Article

Social Psychological and Personality Science
2023, Vol. 14(1) 51–59

DOI: 10.1177/19485506211067673
journals.sagepub.com/home/spp
SAGE

Attitudinal Effects of Stimulus Co-occurrence and Stimulus Relations: Sleep Supports Propositional Learning Via Memory Consolidation

Rui Jin[1], Tao Xia[1], Bertram Gawronski[2], and Xiaoqing Hu[1,3]

Abstract

Adaptive behavior requires that organisms learn not only which stimuli tend to co-occur (e.g., whether stimulus A co-occurs with unpleasant stimulus B) but also how co-occurring stimuli are related (e.g., whether A starts or stops B). In a preregistered study (N = 200 adults), we investigated whether sleep would promote adaptive evaluative choices requiring joint memories for stimulus co-occurrences and stimulus relations. Participants learned about hypothetical pharmaceutical products that either cause or prevent positive or negative health conditions, followed by measures of evaluative choices and explicit memory. After a 12-hr retention interval including either nocturnal sleep or daytime wake, participants completed the same measures a second time. Results showed that sleep strengthened the impact of causal product–condition relations on choices (revealed by multinomial modeling analyses) and enhanced memories for specific stimulus co-occurrences (revealed by memory preservation analyses). The findings suggest that sleep promotes adaptive evaluative choices via offline memory consolidation.

Keywords

attitudes, evaluative learning, memory consolidation, sleep, multinomial modeling

Acetaminophen reduces pain; flu vaccines prevent seasonal flu; sunscreen prevents skin cancer; sustainable energy sources reduce global warming. When people learn such information, adaptive choices require that people consider not only which stimuli co-occur (e.g., whether stimulus A co-occurs with a pleasant or unpleasant stimulus B) but also how co-occurring stimuli are related (e.g., whether A causes or prevents B). For example, when being exposed to the message *acetaminophen reduces pain*, people will likely make superior decisions when they recall the causal relation between *acetaminophen* and *pain* than when they recall the mere co-occurrence of *acetaminophen* and *pain* without remembering their specific relation (see De Houwer, 2009; De Houwer et al., 2020). Nevertheless, some studies suggest that mere co-occurrence of two stimuli can influence evaluative responses irrespective of information about their specific relation (e.g., Heycke & Gawronski, 2020; Hu et al., 2017; Kukken et al., 2020; Moran & Bar-Anan, 2013). Although the boundary conditions of such effects are still unclear (Corneille & Stahl, 2019; De Houwer et al., 2020; Kurdi & Dunham, 2020), adaptive evaluations likely depend on (a) effective encoding and storage of both co-occurrence and relational information and (b) complete retrieval of the stored information (De Houwer, 2018; Gawronski & Bodenhausen, 2018).

A plausible, hitherto untested, hypothesis is that sleep supports adaptive evaluative learning via consolidation of memories for stimulus co-occurrences and stimulus relations. According to the system consolidation account, recently acquired memories are repeatedly reactivated during sleep—particularly during slow-wave sleep—which leads to their consolidation and transformation to long-term memories (Diekelman & Born, 2010 ; Hu et al., 2020; Klinzing et al., 2019; Rasch & Born, 2013; Stickgold, 2005). Via offline memory consolidation, newly learned information is gradually integrated with existing knowledge to form coherent knowledge structures (Klinzing et al., 2019). Intriguingly, sleep not only consolidates but also reorganizes memory to facilitate integration, generalization, and extractions of hidden rules and regularities (Landmann et al., 2014; Lerner & Gluck, 2019; Lupo &

[1]The University of Hong Kong, China
[2]University of Texas at Austin, USA
[3]HKU-Shenzhen Institute of Research and Innovation, Shenzhen, China

Corresponding Author:
Xiaoqing Hu, Department of Psychology, The State Key Laboratory of Brain and Cognitive Sciences, The University of Hong Kong, Pokfulam, Hong Kong, China.
Email: xiaoqinghu@hku.hk

Zárate, 2019; Stickgold & Walker, 2013; Wagner et al., 2004). For example, sleep has been found to enhance transitive inferences based on overlapping features of individual memories (Ellenbogen et al., 2007): After participants learned the stimulus relations A >B and B > C, sleep (vs. wake) improved accurate judgments of A > C relations that were never directly learned before (see also Alger & Payne, 2016; Huguet et al., 2019). In the current research, we investigated whether sleep similarly promotes adaptive evaluative learning by consolidating memories for stimulus co-occurrences and stimulus relations (see also Richter et al., 2021).

To test this idea, participants were presented with stimulus pairings involving hypothetical pharmaceutical products (conditioned stimuli, CSs) and positive or negative health outcomes (unconditioned stimuli, USs). For each CS–US pairing, participants were additionally presented with information about whether the depicted product causes or prevents the depicted health outcome (see Hu et al., 2017). After the learning task, participants were asked to indicate for each product whether they would choose it (see Heycke & Gawronski, 2020). In addition, we tested participants' memories for (a) the specific US a given CS had been paired with and (b) the causal relation to the identified US. Using this procedure, we tested whether a night of sleep, compared with an equally long period of wake-time, (a) influences the impact of CS–US co-occurrences and CS–US relations on evaluative choices and (b) improves memories for CS–US co-occurrences and CS–US relations.

Method

The study was preregistered prior to data collection. Preregistration, data, materials, and analysis scripts are available at https://osf.io/9rsjg/. The study protocol was approved by the Human Research Ethics Committee of the University of Hong Kong.

