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RESEARCH ARTICLE

Laugh yourself to sleep: memory consolidation for humorous information

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Abstract There is extensive evidence that emotional information is better remembered than neutral information across long delays, especially if the delay interval contains an opportunity for sleep. However, as prior studies have focused on memory for negative stimuli, it is unclear whether positive memories benefit from time and sleep as well. To investigate the consolidation of positive memories, the current study examined differences in memory for humorous and non-humorous cartoons. While prior evidence demonstrates that humorous information is preferentially remembered relative to non-humorous information over brief delays, it is unknown whether this benefit lasts across longer delay intervals or whether sleep is important for lasting humor memories to form. Thus, we tested memory for 27 cartoons across 12-h delay periods containing either sleep or wakefulness. Results indicate that humor's enhancing effect on recall memory is robust across a 12-h delay and that a period of sleep facilitates this effect over wakefulness when cartoons are novel to participants and ranked based on subjective emotional ratings. Further, in accordance with previous studies that reveal diminished emotional reactivity to stimuli following sleep, in a supplemental experiment, we found that sleep reduced subjective ratings of humor, arousal, and positivity of humorous cartoons. These findings provide preliminary evidence that sleep's impact on negative emotional memory consolidation and emotional reactivity can be extended to positive stimuli as well.

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Introduction

Emotion has consistently been shown to improve subsequent memory. Many studies have shown memory improvements for emotionally negative compared to neutral material (see Levine and Edelstein 2009 for a review), and this enhancement can be particularly pronounced across lengthy (≥12 h) consolidation delays (Kleinsmith and Kaplan 1963; Sharot and Yonelinas 2008; Walker and Tarte 1963). Several studies suggest that the key to delayed emotional memory enhancement is whether the delay interval contains an opportunity for sleep (Payne et al. 2008; Hu et al. 2006; Wagner et al. 2001; Kaestner et al. 2013). One problem with such studies, however, is the lack of information they provide about how sleep affects memory for positively valenced information. The aforementioned studies either compared memory for neutral to negative material only (e.g., Payne et al. 2008, 2012; Wagner et al. 2001) or collapsed positive and negative material into a general "emotional" category based on the common characteristic of arousal (e.g., Hu et al. 2006). While such investigations have been important in advancing scientific knowledge about sleep's contribution to emotional memory consolidation, they have left a considerable gap in the literature, as virtually nothing is known about how sleep influences memory for positive information.

Currently, the majority of data on memory for positive information is found within the non-sleep literature, and the results are mixed. For instance, some researchers have found that memory for negative pictures is better than memory for positive or neutral pictures, even when arousal

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is controlled (e.g., Ochsner 2000). Negative materials are also better retrieved when people are distracted during encoding and consolidation (Kern et al. 2005). However, a separate group of studies suggest the opposite, finding evidence for selective memory enhancement for positive information, a phenomenon deemed the Pollyanna Principle (e.g., Boucher and Osgood 1969).

Consistent with this principle, Lang et al. (1995) found that people remembered positive video clips better than negative video clips. Participants watched 12 short video segments of comedies, dramas, news broadcasts, and soap operas that included both positive and negative subject matter balanced for both high and low arousal. Memory was superior for positive clips relative to negative clips. Another study (McCabe 1999) compared individuals with high or low sensitivity to physical manifestations of anxiety. They found that those with low sensitivity to anxiety recalled more positive words than either neutral or anxiety-related words.

More recent studies also find evidence for the Pollyanna Principle, although the term is rarely used in the present literature. For example, Libkumen et al. (2004) found that memory is better for positive as opposed to negative pictures. By distracting participants, which prevented them from rehearsing the material just viewed, they found that memory was hindered for negative, but not positive pictures, and this was independent of arousal. This result stands in stark contrast, however, to the previously mentioned distraction studies (Kern et al. 2005). Clearly, not only have varying methods produced conflicting results, but very similar methods have also yielded divergent conclusions.

Although not typically included under the umbrella of emotional memory research (although see Lang et al. 1995), a separate literature sheds light on the question of positivity and memory by examining memory for humorous materials. Like other forms of emotional stimuli, humorous information is consistently better remembered than non-humorous information. This "humor effect" on memory (Schmidt 2002) has been found with cartoons (Schmidt and Williams 2001; Schmidt 2002; Takahashi and Inoue 2009) and sentences (Schmidt 1994) and has been studied extensively in advertising research (Hansen et al. 2009). For instance, Schmidt and Williams (2001) used three versions of 24 cartoons from Larson's the *Far Side* (1985, 1987, 1988) to investigate how humor impacts memory. Memory for original cartoons (those designed by the creator) was compared to two control versions of the cartoons—a literal version that removed the humorous aspect of the image and replaced it with an element congruent with the caption, and a weird version that also removed the humor, but replaced it with incongruent information that could not be interpreted and thus not perceived as humorous (Schmidt and Williams 2001). This last set of stimuli controlled for the possibility that humor's positive impact on memory was simply the result of the incongruence between the caption and image, as the resolution of this unexpected incompatibility is what commonly accompanies the humor associated with such cartoons as well as the punch lines of jokes and comedy performances. Participants viewed lists of these stimuli that included either all three versions or only two of the versions, and then performed an incidental free recall test. The original, humorous cartoons were remembered better than both the literal and weird cartoons, which did not differ from each other with respect to memory. Thus, humor specifically appears to enhance memory and not simply because of incongruity resolution thought to be needed to perceive the humor.

The humor effect has been replicated using similar methods (Schmidt 2002) and has also found support with different methodology. For instance, humor has been shown to enhance memory for cartoons known as "droodles," with participants in a high-humor group recalling significantly more "droodles" than those in a low- or no-humor group. Therefore, various methodologies reveal a reliable memory enhancement of humorous cartoons (Takahashi and Inoue 2009). Moreover, humor has also resulted in superior memory for sentences, whether recall is free or cued, encoding is incidental or intentional, and even if participants are warned of the humorous nature of the sentences before encoding (Schmidt 1994). Thus, humor appears to be a consistent and robust memory aid.

