Personal Importance	1, 185	7.39	< 0.01	0.038	[.003, 0.105]
Ease of Imagining/Remembering	1, 185	23.04	< 0.001	0.111	[.040, 0.200]

main effect of temporal direction in valence, indicating that future events were rated more positively than past events. The raincloud plots for these main effects are illustrated in Fig. 3.

We observed a significant main effect of task type in vividness, visual imagery, auditory imagery, spatial imagery, pre/re-experiencing, personal importance, and ease of remembering/imagining (please see Table 3). These main effects were driven by the lower ratings in the dual-task condition than in the single-task condition (all $ps < 0.05$).

3.2.2. Two-way interactions

There was a significant two-way interaction between temporal direction and task type in auditory imagery $F(1, 185) = 6.46$, $p < 0.05$, $\eta_p^2 = 0.034$, 95% C.I. [.002, 0.098]. Past events were rated lower on auditory imagery in the dual-task condition ($M = 4.68$, $SD = 0.14$) compared to the single-task condition ($M = 5.31$, $SD = 0.11$); $p < 0.001$, 95% CI = [-0.92, −0.34], while the future events ratings did not significantly differ across task types ($p = 0.33$, $\eta_p^2 = 0.004$). Additionally, in the single-task condition, participants experienced the past events ($M = 5.31$, $SD = 0.12$) with more auditory imagery than the future events ($M = 4.98$, $SD = 0.12$); $p < 0.01$, 95% CI = [.08, 0.59]. In the dual-task condition, there was no such difference between the past and future events ($p = 0.29$, $\eta_p^2 = 0.006$).

There was a significant two-way interaction between temporal direction and 2-back groups in personal importance, $F(1, 185) = 7.34$, $p < 0.01$, $\eta_p^2 = 0.038$, 95% C.I. = [.003, 0.105], and emotional intensity, $F(1, 185) = 7.73$, $p < 0.01$, $\eta_p^2 = 0.040$, 95% C.I. = [.003, 0.108], Pairwise comparisons showed that regardless of the task type (i.e., single- or dual-task), future events were less personally important; $p < 0.05$, 95% C.I. = [-0.1.007, −0.166], and less emotionally intense; $p < 0.05$, 95% C.I. = [-0.868, −0.121], in the visual 2-back group than in the verbal 2-back group. However, the ratings for past events were similar in the verbal and visual 2-back groups ($p > 0.05$). Additionally, in the verbal 2-back group, past events were less personally important; $p < 0.05$, 95% C.I. = [-0.908, −0.202], and emotionally intense; $p < 0.05$, 95% C.I. = [-0.627, −0.023], than future events regardless of the task type. No such effects were observed in the visual 2-back group. The remaining two-way interactions were not significant (all $ps > 0.05$).