Participants

We preregistered to recruit 200 participants, with $n = 100$ in each of the two conditions. A sensitivity analysis using G*Power 3 (Faul et al., 2007) indicated that this sample provides a power of $\beta = .80$ in detecting a small effect of $f = .099$ with a false positive rate of $\alpha = .05$. Participants were recruited from the University of Hong Kong. To qualify for the study, participants were required to have a regular sleep pattern with at least 6 hr of sleep per night during the prior week and on the day of the experiment, as confirmed by sleep diaries. Participants were prescreened for previous/current sleep disorders, and they were required to have Pittsburgh Sleep Quality Index scores $\leqslant 7$ (Buysse et al., 1989) and Insomnia Severity Index scores $\leqslant 14$ (Morin et al., 2011). Participants who met the inclusion criteria were randomly assigned to a sleep or a wake condition. We then emailed participants about possible timeslots based on their condition assignment. Those who were assigned to the sleep (wake) condition could only choose 9:00 pm (9:00 am) for their first session, and they had to confirm that they can come back again around 9:00 am on the next morning (around 9:00 pm in the evening on the same day). Each participant was offered multiple dates to choose so that participants could find a date that suits their schedule. We stopped the data collection once we reached our target of 200 participants (151 women; $M_{age} = 21.81$, $SD_{age} = 3.48$). Seventy-five additional participants were excluded based on our preregistered exclusion criteria: taking naps ($n = 15$) or consuming caffeinated drinks ($n = 60$) on the day of the experiment.

Procedure

The experiment employed a 2 (US Valence: Positive vs. Negative) × 2 (CS-US Relation: Causes vs. Prevents) × 2 (Time: Time 1 vs. Time 2) × 2 (Condition: Sleep vs. Wake) mixed design, with the first three factors varying within participants and the last factor varying between participants. At Time 1, participants completed (a) an evaluative learning task, (b) a speeded choice task, and (c) an explicit memory test. At Time 2, participants completed the same choice task and memory test, followed by several supplemental questionnaires regarding chronotype and sleep quality (see Figure 1A). The evaluative learning task and the speeded choice task were directly adapted from Heycke and Gawronski (2020), including all of the stimulus materials (see also Gawronski, 2021; Gawronski & Brannon, 2021). Participants in the wake condition completed the Time 1 session at ~9:00 AM and the Time 2 session at ~9:00 pm of the same day. Participants in the sleep condition completed the Time 1 session at ~9:00 pm and the Time 2 session at ~9:00 am of the following day. Thus, the critical difference between the two conditions was the mapping of the two sessions with specific times of the day, and whether they had slept during the 12-hr retention interval (see Figure 1A).

Evaluative Learning Task. The materials included 12 images of hypothetical pharmaceutical products (CS), each of which was paired with 1 of 12 images depicting a positive or negative health condition (US) and relational information about whether the product causes or prevents the depicted health condition. Thus, the materials included four types of CS-relation-US combinations (i.e., CS-causes-positive-US; CS-causes-negative-US; CS-prevents-positive-US; CS-prevents-negative-US) with three unique combinations of stimuli for each type. The use of a given CS for pairings with positive versus negative USs and the relations *causes* versus *prevents* was counterbalanced by means of a Latin

square. On each trial, a CS-relation-US combination was presented for 3,000 ms, followed by a 1,000 ms inter-trial-interval (Figure 1B). Participants completed four blocks of trials with each of the 12 CS-relation-US combinations presented twice within each block, summing up to 96 trials. Participants received the following instructions for the learning task:

> *In this study, you will be presented with images of pharmaceutical products and visual information about their effects. As you know, many pharmaceutical products have positive effects, but some products also have negative side effects. For each product, you will see whether this product causes or prevents a health outcome. Your task is to think of the image pairs, such that the pharmaceutical product CAUSES or PREVENTS what is displayed in the other photograph. For example, if a product is paired with a positive image, and it says "causes," you should think of the product in terms of it causing the positive outcome displayed in the image. Conversely, if a product is paired with a negative image, and it says "causes," you should think of the product in terms of it causing the negative outcome displayed in the image. If a product is paired with a positive image, and it says "prevents," you should think of the product in terms of it preventing the positive outcome displayed in the image. Conversely, if a product is paired with a negative image, and it says "prevents," you should think of the product in terms of it preventing the negative outcome displayed in the image. Again, please think of the image pairs in terms of the relation mentioned on the screen (causes or prevents).*

Speeded Choice Task. Each trial started with a 100 ms blank screen, followed by a 900 ms fixation cross. One of the CSs was then presented in the center of the screen for 1,000 ms. Participants were asked to indicate whether they would choose the product by pressing one of two response keys (yes = *A*, no = *Numpad5*).[1] Participants were instructed to respond as quickly as possible, and they had 1,000 ms to provide their response. If participants did not provide a response within the 1,000 ms window, they were presented with a message *Please try to respond faster!* for 750 ms before the next trial started (Figure 1C). Each of the 12 CSs was presented 5 times, summing up to 60 trials.

Explicit Memory Task. On each trial of the memory task, a CS was presented in the upper-center of the screen with all 12 USs presented below (Figure 1D). Participants were asked to identify the US that had been paired with the depicted CS during the learning task. Afterward, participants were asked to indicate the specific relation (causes vs. prevents) associated with the identified CS–US pairing. Although there was no response deadline, participants were prompted to respond faster if they took longer than 8,000 ms on a given trial.