There is also evidence that humor is associated with positive affect and liking, as well as with physiological reactivity. For instance, commercials, teachers, educational programs, and texts are commonly rated more positively if they incorporate humor into their messages than those that do not (see Weinberger and Gulas 1992 for a review), and humor has been successfully used to induce positive effect by having participants view humorous movies to improve their mood (Buchanan et al. 1999). Moreover, the physiological effects of viewing humorous stimuli are similar to physiological effects of viewing other types of positive stimuli, which tend to increase sweat production, heart rate, and amygdala activation (Hamann 2001; Hamann et al. 2002; Greenwald et al. 1989; Moran et al. 2004). As a specific example, Buchanan et al. (1999) found that while a stressful speech increased both positive and negative affect and increased cortisol secretion, a video with humorous storylines increased positive affect, decreased negative affect, and significantly lowered cortisol levels from baseline. Moreover, in a functional magnetic resonance imaging study, Moran et al. (2004) found that the act of understanding humor was associated with activations in both the left posterior middle temporal gyrus and left inferior frontal gyrus, while the act of responding to humor (i.e., laughing) was associated with activations in both the insular cortex and amygdala. These results are most important in that amygdala activation is closely associated with emotional memory processes (Hamann 2001; Hamann et al. 2002; Kensinger 2004; Steinmetz et al. 2010). Together, these findings suggest that even though humorous stimuli are used less frequently in emotional memory research, they are behaviorally and physiologically similar to other forms of positive arousing memory stimuli (e.g., to the IAPS pictures, Lang et al. 2008).

Of the few studies of humor and memory to date (Schmidt 1994, 2002; Schmidt and Williams 2001; Takahashi and Inoue 2009), all have employed brief delay intervals between encoding and recall/recognition. For example, Schmidt and Williams (2001) tested their participants after only a 10-min delay, while Takahashi and Inoue (2009) tested their participants immediately after encoding. Yet, important information about positive memory consolidation can be gleaned by examining humor's impact on memory following longer delays. Several studies found that memory enhancements for negative relative to neutral materials are exaggerated after longer delays (≥24 h) compared to shorter delays (≤30 min), suggesting a role for time-dependent consolidation processes (Sharot and Yonelinas 2008), including those that occur during sleep (Payne et al. 2008). Given these findings for negative information, we reasoned that the humor effect on memory might likewise be amplified across longer consolidation delays.

The goal of Experiment 1 was twofold. The first goal was to investigate the role of humor in positive memory formation across longer-term delays (i.e., 12 h) than those studied previously. The second was to test whether sleep would influence the retention of humorous information, perhaps leading to an enhancement of the humor effect over an equal delay spent awake.

We also had a secondary aim, addressed in a supplemental experiment, which was to probe whether there were changes in affective reactivity to humorous stimuli across the different delay intervals (sleep vs. wake). A recent debate in the sleep and emotion literature focuses on whether sleep changes affective responding to emotional stimuli in a manner different from wakefulness. Emotional ratings (i.e., valence, arousal) of stimuli collected prior to and following a delay filled with sleep or wakefulness have been compared. Some studies show that sleep maintains affective responding across this delay while wake reduces them (Baran et al. 2012), but others have shown that sleep attenuates affective responding while wakefulness intensifies it (van der Helm et al. 2011). To help shed light on the question of sleep's role in emotional reactivity, and to extend it to an examination of sleep's impact on affective responding to positive information, we thus conducted a preliminary investigation of how perceived cartoon arousal, humorousness, and valence changed from time 1 (encoding) to time 2 (retrieval) across sleep and wake in a subset of our subjects.

Experiment 1

Methods

Participants

Participants in the experimental groups were 79 Notre Dame students who completed the study for course credit or payment. The sample had a mean age of 19.95 ± 1.33 years and was 65 % female. Informed consent was obtained in a manner approved by the University of Notre Dame Institutional Review Board. Nine participants were excluded from the study due to failure to comply with study requirements, four in the wake group because they failed to return for the second session, two from the wake group because they napped between sessions, and three in the sleep group because they obtained <6 h of sleep between sessions. This left a total of 70 participants who were included in the subsequent analyses (Wake group, $n = 33$; Sleep group, $n = 37$). Participants in the wake and sleep groups did not differ on their scores on the Beck Depression Inventory (BDI; Beck et al. 1996), State-Trait Anxiety Inventory (STAI-X2; Hedberg et al. 1972), or Pittsburgh Sleep Quality Index (PSQI; Buysse et al. 1989) nor did they differ in the amount of sleep obtained the night prior to completing the experiment (see Table 1). A further 25 Notre Dame students served as circadian control participants who were tested following a brief delay either in the morning

Table 1 Demographic measures for the sleep, wake, AM control, and PM control groups

Demographic measures						
Groups	*N*	Female (%)	BDI	STAI	PSQI	Hours slept prior to experiment
Wake	33	73	5.76 ± 4.60	37.55 ± 8.68	5.45 ± 3.25	6.73 ± 1.74
Sleep	37	60	4.49 ± 5.08	38.00 ± 9.38	4.84 ± 2.59	7.45 ± 1.73
AM control	12	50	5.00 ± 6.09	40.75 ± 7.45	5.92 ± 2.07	6.33 ± 1.32
PM control	13	62	3.85 ± 4.00	35.54 ± 6.96	5.00 ± 2.04	7.04 ± 1.16

($n = 12$) or evening ($n = 13$). This sample had a mean age of 19.28 ± 1.14 years and was 56 % female. Control participants did not differ on BDI scores, STAI scores, PSQI scores, or amount of sleep prior to beginning the experiment (Table 1).

Materials

Encoding materials Encoding materials were 27 single-panel comic cartoons created by Larson (1985, 1987, 1988). Images were obtained from Schmidt and Williams (2001) and the internet. They were black-and-white and included a caption at the bottom of the cartoon. To vary the humor associated with the cartoons, nine of the cartoons appeared in their original humorous version (Original), nine had altered images so that they were literal, non-humorous translations of the captions (Literal), and nine were altered so that their images were incompatible with the caption (Weird). Previous research counterbalanced the use of original, literal, and weird versions of the same cartoon panel among participants to control for the memorability of a particular cartoon, but found this control to be unnecessary (Schmidt and Williams 2001; Schmidt 2002). Therefore, we presented one list of cartoons to all participants regardless of group assignment, with a particular cartoon appearing only once in either its original, literal or weird cartoon version. To determine which cartoons would appear in their original version, and in order to maximize the effect of humor, 23 separate Notre Dame students rated the original versions of the 27 cartoons on a 1–5 scale of humorousness (1 = not funny, 5 = very funny), and the nine most humorous cartoons were chosen to comprise the original, humorous category of cartoons in the study list. The remaining 18 cartoons were randomly assigned to either the literal or weird category. These cartoons were presented in the main study in one of two lists, each of which contained the same cartoons, but in a different randomized order to control for possible order effects on memory. Each list was created by pseudo-randomizing the nine humorous, nine literal, and nine weird versions of the cartoons, such that no more than two cartoons of a particular version were repeated in succession.