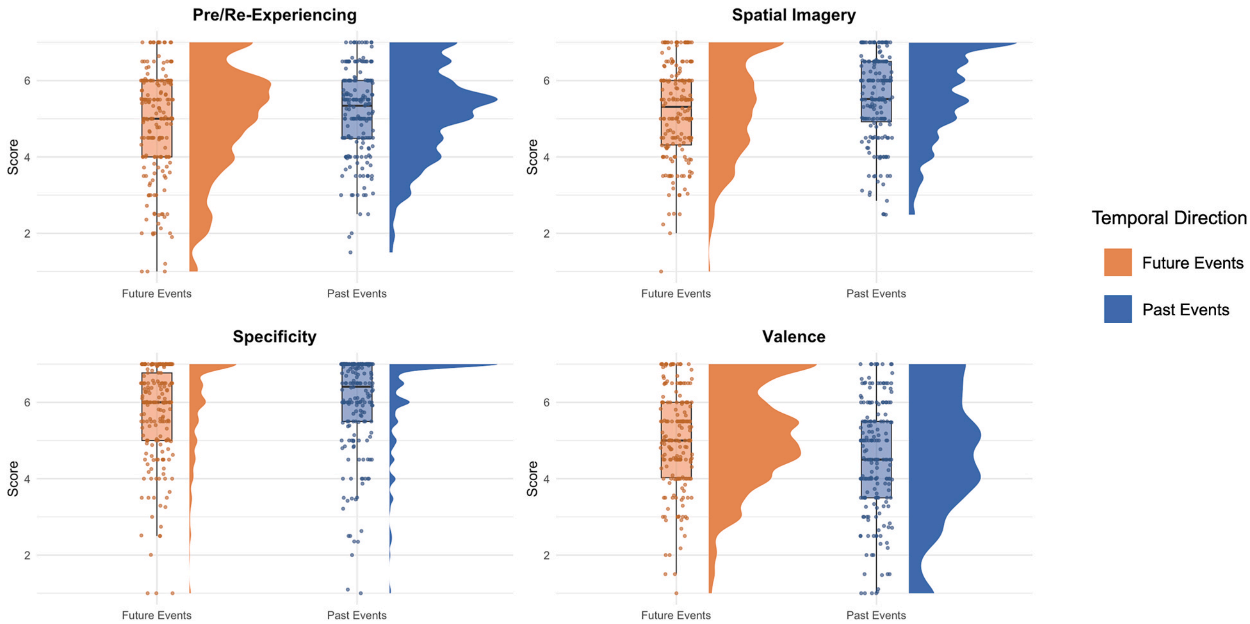

Fig. 3. Raincloud plots showing individual distributions of pre/re-experiencing, spatial imagery, specificity, and valence scores for past and future events (each averaged across single- and dual-task conditions). Each colored dot represents an individual participant's aggregated score, while the half-violins illustrate the overall distribution of these scores. *Note.* Although mean differences between past and future events were statistically significant for several phenomenological ratings, the corresponding effect sizes were small to medium (η_p^2 = 0.03–.06), resulting in partially overlapping distributions in the plots.

3.2.3. Three-way interactions

We observed a three-way interaction between temporal direction, task type, and operation span score in pre/re-experiencing, $F(1, 184) = 7.85$, $p < 0.05$, $\eta_p^2 = 0.041$, 95% C.I. = [.004, 0.109]. The remaining three-way interactions were not statistically significant (all *ps* > 0.05). To further investigate this significant interaction, we examined the correlations between operation span scores and pre/re-experiencing scores across temporal directions and task types. None of the correlations were significant (all *ps* > 0.05); however, we observed slope asymmetries in the relationship between operation span scores and pre/re-experiencing scores across temporal directions and task types. As operation span scores increased, pre-experiencing ratings for past events decreased in the single-task condition but increased in the dual-task condition. Conversely, for future events, these ratings increased in the single-task condition but decreased in the dual-task condition. These reversed patterns likely underlie the observed three-way interaction (please see Appendix D).

3.3. Secondary task performance and further analyses

To better understand the interaction effects between temporal direction and 2-back task modality observed in emotional intensity and personal importance ratings, we conducted follow-up analyses focusing on secondary task performance and individual cognitive capacities. Together, these analyses aim to clarify whether task interference or individual cognitive differences underlie the emotional and importance-related patterns observed in episodic simulation. Below, we present the details of these analyses and their implications for interpreting the main findings.

3.3.1. Emotional intensity and importance of past versus future events in the verbal 2-back group

Our results showed significant two-way interactions between 2-back groups (visual/verbal) and temporal direction in emotional intensity and personal importance variables. These interactions suggest that participants in the verbal 2-back group recalled past events that were less emotionally intense and less personally important compared to future events. However, it remains unclear whether these effects originated from the dual-task condition, as these two-way interactions were calculated using the means of the single- and dual-task conditions.[4] To address this issue, we conducted additional analyses that focused on the accuracy and response times associated with the secondary tasks, specifically the 2-back tasks (see Appendix E for descriptive statistics of each working memory task). This allowed us to see whether episodic memory load affected one of the 2-back tasks more adversely. If, for example, participants had difficulty in executing the verbal 2-back task while performing the episodic memory task, they may have strategically