Preregistered Analysis Plan. We analyzed speeded evaluative choices using Heycke and Gawronski's (2020) RCB model, a multinomial model that quantifies the extent to which participants' responses are influenced by (a) CS–US relations, (b) mere CS–US co-occurrence, and (c) general response biases (see Figure 2). The model's *R* parameter quantifies the extent to which responses are influenced by CS–US relations (i.e., favorable responses to CSs that cause positive USs and to CSs that prevent negative USs; unfavorable responses to CSs that cause negative USs and to CSs that prevent positive USs). The model's *C* parameter quantifies the extent to which responses are influenced by mere CS–US co-occurrences (i.e., favorable responses to CSs that co-occur with positive USs; unfavorable responses to CSs that co-occur with negative USs). Finally, the model's *B* parameter quantifies the extent to which participants show a general bias toward favorable or unfavorable responses regardless of the information in the learning task. Modeling analyses were conducted using the software multiTree (Moshagen, 2010) and the template files for RCB model analyses provided by Heycke and Gawronski (2020) at https://osf.io/7ac4d/. Following our preregistered analysis plan, we investigated the effect of sleep on the impact of CS–US relations by testing whether the *R* parameter differs across Time 1 and Time 2 within the sleep and the wake condition, respectively. Correspondingly, the effect of sleep on the impact of CS–US co-occurrence was investigated by testing whether the *C* parameter differs across Time 1 and Time 2 within the sleep and the wake condition, respectively.

Memory responses were aggregated by calculating three accuracy indices: (a) an index labeled *US_identity* reflecting accuracy in identifying the specific US a given CS had been paired with; (b) an index labeled *US_valence* reflecting US identifications of the correct valence (regardless of the specific US); (c) an index labeled *Relation* reflecting accuracy in identifying the causal relation associated with a given CS. To investigate joint memories, we additionally calculated (d) an index labeled *US_identity + relation* reflecting accuracy in identifying both the US a given CS had been paired with and the causal relation between the two, and (e) an index labeled *US_valence + relation* reflecting US identifications of the correct valence and correct identification of the causal relation associated with a given CS. Memory indices were calculated based on the percentage of correct responses. We preregistered to calculate preservation scores for the five memory indices by scaling participants' Time 2 scores to their Time 1 scores to control for individual baseline differences in memory performance. Following our preregistered analysis plans, effects of sleep were investigated by testing whether preservation scores for US_identity, US_valence, Relation, US_identity +