Design

All sessions took place between 8:30 and 9:30 a.m./p.m., depending on experimental condition. Those in the wake group arrived between 8:30 and 9:30 a.m. for session one (encoding) and returned approximately 12 h later for session two (retrieval) after a period of wake (no naps allowed, as verified by sleep logs) during the day. Those in the sleep group arrived between 8:30 and 9:30 p.m. for session one (encoding) and returned approximately 12 h later for session two (retrieval) after a night of sleep [they had to get at least 6 h of sleep to be included in data analyses, as verified by sleep logs, though they actually slept approximately 7 h on average ($M = 6.91 \pm .86$)]. The circadian control groups completed the first session tasks at either 9:30 a.m. or p.m. and then completed the second session tasks after a 15-min delay.

Procedure

During session one, participants were greeted and taken to an assigned computer workstation. After providing informed consent, they were given an initial questionnaire packet, which included the demographics questionnaire with a 3-day sleep log, STAI-X2, PSQI, and BDI. They were then given instructions for the encoding task, which were provided on the computer screen and orally by the experimenter, and completed a brief practice session with the experimenter nearby to answer any questions. After insuring compliance with the instructions, participants were left alone to complete the task, in which they viewed all 27 of the cartoons one at a time for 15 s each. At the end of the 15 s given to view each cartoon, participants were prompted to make ratings of each cartoon using a 1–5 scale, including ratings on humor (1 = not funny, 5 = very funny), valence (1 = positive, 3 = neutral, 5 = negative), arousal (1 = low, 5 = high), and familiarity or confidence that they had seen the cartoon prior to the study (1 = not seen before, 3 = maybe seen before, 5 = seen before). Following completion of the task, participants were thanked and reminded to return for their second session.[1]

During the second session, participants were handed a blank recall form and informed that they were about to complete a surprise memory test. The recall test consisted of several steps to maximize the content recalled. Participants were first asked to give a brief description of each cartoon so that someone reading it could identify the cartoon, using a new page for each cartoon they recalled (Schmidt and Williams 2001). They were then reminded that there were 27 cartoons total and were asked to go back through their brief descriptions and recall as many details as they could about the cartoons they had recorded. They were told that no detail was too small. They were also asked to recall the caption associated with each cartoon as close to word-for-word as possible. Once finished with this task, they were debriefed, compensated, and allowed to leave the laboratory.

[1] Those in the AM and PM control groups completed all tasks during just one session due to the brief delay between encoding and retrieval for these groups (i.e., 15 min). Instead of leaving the laboratory, those in the two control groups were asked to complete the questionnaire packet during this delay, which took place after the encoding task instead of before it.

Data analysis

Due to the popularity of the *Far Side* (Larson 1985, 1987, 1988) cartoons, as indicated in a pilot study, we were concerned that prior exposure to the cartoons might influence our memory results. For this reason, we collected information on participants' familiarity with the cartoons (see section "Procedure" above). As part of our investigation, and to fully explore the influence of humor on memory, we planned to analyze our memory data in two ways. We first examined memory performance in all subjects, regardless of familiarity ratings, and second, we utilized the familiarity ratings collected at encoding to restrict our sample to only those participants (54 %) who had never seen the cartoons before, which allowed us to achieve a pure measure of memory unbiased by familiarity or prior exposure to the images.

Moreover, to account for individual differences in humor perception, we scored the data based not only on the predetermined cartoon categories (i.e., humorous, literal, and weird, as determined by Schmidt and Williams 2001), but also based on the humor rankings provided by our own participants. On this basis, we created a new group of nine humorous cartoons determined by participants in the current study. The remaining 18 cartoons were grouped into a single, non-humorous (neutral) category[2] for this analysis.

For statistical comparisons, one-way and mixed ANOVAs were used to investigate the impact of sleep and cartoon type on memory performance. Further, a priori contrasts were utilized to further examine significant main effects and interactions.[3]

Results

Inter-rater reliability

One researcher, blind to experimental condition, scored the cartoons recalled by all participants, while a second researcher, also blind to experimental condition, scored each of the cartoons recalled by a random subset of the participants (25 %) to determine inter-rater reliability. The researchers scored a cartoon as "recalled" if the participant included enough information in their overall written description of the cartoon so as to distinguish it from the other cartoons in the set, similar to criteria used in previous studies (e.g., Schmidt and Williams 2001). Of this subset scored by both researchers, agreement on the recall of cartoons was 96.6 %, indicating adequate inter-rater reliability.

Confirmation of humor as a positive, arousing stimulus

We first investigated whether participants subjectively experienced the humorous cartoons as both positive and arousing. Ratings of valence, arousal, and humor for the three cartoon types were investigated using one-way ANOVAs. For valence ratings, there was a significant difference among the ratings for the humorous ($M = 2.53 \pm .66$), literal ($M = 3.01 \pm .52$), and weird ($M = 2.85 \pm .47$) cartoons, $F_{(2, 209)} = 13.21$, $p < .001$. As expected, humorous cartoons were rated as significantly more positive than both literal, $t(207) = -5.06$, $p < .001$, and weird cartoons, $t(207) = -3.31$, $p = .001$. There was also a significant difference in arousal ratings for humorous ($M = 2.63 \pm .85$), literal ($M = 1.69 \pm .55$), and weird ($M = 1.72 \pm .57$) cartoons, $F_{(2,209)} = 44.25$, $p < .001$. Individual contrasts revealed that the humorous cartoons were rated as significantly more arousing than both literal, $t(207) = 8.26$, $p < .001$, and weird cartoons, $t(207) = 8.03$, $p < .001$. Finally, there was a significant difference among humor ratings of humorous ($M = 3.22 \pm .79$), literal ($M = 1.89 \pm .66$), and weird ($M = 2.00 \pm .64$) cartoons, $F_{(2,209)} = 77.51$, $p < .001$, with humorous cartoons being rated as significantly more humorous than the literal cartoons, $t(207) = 11.21$, $p < .001$, and the weird cartoons, $t(207) = 10.30$, $p < .001$. These results confirm that participants experienced the humorous cartoons as positive, arousing, and funny.