[4] The type of 2-back group had no effect on the temporal direction factor in the single-task condition, as participants performed the episodic memory and episodic future thinking tasks without cognitive load of the secondary task in this condition.

reconstructed simpler (i.e., less important and less emotional) past events under the cognitive load imposed by the verbal 2-back task. We first calculated the ratio of single-task accuracy to dual-task accuracy for each 2-back group (single-task accuracy in 2-back tasks / dual-task accuracy in 2-back tasks). While higher ratios would mean a performance decrease under the cognitive load of episodic memory, lower ratios would mean a performance increase. We then compared these ratios between 2-back groups using independent samples *t*-test to see if the cognitive load of episodic memory affects the accuracy in the secondary task differently. There was a significant difference between groups, $t(160) = -3.32$, $p = 0.001$, $d = -0.52$, 95% C.I. [-0.82, −0.21] with the verbal 2-back accuracy ratio ($M = 1.47$, $SD = 1.05$) being higher than the visual 2-back accuracy ratio ($M = 1.01$, $SD = 0.66$). The analysis points out that the accuracy in verbal 2-back task was more adversely affected than the accuracy in visual 2-back task under the cognitive load of episodic memory.

We also calculated the ratio of single-task response time to dual-task response time for each 2-back group (single-task response times in 2-back tasks / dual-task response times in 2-back tasks). While higher ratios would indicate a performance increase under the cognitive load of episodic memory, lower ratios would indicate a performance decrease. We compared these ratios between 2-back groups using independent samples *t*-test to see if the cognitive load of episodic memory affects the response time in the secondary task differently. There was a significant difference between groups $t(160) = 3.71$, $p < 0.001$, $d = 0.59$, 95% C.I. [0.28, 0.89], with the visual 2-back response time ratio ($M = 1.22$, $SD = 1.13$) being higher than the verbal 2-back response time ratio ($M = 0.95$, $SD = 0.92$). This finding indicates that response time to verbal 2-back stimuli was more adversely affected than response time to visual 2-back stimuli under the cognitive load of episodic memory.

Overall, these two findings might clarify the tendency to recall a past event that was less important and less emotionally intense during the stage when participants had to perform the verbal 2-back and episodic memory tasks simultaneously. It appears that the interference between these tasks prevented participants from reconstructing past events in detail, leading them to report simpler events rather than more significant, emotionally intense ones. This tendency may reflect a strategy to allocate verbal working memory resources more effectively between the two tasks by recalling simpler events.

3.3.2. Emotional intensity and importance of future events in the visual versus verbal 2-back groups

The significant two-way interactions further suggest that future events were experienced with less emotional intensity and personal importance in the visual 2-back group compared to the verbal 2-back group. To determine whether these effects originated from the dual-task condition, we conducted further analyses. Interestingly, although the single-task condition of episodic future thinking did not involve modality-specific cognitive load, our independent samples *t*-test analyses still showed a difference between the visual and verbal 2-back groups in emotional intensity $t(190) = -2.68$, $p < 0.01$, $d = -0.39$, 95% C.I. [-0.67, −0.10], and personal importance $t(190) = -2.88$, $p < 0.01$, $d = -0.42$, 95% C.I. [-0.70, −0.13]. In our exploratory analyses, we found a difference in operation span scores between the 2-back groups: the visual 2-back group had lower operation span scores ($M = 30.89$, $SD = 13.94$) compared to the verbal 2-back group ($M = 35.98$, $SD = 13.79$), $t(187) = -2.52$, $p < 0.05$, $d = -0.37$, 95% C.I. [-0.66, −0.08]. Although this finding is somewhat unexpected, it may help clarify why future events were rated as less emotionally intense and personally important in the visual 2-back group compared to the verbal 2-back group, as reduced working memory capacity might have hindered the construction of personally significant and emotionally rich future-oriented events.