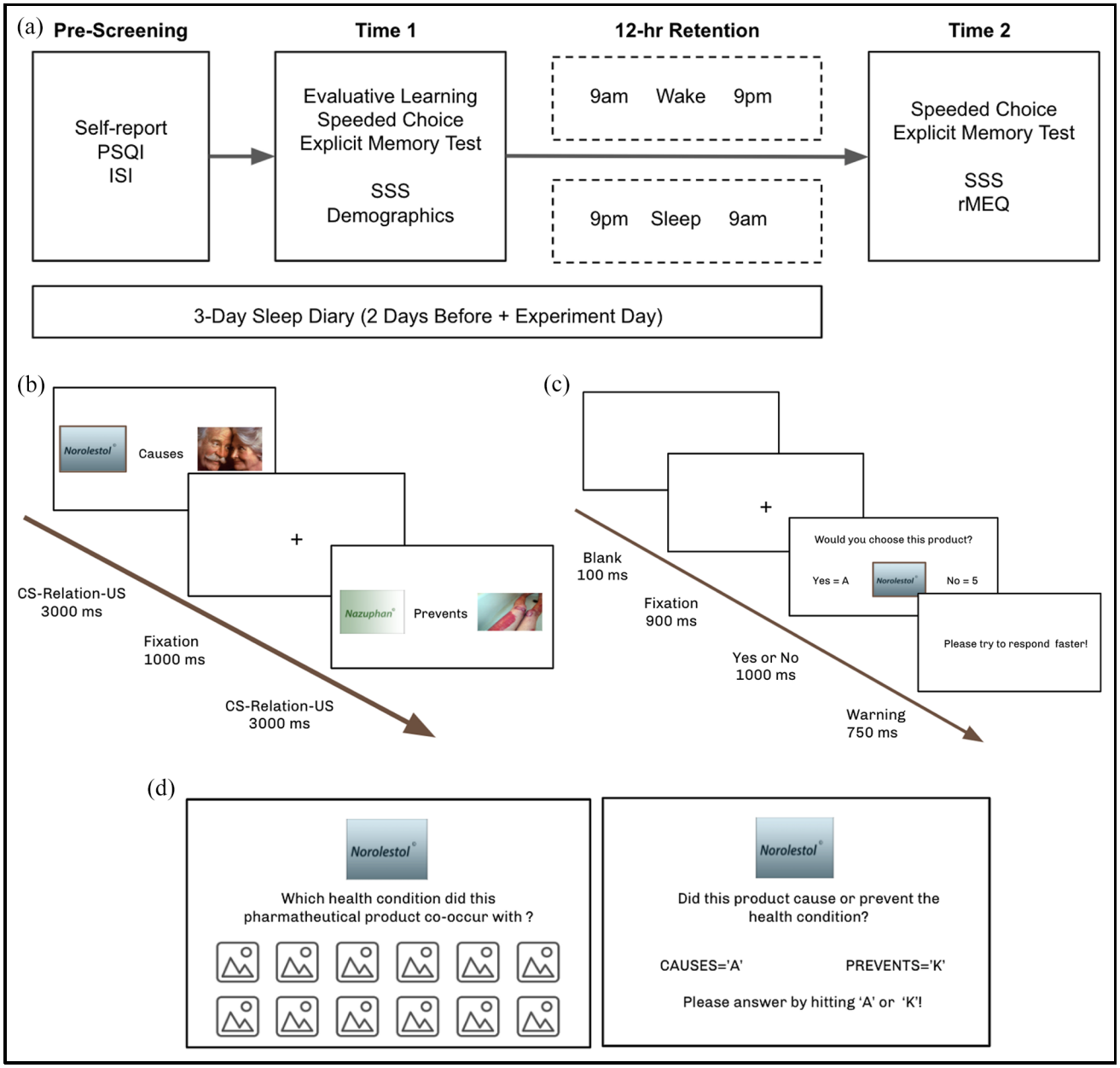

Figure 1. Experimental Procedure and Task Illustrations: (a) Participants Were First Prescreened Based on Pittsburgh Sleep Quality Index Scores (⩽7) and Insomnia Severity Index Scores (⩽14). At Time 1, participants completed an evaluative learning task, a speeded evaluation task, and an explicit memory task, followed by assessments of alertness (Stanford Sleepiness Scale) and demographics. Following a 12-hr retention interval of either nocturnal sleep or no sleep, participants returned to the lab for Time 2 tests. (b) Evaluative Learning Task. Participants viewed each CS-relation-US combination for 3,000 msec. (c) Speeded Choice Task. Participants were presented with each CS and were given 1,000 ms to provide a yes/no response. Participants were presented with the message Please try to respond faster! for 750 ms if they did not respond within 1,000 ms. (d) Explicit Memory Task. Participants first chose the US that had been paired with the CS, followed by choosing the relational information associated with the CS–US pairing.

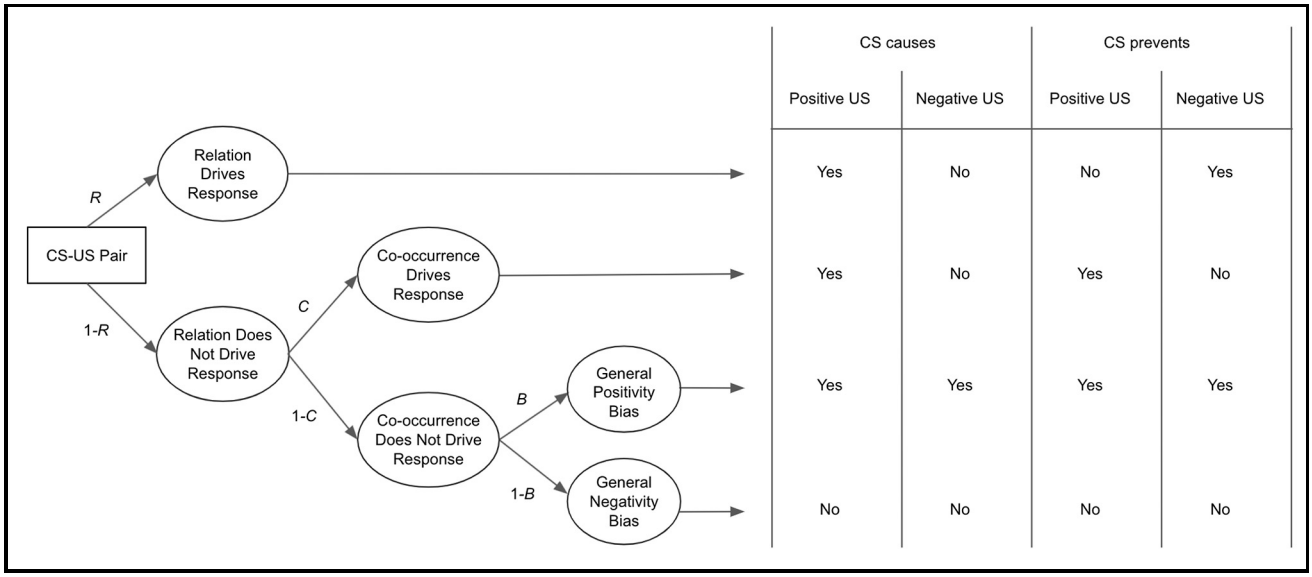

Figure 2. Multinomial Processing Tree Depicting Effects of CS–US Relation, CS-US Co-occurrence, and General Responses Biases on Evaluative Decisions

Note. Figure adapted from Heycke and Gawronski (2020). Reprinted with permission.

Table 1. Parameter Estimates of the RCB Model as a Function of Time (Time 1 vs. Time 2) and Experimental Condition (Sleep vs. Wake)

Parameter	Sleep			Wake		
	Estimate	95% CI	*p*	Estimate	95% CI	*p*
R						
Time 1	.19	[.16, .21]	<.001	.17	[.14, .20]	<.001
Time 2	.22	[.20, .25]	<.001	.19	[.16, .22]	<.001
C						
Time 1	.14	[.10, .17]	<.001	.11	[.08, .14]	<.001
Time 2	.14	[.11, .18]	<.001	.10	[.07, .13]	<.001
B						
Time 1	.59	[.57, .61]	<.001	.55	[.53, .57]	<.001
Time 2	.54	[.52, .56]	<.001	.50	[.49, .52]	.655

Note. The *R* parameter captures the impact of CS–US relations on choice decisions; the *C* parameter captures the impact of CS–US co-occurrence on choice decisions; the *B* parameter captures general response biases. The *p* values indicate whether a given parameter estimate is significantly different from its neutral reference point. The neutral reference point for *R* and *C* is 0; the neutral reference point for *B* is .5, with scores $>$ .5 indicating a positive response bias and scores $<$ .5 indicating a negative response bias. CI = confidence interval; CS = conditioned stimuli; US = unconditioned stimuli.

relation, and US_valence + relation significantly differ across experimental conditions.