Short-term effects of humor on memory: no circadian effects

To examine whether we could directly replicate the humor effect on memory following a short (15 min) delay, and also to test for circadian effects on memory, the number of each type of cartoon recalled in the control groups was totaled and entered into a 2 (Control group: AM, PM) by 3 (Cartoon type: Humorous, Literal, Weird) mixed ANOVA. As expected, there was a significant main effect of cartoon type, $F_{(2,22)} = 5.46$, $p = .01$. Individual contrasts revealed that humorous cartoons ($M = 4.40 \pm 0.87$) were remembered significantly better than both literal ($M = 3.40 \pm 1.80$), $F_{(1,23)} = 6.73$, $p = .02$, and weird

[2] This latter category consisted of twice as many cartoons because we had no way to logically split the cartoons based on subjective ratings of humor into categories that would have been equivalent to the previously used literal and weird categories. Thus, there is only a humorous and a non-humorous (referred to as "neutral") category for the respective analyses, with proportions of recall reported for each category.

[3] Because all contrasts were a priori, we did not apply multiple comparison corrections (see Maxwell and Delaney 2004); however, such corrections would not have significantly impacted the outcome of our memory results. For example, our significant memory finding of $p < .001$ under *A Role for Sleep in Memory for Humor?* would still fall below the adjusted p value of .0125 if the multiple comparison correction had been applied.

Table 2 Humor, arousal, and valence scores for cartoons ranked by subjective ratings of humor and arousal

Cartoon type								
Ratings	Humorous		Non-humorous		Arousing		Non-arousing	
	M	SD	*M*	SD	*M*	SD	*M*	SD
Humor	3.46	0.74	1.66***	0.56	3.38	0.77	1.70***	0.55
Arousal	2.70	0.84	1.51***	0.51	2.86	0.88	1.44***	0.49
Valence	2.45	0.68	2.97***	0.46	2.47	0.68	2.96***	0.46

*** $p \leq .001$

cartoons ($M = 3.24 \pm 1.59$), $F_{(1,23)} = 8.81$, $p = .007$, but there was no difference between the recall of literal and weird cartoons, $F_{(1,23)} = .085$, $p = .77$, thus replicating the humor effect on memory following a brief delay (Schmidt and Williams 2001). Importantly, comparing memory performance between the AM and PM control groups revealed that there were no circadian effects on recall, as the main effect of group and the interaction between group and cartoon type did not reach significance ($F_{(1,23)} = .30$, $p = .59$; $F_{(2,22)} = 1.80$, $p = .19$, respectively). The AM and PM groups were thus collapsed for subsequent analysis.

Long-term effects of humor on memory

We next attempted to extend the findings of Schmidt and Williams (2001) by examining whether the humor effect on memory would persist across a longer delay, with humorous cartoons being preferentially remembered 12-h post-encoding (regardless of group assignment). As expected, a one-way ANOVA revealed a significant main effect of cartoon type, $F_{(2,209)} = 7.64$, $p = .001$. As anticipated, humorous cartoons ($M = 3.21 \pm 1.44$) were remembered significantly better than literal cartoons ($M = 2.63 \pm 1.71$), $t(207) = 2.22$, $p = .028$, and weird cartoons ($M = 2.18 \pm 1.52$), $t(207) = 3.90$, $p < .001$. There was no difference between literal and weird cartoons, $t(207) = 1.68$, $p = .095$.

A role for sleep in memory for humor?

To investigate differences between a period of sleep versus a period of wakefulness on memory for the predetermined cartoon categories (Schmidt and Williams 2001), we first conducted a 2 (Sleep Condition: Sleep, Wake) by 3 (Cartoon type: Humorous, Literal, Weird) mixed ANOVA with cartoon type as the repeated measure, which revealed no main effect of group, $F_{(1,68)} = .75$, $p = .39$, and no interaction between group and cartoon type, $F_{(2,67)} = 1.47$, $p = .24$.

We next examined memory performance in the subsample of participants who had never seen the cartoons before (see section "Data analysis" above). However, even when comparing only those individuals in the sleep ($n = 15$) and wake ($n = 15$) groups who indicated at session one that they had never seen the cartoons before, the 2 (Group: Sleep, Wake) by 3 (Cartoon type: Humorous, Literal, Weird) mixed ANOVA showed no evidence of a group main effect, $F_{(1,28)} = .01$, $p = .91$, or interaction $F_{(2,27)} = .72$, $p = .50$, although there was a significant cartoon type main effect, $F_{(2,27)} = 12.22$, $p < .001$, with humorous cartoons ($M = 2.93 \pm 1.46$) remembered better than both literal ($M = 2.27 \pm 1.51$), $F_{(1,28)} = 5.00$, $p = .03$, and weird cartoons ($M = 1.60 \pm 1.19$), $F_{(1,28)} = 24.67$, $p < .001$.

Since humor evaluation is a subjective construct, we subsequently reexamined the memory data based on the participants' individual ratings of humor, again within those subjects who were unfamiliar with the cartoons. Following this new organization, humorous cartoons were again perceived as more humorous, $t(29) = 22.32$, $p < .001$, arousing, $t(29) = 11.27$, $p < .001$, and positive, $t(29) = -4.69$, $p < .001$, than non-humorous cartoons (Table 2). Importantly, the 2 (Group: Sleep, Wake) by 2 (Cartoon type: Humorous, Non-humorous) mixed ANOVA did reveal evidence for the sleep effect. While there was no main effect of group $F_{(1,28)} = .19$, $p = .67$, there was a main effect of cartoon type, $F_{(1,28)} = 12.96$, $p = .001$, demonstrating that humorous cartoons ($M = .31 \pm .17$) were again remembered better than non-humorous ones ($M = .22 \pm .12$). This main effect was qualified by a group by cartoon type interaction $F_{(1,28)} = 4.96$, $p = .03$ (Fig. 1a). Although there was no difference between the sleep and wake groups for memory of humorous, $t(28) = -1.23$, $p > .20$, or non-humorous cartoons, $t(28) = .75$, $p > .45$, there was evidence for the humor effect on memory within the sleep group, but not the wake group. Individual comparisons indicated that memory for humorous cartoons ($M = .35 \pm .13$) was significantly better than memory for non-humorous cartoons ($M = .21 \pm .14$) in the sleep group, $t(14) = 6.48$, $p < .001$, while there was no difference between humorous ($M = .27 \pm .19$) and non-humorous ($M = .24 \pm .10$) cartoon memory in the wake group, $t(14) = .77$, $p > .45$. This finding suggests that the humor effect can persist across a 12-h delay, but only if sleep occurs during this interval. Importantly, this influence of sleep on memory for humorous information does not appear to be driven by general circadian factors, as the AM and PM control groups were