To determine whether differences in secondary task difficulty might have confounded our results, we examined whether task difficulty varied between the visual and verbal 2-back tasks in the single-task condition. We conducted independent samples t-tests on response time and accuracy. The analyses showed that participants responded more quickly in the visual 2-back task ($M = 760$, $SD = 308$) compared to the verbal 2-back task ($M = 957$, $SD = 301$), $t(191) = -4.48$, $p < 0.001$, $d = -0.65$, 95% C.I. [-0.94, −0.36]. However, accuracy was lower in the visual 2-back task ($M = 2.7$, $SD = 1.1$) than in the verbal 2-back task ($M = 3.2$, $SD = 0.9$), $t(190) = -3.59$, $p < 0.001$, $d = -0.52$, 95% C.I. [-0.81, −0.23]. Typically, increasing task difficulty is associated with slower responses and lower accuracy (Meule, 2017). In our findings, while accuracy declined for the visual task, response speed remained relatively stable, making it difficult to conclude that secondary task difficulty differed meaningfully between modalities. We further performed a set of independent samples t-tests on response time and accuracy for the visual and verbal 2-back tasks in the dual-task conditions to determine if any potential differences in task difficulty had emerged. The analyses revealed no significant differences between visual and verbal 2-back tasks for both accuracy $t(135) = 0.16$, $p = 0.87$, $d = 0.03$, 95% C.I. [-0.31, 0.36], and response time $t(190) = 1.12$, $p = 0.27$, $d = 0.16$, 95% C.I. [-0.12, 0.44]. This suggests that the tasks did not significantly differ in difficulty, at least in the dual-task conditions. Overall, these results suggest that differences in secondary task difficulty are unlikely to have confounded our results.

4. Discussion

This study investigated whether the visual and verbal components of working memory contribute differently to episodic future thinking and whether component utilization differs across temporal directions while controlling the effects of working memory capacity. To this end, we conducted an experiment using a novel dual-task paradigm. Participants were asked to remember a personal past event or imagine a personal future event (primary tasks) while simultaneously performing either a visual or a verbal 2-back task (secondary task) in single- and dual-task conditions. We analyzed the response times for event constructions during the 2-back tasks and the phenomenological ratings of the events remembered/imagined during dual-tasking.

4.1. Remembering past and imagining future events

We expected that constructing future events would be a slower process than remembering past events, as these future-oriented events require the flexible recombination of episodic details stored in episodic memory, which results in additional cognitive demand. Our findings supported this prediction, revealing that constructing future events takes more time than constructing past events. These results are in line with the constructive episodic simulation hypothesis, suggesting that future thinking requires more cognitive resources and entails more relational processing than past remembering (Anderson et al., 2012; Roberts et al., 2018).

We also found that future events were pre/re-experienced to a lesser extent and they were rated as less specific than past events. This finding aligns with studies showing poorer specificity for future events compared to past events (Addis et al., 2008; Anderson & Dewhurst, 2009; Özbek et al., 2017). The difference in specificity appears to be more nuanced in spatial details, as future events were experienced with less spatial imagery than past events. This is consistent with studies demonstrating fewer sensory details for future events than for past events (Addis et al., 2008; Berntsen & Bohn, 2010; D'Argembeau & Van der Linden, 2004). The constructive demands of future thinking may, therefore, limit individuals' ability to generate specific future events compared to past events, leading to poorer spatial details, less specificity, and less pre/re-experience.

We also observed that future events were evaluated as more positively valenced compared to past events. This pattern points to the well-known phenomenon of positivity bias in future thinking (D'Argembeau & Van der Linden, 2004; Salgado & Berntsen, 2020). People tend to perceive the future more positively than the past, possibly due to the self-enhancement function of imagining positive events or the ease of finding a positive event from the future. D'Argembeau and Van der Linden (2004) showed that participants could easily access positive future events rather than negative ones, allowing them to create a clear representation of the future in an experimental setting. Therefore, in our experiment, which requires considerable cognitive demand, participants may have been inclined to imagine a positive future event as it would be easier than imagining negative ones.