Results

Speeded Choices

The RCB model was fit to the data of participants in the two experimental conditions (sleep vs. wake) at the two time points (Time 1 vs. Time 2) with the three parameters varying freely across conditions and time points. This baseline model fit the data well, $G^2(4) = 4.02$, $p = .403$. Estimated parameter scores and 95% CIs are presented in Table 1. Our preregistered analysis regarding the effect of sleep on the *R* parameter revealed that the impact of CS–US relations significantly increased from Time 1 to Time 2 in the sleep condition, $\Delta G^2(1) = 3.97$, $p = .046$, but not in the wake condition, $\Delta G^2(1) = 1.16$, $p = .281$.[2] In contrast, our preregistered analysis regarding the effect of sleep on the *C* parameter revealed that the impact of CS–US co-occurrence did not significantly differ across time points in both the sleep condition, $\Delta G^2(1) = 0.10$, $p = .750$, and the wake condition, $\Delta G^2(1) = 0.16$, $p = .688$. Exploratory analyses further revealed a significant effect of Time on the *B* parameter, indicating that participants showed a less pronounced positive response bias over time in both the sleep condition, $\Delta G^2(1) = 12.41$, $p < .001$, and the wake condition, $\Delta G^2(1) = 14.54$, $p < .001$.

Table 2. Means and 95% CIs of Memory Indices as a Function of Time (Time 1 vs. Time 2) and Experimental Condition (Sleep vs. Wake)

Memory index	Sleep		Wake	
	Time 1 in %	Time 2 in %	Time 1 in %	Time 2 in %
US_identity (8%)	53.25 [47.48, 59.02]	51.25 [45.38, 57.12]	60.92 [55.29, 66.54]	52.00 [46.11, 57.90]
US_valence (50%)	76.08 [72.37, 79.80]	74.42[70.32, 78.51]	80.92 [77.38, 84.45]	77.75 [74.27, 81.23]
Relation (50%)	65.08 [61.72, 68.45]	62.67 [58.73, 66.60]	68.75 [64.60, 72.90]	64.83 [60.95, 68.71]
US_identity + relation (4.2%)	43.58 [38.20, 48.96]	41.08 [35.72, 46.45]	49.92 [43.97, 55.86]	40.33 [34.54, 46.12]
US_valence + relation (25%)	55.67 [51.42, 59.91]	52.33 [47.57, 57.09]	60.42 [55.41, 65.42]	53.83 [49.02, 58.65]

Note. Chance-level performance for each memory indices is provided in parentheses. US_identity = identification of the specific US a given CS had been paired with; US_valence = US identifications of the correct valence (regardless of the specific US); Relation = identification of the correct causal relation associated with a given CS; US_identity + relation = correct identification of both the US a given CS had been paired with and their causal relation; US_valence + relation = US identifications of the correct valence and correct identification of the causal relation associated with a given CS. CI = confidence interval; CS = conditioned stimuli; US = unconditioned stimuli.

Table 3. Means and 95% CIs of Memory Preservation Scores as a Function of Experimental Condition (Sleep vs. Wake)

Memory indexes	Sleep	Wake
US_identity	106.42% [93.78, 119.06]	88.29% [78.32, 98.25]
US_valence	99.99% [95.31, 104.67]	100.15% [93.83, 106.46]
Relation	99.14% [92.96, 105.33]	98.64% [92.57, 104.72]
US_identity + relation	103.47% [93.93, 113.02]	87.37% [75.58, 99.15]
US_valence + relation	100.13% [89.34, 110.93]	102.84% [85.46, 120.23]

Note. US_identity = identification of the specific US a given CS had been paired with; US_valence = US identifications of the correct valence (regardless of the specific US); Relation = identification of the correct causal relation associated with a given CS; US_identity + relation = correct identification of both the US a given CS had been paired with and their causal relation; US_valence + relation = US identifications of the correct valence and correct identification of the causal relation associated with a given CS. A preservation score of 100% indicates preserved memory; preservation scores >100% indicate improved memory; preservation scores <100% indicate memory decay. CI = confidence interval; CS = conditioned stimuli; US = unconditioned stimuli.

Explicit Memory

Mean scores of memory performance are presented in Table 2. Memory preservation scores are presented in Table 3. Our preregistered analyses revealed that participants in the sleep (vs. wake) condition showed significantly higher memory preservation scores for US_identity, $t(198) = 2.24$, $p = .027$, $d = 0.32$, and US_identity + relation, $t(198) = 2.11$, $p = .036$, $d = 0.30$ (see Figure 3). There were no significant between-condition differences for memory preservation regarding US_valence, $t(198) = -0.04$, $p = .969$, $d = -0.01$, Relation, $t(198) = 0.11$, $p = .910$, $d = 0.02$, US_valence + relation, $t(198) = -0.26$, $p = .793$, $d = -0.04$.