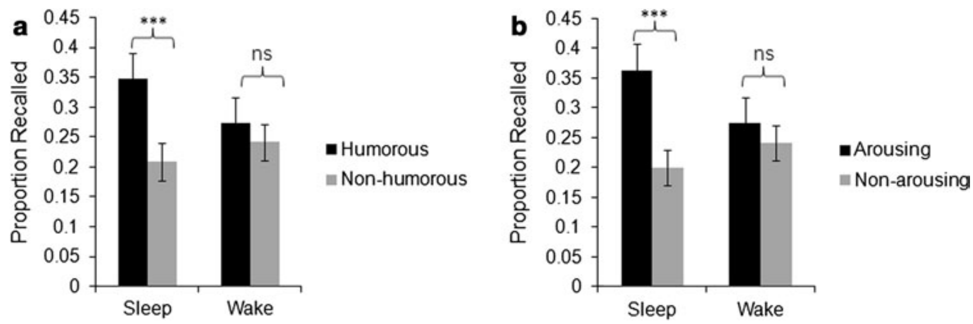

Fig. 1 After ranking cartoons based on humor ratings obtained during the first session (**a**), participants who were unfamiliar with the cartoons remembered significantly more humorous cartoons than non-humorous cartoons after a period of sleep, while there was no difference in memory for humorous and non-humorous cartoons after a period of wakefulness. Similarly, when cartoons were ranked based on arousal ratings obtained during the first session (**b**), arousing cartoons were remembered significantly better than non-arousing cartoons only in those who obtained a period of sleep during the delay, while those who remained awake remembered arousing and non-arousing cartoons similarly. (*Note* ***$p \leq .001$, *ns* not significant)

equivalent in their memory performance and there was no interaction between Control group and Cartoon type, $F_{(1,11)} = 2.25$, $p = .16$.

Given that sleep and emotional memory effects are often attributed to arousal (Hu et al. 2006), we also examined whether the sleep effect emerged when we ranked the cartoons based on participants' individual ratings of arousal (instead of humor). The arousing cartoon category was rated as more humorous $t(29) = 18.62$, $p < .001$, arousing, $t(29) = 13.04$, $p < .001$, and positive, $t(29) = -4.55$, $p < .001$, than the non-arousing category (Table 2). In the same manner that the data were analyzed when ranked for humor, proportions of the number of cartoons recalled within the top nine most arousing and 18 remaining non-arousing cartoons were calculated and subjected to a 2 (Group: Sleep, Wake) by 2 (Cartoon type: Arousing, Non-arousing) mixed ANOVA. The analysis again revealed a cartoon type main effect, $F_{(1,28)} = 16.74$, $p < .001$, with arousing cartoons ($M = .31 \pm .17$) remembered better than non-arousing ones ($M = .22 \pm .12$). Again, while the main effect of group was not significant ($F_{(1,28)} = .24$, $p = .63$), there was a significant interaction between group and cartoon type, $F_{(1,28)} = 7.30$, $p = .01$. Although there was no difference between the sleep and wake groups for memory of arousing, $t(28) = -1.42$, $p > .16$, or non-arousing cartoons, $t(28) = .97$, $p > .30$, there was evidence that memory for arousing cartoons ($M = .36 \pm .15$) was significantly better than memory for non-arousing cartoons ($M = .20 \pm .13$) in the sleep group, $t(14) = 6.13$, $p < .001$, while there was no difference between arousing ($M = .27 \pm .19$) and non-arousing ($M = .24 \pm .10$) cartoon memory in the wake group, $t(14) = .83$, $p > .40$ (Fig. 1b), a finding consistent with the idea that sleep benefits memory for arousing information (Hu et al. 2006; Payne et al. 2008). Notably, these results map onto the findings obtained when cartoons were ranked by humor, which may be related to the fact that humor and arousal ratings were highly correlated, both when cartoons were ranked by humor (Arousing $r = .75$, $p < .001$; Non-arousing $r = .77$, $p < .001$) and arousal (Arousing $r = .67$, $p < .001$; Non-arousing $r = .80$, $p < .001$). General circadian influences again did not influence memory performance, as the AM and PM control groups were equivalent in their memory performance, with no interaction between Control group and Cartoon type, $F_{(1,11)} = 1.86$, $p = .20$, which minimizes concerns about circadian influences.

Supplementary experiment 2

Methods

Participants

Participants consisted of a subsample of participants from experiment one ($N = 33$; Wake, $n = 15$; Sleep, $n = 18$) who performed an additional rating task at the completion of session two. This subsample had an average age of 19.82 years and was 58 % female. Participants did not differ on BDI, STAI, or PSQI scores prior to the experiment (all p's > .25). Hours slept prior to the experiment did not differ between the wake ($M = 6.87 \pm 1.00$) and sleep ($M = 7.46 \pm 1.48$) participants, $t(31) = -1.32$, $p > .19$. The AM and PM control subjects from Experiment 1 (all of whom rerated the cartoons during the second session) were additionally examined to rule out the impact of circadian factors on changes in emotional reactivity.

Materials

Participants completed the same questionnaires and encoded the same 27 cartoons used in experiment one.

Design and procedure

The design and procedure were the same as experiment one, except that once the recall forms were collected during session two, participants were asked to again rate the humor, arousal, and valence of all the previously seen cartoons, just as they did during the first session. Once finished with this task, they were debriefed, compensated, and allowed to leave the laboratory.

Data analysis

To investigate changes in emotional reactivity to the cartoons across the sleep versus wake delay intervals, we compared how perceived arousal, humorousness, and valence of the cartoons changed from time 1 (encoding) to time 2 (retrieval). After Baran et al. (2012), ratings from the first session were subtracted from the ratings obtained during the second session to create a change score for each cartoon type across the categories of arousal, humor, and valence, with positive scores reflecting increases, negative scores reflecting decreases, and a score of zero reflecting no change across the delay. Further, to simplify the interpretation of these results and to allow closer comparison with the methods of Baran et al. (2012), we combined change scores for the literal and weird cartoons into one "neutral," non-humorous group, because both stimulus types corresponded to the non-emotional group of stimuli used by Baran et al. (2012), based upon our ratings of arousal, valence, and humor. For the remainder of this section, we will refer to this combined category as the neutral cartoons.