4.2. Remembering past and imagining future events under cognitive load

We initially expected to find a detrimental effect of cognitive load on constructing past and future events, assuming that the load would tax cognitive resources and make it difficult to construct an event. Contrary to expectations, participants constructed events more quickly under cognitive load (i.e., dual-task) than in the absence of load (i.e., single-task). However, phenomenological measures indicated that cognitive load negatively impacted various experiential aspects of events, including vividness, pre/re-experiencing, visual and auditory imagery, spatial imagery, personal significance, and the ease of recalling or imagining. This suggests that while cognitive load led participants to construct an event more quickly than in the no-load condition, it simultaneously reduced the phenomenological richness of those events. One possible explanation is that participants strategically allocated their limited working memory resources between the primary and secondary tasks. Under cognitive load, they may have quickly constructed simpler and less significant past and future events, requiring less cognitive effort. In contrast, in the no-load condition, they likely devoted more cognitive resources to recalling or imagining events, resulting in more detailed and phenomenologically rich experiences.

4.3. Remembering past and imagining future events under modality-specific cognitive load

Our results did not support our main hypothesis that imagining future events while engaging in a visual working memory task would result in longer response times and lower phenomenological ratings compared to a verbal working memory task. The modality-specific cognitive load had no significant effect on either response times or phenomenological ratings for future events. These findings suggest that visual and verbal working memory components do not differ significantly in their contributions to episodic future thinking. Instead, as the operation span performance showed, working memory capacity appears to play a pivotal role in episodic future thinking, particularly in shaping the emotional intensity and personal importance of future-oriented events, regardless of modality. Further analyses support this, showing that the visual 2-back group reported lower emotional intensity and personal importance for future events than the verbal 2-back group under no cognitive load. This likely stems from the unexpected finding of lower working memory capacity in the visual 2-back group. It is likely that participants in this group experienced future events with less emotional intensity and personal importance due to their lower working memory capacity compared to the verbal 2-back group. This finding aligns with prior research emphasizing the importance of working memory capacity in episodic future thinking (Hill & Emery, 2013).

Our second main hypothesis was that the visual working memory task would interfere more with the construction of future events than past events, leading to longer response times and lower phenomenological ratings for future events. However, contrary to this expectation, no differences were observed between constructing past and future events under visual working memory load, which contrasts with the findings of de Vito et al. (2015). This discrepancy might stem from differences in the experimental procedures, as the voluntary eye movements used in their study and the visual 2-back task employed in our study could involve various cognitive processes beyond visuospatial information processing.

Our study diverged from previous dual-task studies that have emphasized the importance of visual information processing in recalling episodic memories (Anthony et al., 2023; Gatti et al., 2022; Sheldon et al., 2017). While these studies have suggested a prominent role for visual processing in episodic memory, they did not directly compare the contributions of visual and verbal working memory within a dual-task framework. Our study suggests that verbal information processing may play a prominent role in recalling past events, at least within a controlled experimental setting. This finding highlights the importance of considering both modalities when investigating episodic memory.

Further analysis revealed that participants in the verbal 2-back group tended to recall past events that were perceived as less important and emotionally intense. This suggests that interference between the two tasks, both likely relying on verbal working memory resources, may have led participants to select simpler, less significant events that required fewer cognitive resources. This is reflected in the performance decline when participants performed the verbal working memory task alongside the episodic memory task, compared to the visual working memory task. Since the verbal working memory task and episodic memory recall likely share similar resources, the load on verbal working memory may have restricted participants' ability to access richer episodic memories. This tendency to report simpler events aligns with our other finding, which highlights the role of auditory information in episodic memory. We observed that auditory imagery for past events was adversely affected under cognitive load, whereas auditory imagery for future events remained unaffected. Furthermore, in the absence of cognitive load, past events were rated higher in auditory imagery compared to future events, suggesting that auditory imagery may play a more central role in recalling past experiences compared to imagining future events. Given that episodic memory in our study often relied on auditory details, recalling such events likely competed for verbal working memory resources while participants were engaged in another verbal task. This interference may have further limited the complexity of the events that could be retrieved, emphasizing the pivotal role of verbal working memory in episodic memory processes. In this vein, our results are consistent with the narrative framework of memory (Fivush, 2008; Fivush et al., 2006), which suggests that language plays a crucial role in organizing and sharing memories. According to this framework, individuals construct life stories and recall past events in the form of narratives, which are influenced by culturally shaped linguistic structures. In this sense, remembering past events may involve more verbal processing compared to episodic future thinking, as past events are often recalled as structured narratives. Therefore, people may recall their past experiences not only by accessing the original details of the events but also by retrieving the narratives they have shared with others. As a result, they may rely on their verbal working memory resources to reconstruct these stories.