Robustness Analyses

Recognizing potential influences of chronotypes and time-of-day, we also conducted non-preregistered exploratory analyses to test the robustness of our findings (for details, see Supplemental Online Materials). To address the concern that chronotypes may contribute to the effect of sleep reported here, we categorized participants into morning vs. evening types based on a median split of rMEQ scores, following Bodenhausen (1990). We then repeated the preregistered analyses, adding chronotype as a between-participant factor. Results showed that the chronotype-by-condition interactions were far from significant for all of the critical memory indices (all $ps > .32$). We next controlled for time-of-day effects by including Time 1 memory performance and Time 2 alertness levels as covariates in the ANCOVA. The results again replicated the ones of our preregistered analyses (all $ps < .05$). Finally, we repeated the analyses after outlier exclusions, and examined how trial exclusions influenced the findings obtained with the RCB model. All results remained consistent with the ones of our preregistered analyses (see Supplemental Online Materials).

Discussion

The current findings suggest that sleep (a) increases the impact of causal CS–US relations on choices and (b) consolidates memories for specific CS–US co-occurrences and, by extension, joint memories for CS–US co-occurrences and CS–US relations. Together, the two sets of findings suggest that sleep promotes adaptive evaluative choices via offline memory consolidation.

Our findings significantly extend prior research on how sleep reorganizes and transforms memories (e.g.,

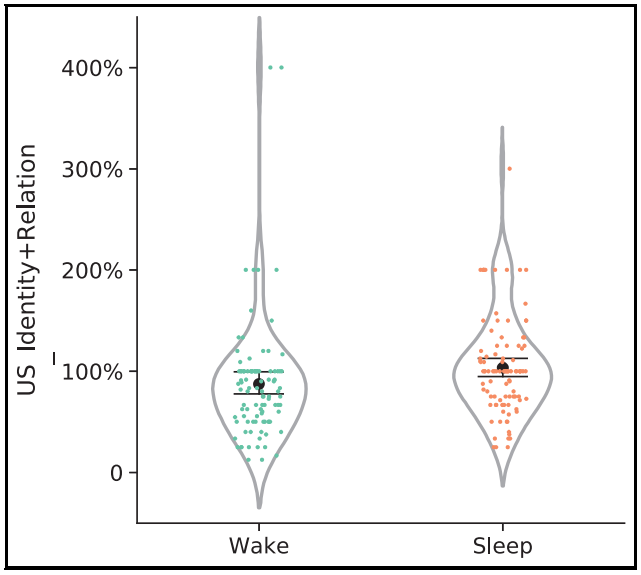

Figure 3. Memory Preservation Scores (Time 2 / Time 1) in Sleep and Wake Conditions

Note. Sleep enhanced memory preservation for joint memories of US identity and causal relations. Each point indicates data from one participant. A preservation score of 100% indicates memory stability; a preservation score >100% indicates memory enhancement; a preservation score <100% indicates memory decay. Results are robust after the exclusion of potential outliers (see Supplemental Online Materials). Error bars indicate 95% confidence intervals. US = unconditioned stimuli. *indicates $p < .05$

Landmann et al., 2014). Previous evidence suggests that sleep enhances relational memories based on transitive inferences. For example, after participants learned the stimulus relations A > B and B > C, sleep has been found to promote accurate judgments of A > C relations, which should emerge only when the learned A-B and B-C links were consolidated based on the overlapping component B (Alger & Payne, 2016; Ellenbogen et al., 2007). Unlike transitive AB/BC-AC learning, the paradigm employed in the current study requires successful combination of co-occurrence and relational information for adaptive evaluative judgments. For example, when a CS prevents a negative US, the CS should be evaluated positively only if information about their co-occurrence is effectively combined with information about their causal relation. Arguably, applying causal relations to observed co-occurrences requires even more active mental operations than transitive inferences in AB/BC-AC learning. Thus, the current study highlights a critical role of sleep in supporting adaptive judgment and behavior.

Although declarative memory and retrieval processes play a central role in evaluative learning (De Houwer, 2018; Gast, 2018; Richter et al., 2021), the exact role of evaluative memory remains contentious. The current findings provide novel evidence on how declarative memories contribute to adaptive evaluative learning. Specifically, sleep supported precise memories for the specific US a given CS had been paired with rather than general memories merely capturing the valence of the US. Although general valence memory would be sufficient to guide binary evaluative responses (e.g., positive vs. negative; Stahl et al., 2009), precise memory for specific outcomes (e.g., an unwanted side effect being a skin rash rather than tooth decay) seems more valuable in guiding adaptive behavior. In the current study, sleep consolidated memories for specific USs which, by extension, led to improved joint memories for US identities and CS–US relations. More importantly, sleep also promoted the impact of CS–US relations on spontaneous evaluations. Because adaptive evaluation depends on the complete retrieval of evaluative memories (e.g., complete retrieval of *A prevents negative outcome B* instead of the mere co-occurrence of *A* and *B*), improved specific memories should support adaptive behavior, as reflected in the obtained effect of sleep on choice decisions.

Expanding on the current finding that sleep supports evaluative learning via memory consolidation, an interesting question for future research concerns the specific mechanisms underlying this phenomenon (see Klinzing et al., 2019; Landmann et al., 2014; Lerner & Gluck, 2019; Schlichting & Preston, 2015). On one hand, it is possible that sleep supports the integration of distinct memory components into coherent knowledge structures that include information on specific stimuli and their causal relation (e.g., integrated memory of *A prevents B*). On the other hand, it is possible that sleep supports the consolidation of individual memory components, and thus their subsequent retrieval and recombination (e.g., retrieval and recombination of *A-B* and *A-prevents*). The current findings are consistent with either of these possibilities. Future research, ideally using physiological measures such as EEGs/fMRI, may help to gain deeper insights into the mechanisms by which memory consolidation during sleep supports adaptive evaluation.