For statistical comparisons, mixed ANOVAs were used to investigate effects of sleep on emotional rating changes. A priori t tests were used to further examine significant main effects and interactions.

Results

Changes in emotional reactivity

We first investigated whether there were baseline differences between the groups by examining humor, arousal, and valence ratings obtained during session one. There was no baseline difference between the groups in humor ratings for humorous cartoons (Sleep $M = 3.27 \pm .67$, Wake $M = 3.28 \pm .72$; $t(31) = .07$, $p = .95$) or neutral cartoons (Sleep $M = 1.87 \pm .54$, Wake $M = 1.98 \pm .49$; $t(31) = -.60$, $p = .56$). Likewise, there was no baseline difference between the groups on ratings of arousal for the humorous (Sleep $M = 2.50 \pm .78$, Wake $M = 2.80 \pm .83$; $t(31) = 1.07$, $p = .29$) or neutral cartoons (Sleep $M = 1.68 \pm .53$, Wake $M = 1.73 \pm .45$; $t(31) = .25$, $p = .80$) nor were there baseline differences between the groups on valence ratings for the humorous (Sleep $M = 2.36 \pm .57$, Wake $M = 2.67 \pm .65$; $t(31) = 1.49$, $p = .15$) or the neutral cartoons (Sleep $M = 2.93 \pm .43$, Wake $M = 2.87 \pm .28$; $t(31) = -.45$, $p = .66$).

Given the absence of baseline differences between groups, we next asked whether there were differences in the change scores across the sleep and wake delays using a 2 (Cartoon type: Humorous, Neutral) by 2 (Group: Sleep, Wake) mixed ANOVA for humor, arousal, and valence rating changes (Baran et al. 2012). First for humor ratings, the ANOVA revealed that there was a significant main effect of group, $F_{(1,31)} = 4.18$, $p = .049$ (Fig. 2a), with humor ratings increasing between time 1 and time 2 in the wake group ($M = .15$, SEM $= .11$), but *decreasing* between time 1 and time 2 in the sleep group ($M = -.17$, SEM $= .10$). There was also a significant cartoon type by sleep interaction, $F_{(1,31)} = 6.10$, $p = .019$, indicating that while humorous cartoons ($M = .19 \pm .47$) increased in humorousness similarly to neutral cartoons ($M = .11 \pm .56$) in the wake group, $t(14) = .83$, $p > .40$, humorous cartoons ($M = -.33 \pm .61$) decreased in humorousness more than neutral cartoons ($M = -.004 \pm .31$) in the sleep group, $t(17) = -2.57$, $p = .02$. Further, there was also a significant difference in the humor rating changes of humorous cartoons between the sleep and wake groups, $t(31) = 2.70$, $p = .01$, but this was not true for the neutral cartoons, $t(31) = .72$, $p = .48$ (Fig. 2a). The main effect of cartoon type was not significant, $F_{(1,31)} = 2.33$, $p = .14$.

Second, for arousal changes, there was a significant main effect of group, $F_{(1,31)} = 5.46$, $p = .026$ (Fig. 2b), indicating that arousal ratings increased between the two sessions for the wake group ($M = .21$, SEM $= .14$) but decreased between the two sessions for the sleep group ($M = -.24$, SEM $= .13$). However, here, there was additionally a significant main effect of cartoon type, $F_{(1,31)} = 4.48$, $p = .04$, with arousal ratings decreasing between the two sessions for humorous cartoons ($M = -.13 \pm .13$) but increasing for neutral cartoons ($M = .10 \pm .09$). Interestingly, and unlike rating changes for humor, the interaction here was not significant, $F_{(1,31)} = .47$, $p = .50$. However, like the pattern for humor rating changes, changes in arousal ratings for humorous cartoons ($M = .13 \pm .83$) were no different than changes for neutral cartoons ($M = .29 \pm .63$) in the wake group, $t(14) = -.93$, $p > .35$, but changes in arousal ratings for humorous cartoons ($M = -.39 \pm .66$) were significantly greater than that for neutral cartoons ($M = -.09 \pm .35$) in the sleep group, $t(14) = -2.16$, $p = .045$. There was also a marginally significant difference between the sleep and wake groups for arousal changes of humorous cartoons, $t(31) = 2.02$, $p = .052$, as well as a significant difference of neutral cartoons, $t(31) = 2.15$, $p = .039$ (Fig. 2b).

Finally, for valence changes, there were no significant main effects of group, $F_{(1,31)} = .46$, $p = .50$, or