4.4. Limitations and conclusion

Our study has some limitations that should be considered. One major limitation is that the trials were one-shot, which led to a higher number of missing values. To address this issue, future studies could include additional trials for each measure or provide extra cue words for participants who may have difficulty constructing an event, reducing the likelihood of missing data.

There is some controversy about the best way to measure working memory (Jaeggi et al., 2010; Redick & Lindsey, 2013). In the current study, we used the 2-back as a secondary task to impose cognitive load in the relevant modality and assess its effects on episodic future thinking and episodic memory. Previous studies have similarly utilized the 2-back task for this purpose. For example, in the study conducted by Özbozdağlı et al. (2018) participants engaged in a car driving simulation as their primary task while concurrently performing either an auditory or visual 2-back task as a secondary task. Their findings demonstrated that modality-specific cognitive load induced by the 2-back tasks differentially impacted task performance. Based on this, we anticipated that the modality-specific 2-back tasks would successfully impose cognitive load in the corresponding domains. Future research could enhance the robustness of our findings by incorporating a variety of modality-specific tasks (e.g., Corsi block tapping, counting aloud, etc.) to examine the hypotheses under varying cognitive loads within a dual-task paradigm. Additionally, employing various span tasks (e.g. symmetry span, rotation span, etc.) to measure working memory capacity alongside the operation span task could provide a more comprehensive assessment, as relying on a single indicator is not ideal (Foster et al., 2015). In the present study, we opted for a single indicator with operation span task due to time constraints. However, future studies could use shortened versions of these tasks to more effectively capture working memory capacity (Foster et al., 2015).

The study employed a mixed design with a between-subjects factor, which may have introduced variability due to individual differences in working memory processing. For instance, we unexpectedly observed a difference in working memory capacity between the visual and verbal 2-back groups, which we believe was due to chance. To address this issue, future studies could use a within-subjects design, where participants perform both visual and verbal tasks. This approach would help control for individual differences and provide a more accurate assessment of the distinct contributions of working memory components. However, we opted for a mixed design to ensure the feasibility of the experiment and to avoid participants' fatigue, as incorporating all factors within would have considerably extended the duration of the study.

Finally, in our study, phenomenological assessments of events were based on subjective reports. However, the subjective nature of these reports limits the ability to objectively assess the complexity and accuracy of the episodic details described. For instance, we assumed that episodic memory and the verbal 2-back task interfered with each other, resulting in simpler memories. However, this conclusion was based solely on participants' subjective reports of phenomenological characteristics, leaving it unclear whether verbal working memory load actually impairs episodic memory recall. To gain a deeper understanding, future studies should consider applying content analysis to reports of episodic memory and episodic future thinking. This approach would allow for the examination of factors such as fluency, specificity, and the richness of episodic details, ultimately providing a more nuanced understanding of memory processes.

In conclusion, our study demonstrates the interplay between working memory components and episodic thought, providing new insights into the cognitive underpinnings of mental time travel. We found that working memory capacity plays a critical role in episodic future thinking, regardless of the modality-specific working memory resources involved. Furthermore, our findings suggest a potential role of verbal working memory in recalling past events, raising the possibility that verbal working memory operations may contribute to episodic memory.

CRediT authorship contribution statement

Burak Yildirim: Writing – original draft, Visualization, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Aysu Mutlutürk:** Writing – review & editing, Supervision, Project administration, Funding acquisition.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.concog.2025.103946.

Data availability

Data is available at https://osf.io/3gkhw/?view_only=4f0c73a8b3cc43ddbe29a65678ac8312.

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