Limitations of the present study should be noted. First, participants in the sleep condition slept at home and reported sleep length/quality on the next morning. Although at-home sleep has arguably high ecological validity, it can be suboptimal because it does not permit control over participants' bedtime and objective measurements of sleep quality (e.g., sleep onset/efficiency). Second, one inherent limitation of the sleep vs. wake design is that performance changes are influenced by circadian factors such as time-of-day effects, fatigue/sleepiness, and different degrees of proactive/retroactive interference. Although we were able to address some of these concerns via additional analyses and control measures (e.g., chronotype, Time 1 memory, alertness, see Supplemental Online Materials), future research would benefit from direct memory manipulations during sleep (e.g., Rasch et al., 2007; Rudoy et al., 2009).

In sum, the current research makes a unique contribution to two fields that have largely developed in parallel:

evaluative learning and sleep-based memory consolidation (see also Richter et al., 2021). Our findings offer novel evidence that sleep supports adaptive evaluative learning via offline memory consolidation. These findings require further refinements of extant theories that emphasize the significance of online encoding and retrieval processes in evaluative learning. Specifically, our findings suggest that offline memory consolidation processes influence evaluative learning beyond the processes identified by extant theories. Given that likes and dislikes play a dominant role in guiding judgments and decisions, sleep bears promise in promoting adaptive behavior.

Acknowledgments

The authors thank Alison Preston for helpful comments on this work.

Authors' Note

Preregistration, data, and materials are publicly available via OSF at https://osf.io/9rsjg/. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the funding agencies.

Author Contributions

X.H. and B.G. developed the study concept and designed the study; R.J. collected data; R. J. and T.X. performed the data analyses under the supervision of X. H.; R.J., X.H., and T.X. drafted the manuscript; and B.G. provided critical revisions. All authors approved the final version of the manuscript.

Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The author(s) disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: The reported research was supported by the National Natural Science Foundation of China (Number 31922089) and General Research Fund (Number 17601318) of Hong Kong Research Grants Council to Xiaoqing Hu, and by National Science Foundation Grant Number 1649900 to Bertram Gawronski.

ORCID iDs

Bertram Gawronski https://orcid.org/0000-0001-7938-3339
Xiaoqing Hu https://orcid.org/0000-0001-8112-9700

Supplemental Material

The supplemental material is available in the online version of the article.

Notes

1. Note that the key assignment in the study differed from the one in our preregistration, which stated that no = *A* and yes = *K*.
2. Addressing a comment by an anonymous reviewer, we also conducted exploratory analyses to test whether the effect of Time is significantly different across the two conditions. Toward this end, we calculated the difference between the ΔG^2 values for the effect of Time in the sleep condition and the wake condition, which provides a ΔG^2 value for the difference in the effect of Time across conditions. Using this approach, we obtained a marginal difference in the effect of Time across conditions, $\Delta G^2 = 2.81$, $p = .094$, indicating that the magnitude of increases in *R* scores from Time 1 to Time 2 tended to be larger in the sleep than in the wake condition.

References

Alger, S. E., & Payne, J. D. (2016). The differential effects of emotional salience on direct associative and relational memory during a nap. *Cognitive, Affective, & Behavioral Neuroscience*, *16*, 1150–1163.

Bodenhausen, G. V. (1990). Stereotypes as judgmental heuristics: Evidence of circadian variations in discrimination. *Psychological Science*, *1*, 319–322.

Buysse, D. J., Reynolds, C. F., Monk, T. H., Berman, S. R., & Kupfer, D. J. (1989). The Pittsburgh Sleep Quality Index: A new instrument for psychiatric practice and research. *Psychiatry Research*, *28*, 193–213.

Corneille, O., & Stahl, C. (2019). Associative attitude learning: A closer look at evidence and how it relates to attitude model. *Personality and Social Psychology Review*, *23*, 161–189.

De Houwer, J. (2009). The propositional approach to associative learning as an alternative for association formation models. *Learning & Behavior*, *37*, 1–20.

De Houwer, J. (2018). Propositional models of evaluative conditioning. *Social Psychological Bulletin*, *13*(3), Article e28046.

De Houwer, J., Van Dessel, P., & Moran, T. (2020). Attitudes beyond associations: On the role of propositional representations in stimulus evaluation. *Advances in Experimental Social Psychology*, *61*, 127–183.

Diekelman, S., & Born, J. (2010). The memory function of sleep. *Nature Reviews Neuroscience*, *11*, 114–126.

Ellenbogen, J. M., Hu, P. T., Payne, J. D., Titone, D., & Walker, M. P. (2007). Human relational memory requires time and sleep. *Proceedings of the National Academy of Sciences of the United States of America*, *104*, 7723–7728.

Faul, F., Erdfelder, E., Lang, A. G., & Buchner, A. (2007). G*Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods*, *39*, 175–191.

Gast, A. (2018). A declarative memory model of evaluative conditioning. *Social Psychological Bulletin*, *13*(3), Article e28590.