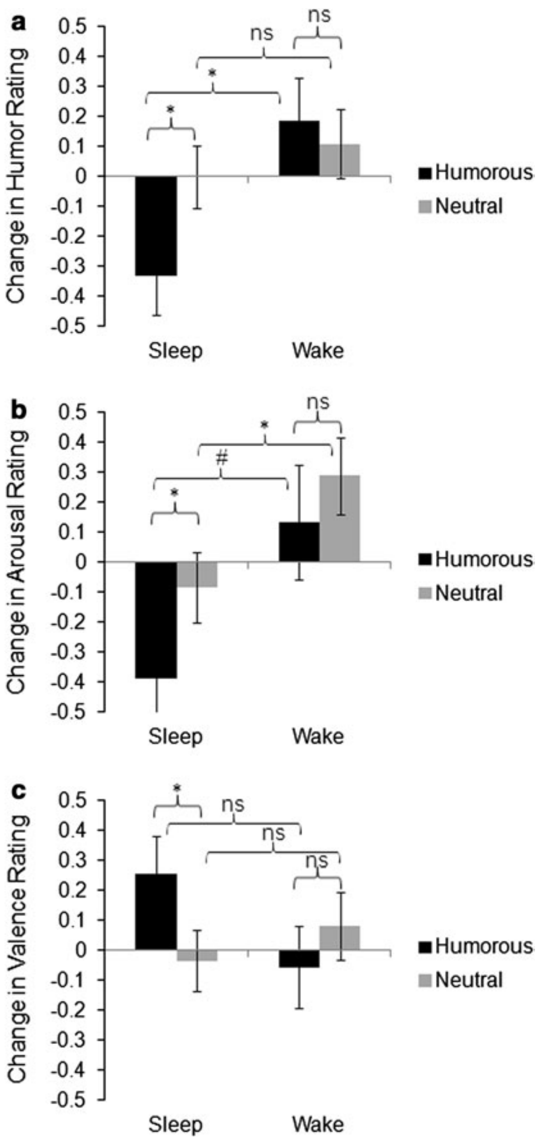

Fig. 2 Humor ratings (**a**) for humorous cartoons decreased over a delay filled with sleep, including a greater decrease in humorous cartoons relative to neutral ones within this group, but increased when the delay was filled with wakefulness. Similarly, arousal ratings (**b**) for humorous cartoons decreased over time when sleep filled the delay, and decreased more than neutral cartoons within the sleep group, but increased over a delay filled with wakefulness. Finally, valence ratings of positivity (**c**) for humorous cartoons decreased more than neutral cartoons over a delay filled with sleep, while there were no such differences within the wake group (*Note* $^{*}p \leq .05$, $^{\#}p \leq .06$, *ns* not significant. Increases in valence correspond to a decrease in positive ratings, which are anchored at 1 on this scale)

cartoon type, $F_{(1,31)} = .73$, $p = .40$, but there was a significant cartoon type by group interaction, $F_{(1,31)} = 5.87$, $p = .02$, with valence (i.e., positivity) changing similarly between the humorous ($M = -.06 \pm .59$) and neutral cartoons ($M = .08 \pm .53$) in the wake group, $t(14) = -1.28$, $p > .20$, but decreasing more for the humorous cartoons ($M = .25 \pm .47$) than the neutral cartoons ($M = -.04 \pm .34$) in the sleep group, $t(17) = 2.17$, $p = .04$. There were no significant differences between the sleep and wake groups in valence changes for humorous, $t(31) = -1.68$, $p > .10$, or neutral cartoons, $t(31) = .76$, $p > .45$ (Fig. 2c).

Although there were no baseline differences between the sleep and wake groups, we further probed the potential impact of circadian effects by comparing change scores in the AM and PM control groups. There were no baseline differences between the AM and PM control groups for ratings of humor (Humorous $t(23) = -1.51$, $p = .14$; Neutral $t(23) = -1.06$, $p = .30$), arousal (Humorous $t(23) = -1.44$, $p = .16$; Neutral $t(23) = -1.48$, $p = .15$), or valence (Humorous $t(23) = -.04$, $p = .97$; Neutral $t(23) = .27$, $p = .79$). Further, the separate one-way ANOVAs for arousal, humor, and valence change scores did not reveal significant differences between the groups (Humor $F_{(1,23)} = 2.05$, $p = .17$; Arousal $F_{(1,23)} = .06$, $p = .82$; Valence $F_{(1,23)} = .22$, $p = .64$). Thus, time of day effects do not appear to account for the differences found between the sleep and wake groups for humor and arousal rating changes.

Discussion

It is known that humor aids memory when tested after a short delay on the timescale of minutes (Schmidt and Williams 2001; Schmidt 2002), and this effect has been consistently shown across a variety of methods using different stimuli (Takahashi and Inoue 2009; Schmidt 1994). The current study extends evidence of the humor effect on memory to a much longer, 12-h delay, indicating that this effect is robust across time. Further, our results suggest that sleep plays a role in preserving memory for information perceived as humorous and arousing across a delay of this length. To our knowledge, this is the first investigation of sleep's effects on memory for positive (as opposed to negative) arousing information. It is also one of the few emotional memory studies to analyze recall (as opposed to recognition) memory after sleep. We now discuss each of our effects in more depth.

Humor as a positive stimulus

The primary motivation for using humorous stimuli in this study was to use it as a way of investigating the impact of time and sleep on memory for positive, arousing stimuli. Previously, there has been difficulty finding an adequate number of positive stimuli that elicit as much arousal as negative stimuli (Kensinger and Schacter 2006; Waring and Kensinger 2009), which has been suggested as a reason for the lack of positive findings in studies of positive emotion that use picture stimuli (Hamann et al. 2002). Alternatively, one can make the argument that laughing at something is a strong positive physiological response, and in fact, studies have shown this reaction to result in robust activations of the amygdala (Moran et al. 2004), a brain structure central to emotional responding (Hamann 2001; Hamann et al. 2002; Steinmetz et al. 2010). Consistent with this notion, the humorous versions of the cartoons in the present study were rated by participants as significantly more humorous, more arousing, and more positive than the literal or weird cartoons. These and previous findings (Moran et al. 2004; Buchanan et al. 1999) support the use of humorous cartoons as a positive and arousing stimulus.

Time, sleep, and memory performance for humorous stimuli

Our results add to the existing literature by showing (1) that the effect of humor on memory persists across a longer-term (12 h) memory delay than the much shorter delays previously investigated and (2) that although its impact was not as robust as we had anticipated, sleep may be important for this effect. We found that sleep preferentially benefited memory for humorous material, but only when cartoons were ranked based on subjective ratings of humor and arousal in those without prior exposure to the *Far Side* (Larson 1985, 1987, 1988) cartoons. Our confidence in this effect is increased by the fact that the same result was obtained whether data were ranked by humor or arousal. On this note, it is worth mentioning that ratings of humor and arousal were correlated across all cartoon types (all r's > .60), making it likely that humor ratings tap into the arousal component of emotion. As humor has been shown to affect physiology, including increasing amygdala activation and decreasing cortisol levels (Moran et al. 2004; Buchanan et al. 1999), it is possible that ratings of humor provide a measure of positive arousal. This is an important point to make in light of suggestions that sleep's impact on emotional memory consolidation might be driven by arousal rather than valence (Payne and Kensinger 2010). Indeed, as the current study does not allow a distinction to be made about whether the results are due to the humorousness of the cartoons, or their arousal, future work will be necessary to clarify this relationship.

Nonetheless, we acknowledge it as a weakness of the study that our sample was ultimately restricted to 15 subjects each in the wake and sleep groups because so many of our subjects indicated familiarity with the *Far Side* (Larson 1985, 1987, 1988) cartoons. The fact that we did not obtain the sleep effect in the sample as a whole may signify that sleep plays a comparatively weaker role in the consolidation of this type of information. Alternatively, however, it may mean that sleep exerts its strongest effect on newly encountered stimuli. Including only participants who had not seen the cartoons prior to the experiment provided us with a purer measure of memory and allowed us to be certain (1) that memory performance on the recall test was uncontaminated by prior experience with the stimuli, and (2) that sleep was acting on the *initial* consolidation of these items directly following learning, which was of greatest interest to us for this study. It is possible that stimuli must be completely novel if sleep is to enhance memory, with no benefit afforded to information that was already consolidated. However, we cannot determine that definitively from the data presented here. Future research will benefit from testing this hypothesis directly, as well as from using stimuli that are less familiar to the general public to avoid this confound.