Gawronski, B. (2021). Attitudinal effects of stimulus co-occurrence and stimulus relations: Paradoxical effects of cognitive load. *Personality and Social Psychology Bulletin*. Advance online publication. https://doi.org/10.1177/014616722110443 22

Gawronski, B., & Bodenhausen, G. V. (2018). Evaluative conditioning from the perspective of the associative-propositional evaluation model. *Social Psychological Bulletin*, *13*(3), Article e28024.

Gawronski, B., & Brannon, S. M. (2021). Attitudinal effects of stimulus co-occurrence and stimulus relations: Range and limits of intentional control. *Personality and Social Psychology Bulletin*, *47*, 1654–1667.

Heycke, T., & Gawronski, B. (2020). Co-occurrence and relational information in evaluative learning: A multinomial modeling approach. *Journal of Experimental Psychology: General*, *149*, 104–124.

Hu, X., Cheng, L. Y., Chiu, M. H., & Paller, K. A. (2020). Promoting memory consolidation during sleep: A meta-analysis of targeted memory reactivation. *Psychological Bulletin*, *146*, 218–244.

Hu, X., Gawronski, B., & Balas, R. (2017). Propositional versus dual-process accounts of evaluative conditioning: I. The effects of co-occurrence and relational information on implicit and explicit evaluations. *Personality and Social Psychology Bulletin*, *43*, 17–32.

Huguet, M., Payne, J. D., Kim, S. Y., & Alger, S. E. (2019). Overnight sleep benefits both neutral and negative direct associative and relational memory. *Cognitive, Affective, & Behavioral Neuroscience*, *19*, 1391–1403.

Klinzing, J. G., Niethard, N., & Born, J. (2019). Mechanisms of systems memory consolidation during sleep. *Nature Neuroscience*, *22*, 1598–1610.

Kukken, N., Hütter, M., & Holland, R. (2020). Are there two independent evaluative conditioning effects in relational paradigms? Dissociating effects of CS-US pairings and their meaning. *Cognition and Emotion*, *34*, 170–187.

Kurdi, B., & Dunham, Y. (2020). Propositional accounts of implicit evaluation: Taking stock and looking ahead. *Social Cognition*, *38*, s42–s67.

Landmann, N., Kuhn, M., Piosczyk, H., Feige, B., Baglioni, C., & Nissen, C. (2014). The reorganization of memory during sleep. *Sleep Medicine Reviews*, *18*, 531–541.

Lerner, I., & Gluck, M. A. (2019). Sleep and the extraction of hidden regularities: A systematic review and the importance of temporal rules. *Sleep Medicine Reviews*, *47*, 39–50.

Lupo, A. K., & Zárate, M. A. (2019). Guilty by association: Time-dependent memory consolidation facilitates the generalization of negative–but not positive–person memories to group and self-judgments. *Journal of Experimental Social Psychology*, *83*, 78–87.

Moran, T., & Bar-Anan, Y. (2013). The effect of object–valence relations on automatic evaluation. *Cognition and Emotion*, *27*, 743–752.

Morin, C. M., Belleville, G., Bélanger, L., & Ivers, H. (2011). The Insomnia Severity Index: Psychometric indicators to detect insomnia cases and evaluate treatment response. *Sleep*, *34*, 601–608.

Moshagen, M. (2010). multiTree: A computer program for the analysis of multinomial processing tree models. *Behavioral Research Methods*, *42*, 42–54.

Rasch, B., & Born, J. (2013). About sleep's role in memory. *Physiological Reviews*, *93*, 681–766.

Rasch, B., Büchel, C., Gais, S., & Born, J. (2007). Odor cues during slow-wave sleep prompt declarative memory consolidation. *Science*, *315*, 1426–1429.

Richter, J., Seffen, A., Benedict, T., & Gast, A. (2021). No evidence of consolidation of evaluative conditioning during waking rest and sleep. *Cognition and Emotion*, *35*, 844–858.

Rudoy, J. D., Voss, J. L., Westerberg, C. E., & Paller, K. A. (2009). Strengthening individual memories by reactivating them during sleep. *Science*, *326*, 1079–1079.

Schlichting, M. L., & Preston, A. R. (2015). Memory integration: Neural mechanisms and implications for behavior. *Current Opinion in Behavioral Sciences*, *1*, 1–8.

Stahl, C., Unkelbach, C., & Corneille, O. (2009). On the respective contributions of awareness of unconditioned stimulus valence and unconditioned stimulus identity in attitude formation through evaluative conditioning. *Journal of Personality and Social Psychology*, *97*, 404–420.

Stickgold, R. (2005). Sleep-dependent memory consolidation. *Nature*, *437*, 1272–1278.

Stickgold, R., & Walker, M. P. (2013). Sleep-dependent memory triage: Evolving generalization through selective processing. *Nature Neuroscience*, *16*, 139–139.

Wagner, U., Gais, S., Haider, H., Verleger, R., & Born, J. (2004). Sleep inspires insight. *Nature*, *427*, 352–355.

Author Biographies

Rui Jin is an M.Phil. student at Department of Psychology, The University of Hong Kong. She is interested in sleep and social cognition.

Tao Xia is a PhD student at Department of Psychology, The University of Hong Kong. He is interested in sleep and memory.

Bertram Gawronski is a professor at Department of Psychology, The University of Texas at Austin. He is interested in evaluative learning and social cognition.

Xiaoqing Hu is an assistant professor at Department of Psychology, and a principal investigator at The State Key Laboratory of Brain and Cognitive Sciences, The University of Hong Kong. He is interested in sleep, memory dynamics, and social cognition.

Handling Editor: Eva Walther