Ranking the cartoons based on subjective ratings given by participants in the current study (rather than relying on prior norms) may have provided a more accurate classification of the cartoon categories (e.g., funny or not, arousing or not) by taking individual differences into account. The presence of such individual differences is an important issue in this type of research, given the subjectivity of how various emotions are experienced due to the different perceptions and backgrounds brought to the experiment by each individual. As a result of such considerations, other studies of emotion have also ranked stimuli based on subjective ratings given by the participants rather than relying on prior norms (Baran et al. 2012). In the current study, using our own participants' ratings of the cartoons resulted in categories that were different from the previously used groupings (Schmidt and Williams 2001) and revealed that sleep-based memory enhancements are restricted to those cartoons perceived to be most humorous and arousing. An alternative explanation is that waking activities interfere only with information perceived as non-humorous, non-arousing, or irrelevant. However, this interpretation is unlikely given the fact that those in the wake group had no difference in their memory performance for humorous (or arousing) and non-humorous (or non-arousing) cartoons, despite having 12 h of waking opportunity for interference.

Emotional reactivity changes across wakefulness and sleep

A current debate in the sleep and emotion literature focuses on whether sleep changes affective reactivity to emotional stimuli. Some researchers have shown that sleeping between two rating periods of the same stimuli maintains the magnitude of these ratings while wake reduces them (Baran et al. 2012). Conversely, others have shown that sleep attenuates ratings while wake increases them (van der Helm et al. 2011). The latter finding (van der Helm et al. 2011) is consistent with the hypothesis that sleep, and particularly REM sleep characteristics, such as the reduction in adrenergic activity associated with emotional arousal and stress, and the increased activation of limbic areas in the brain, provides a unique physiological atmosphere that reduces the emotional tone of previously encountered experiences (Walker and van der Helm 2009), while also preserving emotional memories (Braun et al. 1997; Payne et al. 2012). Consistent with this hypothesis, and similar to the findings of van der Helm et al. (2011), we found that overall humor, arousal, and valence (i.e., positivity) scores tended to decrease in the sleep group, but increase in the wake group. Further, these decreases in the sleep group were greater for the humorous cartoons than the neutral cartoons, revealing a selectivity in sleep-related emotional attenuation for those cartoons that were perceived as more humorous, arousing, and positive. van der Helm et al. (2011) found that sleep-related decreases in subjective emotional ratings were associated with a reduction in amygdala activity in response to emotional pictures, as well as increased connectivity between the amygdala and ventromedial prefrontal cortex, and reduced gamma activity during REM sleep. As we did not obtain fMRI or polysomnographic recordings, we cannot determine whether our results are similarly associated with reductions in amygdala activity, or whether REM sleep plays a role in the depotentiation we observed. However, given the similarities in the subjective rating data between the current study and that of van der Helm et al. (2011), it is possible that similar physiological relationships underlie emotional reactivity to both positive and negative information, highlighting the importance for future work to contribute data from these physiological measures.

Another avenue for future research is to investigate whether sleep's effects on memory and emotional reactivity interact with each other. Given that Baran et al. (2012) found no correlation between valence or arousal changes across a sleep or wake delay and hit rates for negative and neutral pictures, they suggested that emotional reactivity and memory processing during sleep may be separate processes. Unfortunately, neither the van der Helm et al. study (2011) nor the current study can address this inquiry, as van der Helm et al. did not collect memory data and the current study did not have a large enough sample size to investigate correlations between the two constructs. Because only a subsample of our participants provided ratings during the second session, not all participants included in our memory analyses (Experiment 1) are represented in the emotional reactivity analyses (Supplementary Experiment 2). Thus, future research is necessary to properly address this question.

Such work is important not only to advance our understanding of sleep's role in normal emotional processing, but also to shed light on the etiology of disordered emotional and memory processing, such as that which occurs in major depressive disorder (MDD). MDD is associated with a memory preference for specifically negative information, likely the result of exaggerated activations of emotional memory centers of the brain (Hamilton and Gotlib 2008), and also with sleep irregularities, especially those that involve abnormal REM length and latency (Peterson et al. 2008). Importantly, those with MDD also exhibit diminished experiences of positive emotions and smaller neural responses to positive stimuli than healthy individuals (Heller et al. 2009; Gruber et al. 2011). Because of these irregularities in both negative and positive emotions, as well as the bidirectional nature of the relationship between sleep and mood disorders, in which sleep disturbance is a risk factor for mood disorders and vice versa (Peterson et al. 2008), future work in sleep and positive emotional memory is vital to expanding the understanding and treatment of such disorders.

Another interesting avenue for future research concerns the relationship between humor, sleep, and insight (see Rubin et al. 1997). Previous studies have shown that sleep aids in obtaining insight into complex problems (Stickgold 2005). For instance, when compared to a period of wakefulness, sleep allowed more participants to have sudden insight into a hidden rule that resulted in a quick and efficient solution to a complex number reduction task (Wagner et al. 2004). Similarly, the process of humor detection (i.e., understanding a joke) has been discussed as possessing a surprise component, in which the punch line of a joke is first incongruent with expectations, and a coherence component, in which this incongruence is resolved (Moran et al. 2004; Schmidt and Williams 2001). It could be argued that resolving this incongruity (often in a sudden "aha" moment of getting the joke) is similar to attaining insight. Given the findings of sleep's impact on insight, it is possible that sleep could have an impact on this incongruity resolution, influencing the ability to understand humor and/or modulating memory for humorous material. While the current study cannot address this question, it will be an interesting area for further study.

Conclusion

The current study is the first to focus on how time and sleep influence the consolidation of specifically positive emotional information. Our findings reveal that humor exerts a lasting impact on memory, and also offer preliminary support for a selective role for sleep in memory consolidation for humorous and arousing materials when this information is completely new to individuals. Sleep also influenced emotional reactivity, selectively decreasing emotional responding to humorous, arousing information in a manner that is consistent with prior studies of negative arousing information. These results, while in some ways preliminary, not only make an important contribution to the field of emotional memory research, but also offer new insights into the sleep and memory literature by focusing on a new positive arousing stimulus type—humor.

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