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Sandra J. E. Langeslag
UMSL, langeslags@umsl.edu

Jamie R. Oliver

Martine E. Köhlen

Ilse M. Nijs

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Increased attention and memory for beloved-related information during infatuation: behavioral and electrophysiological data

Sandra J. E. Langeslag,[1] Jamie R. Olivier,[2] Martine E. Köhlen,[2] Ilse M. Nijs,[2] and Jan W. Van Strien[2]
[1]Department of Psychology, University of Maryland, College Park, MD 20742, USA and [2]Erasmus Affective Neuroscience Lab, Institute of Psychology, Erasmus University Rotterdam, P.O. Box 1738, 3000 DR Rotterdam, The Netherlands

Emotionally salient information is well attended and remembered. It has been shown that infatuated individuals have increased attention for their beloved. It is unknown whether this attention bias generalizes to information related to the beloved. Moreover, infatuated individuals report to remember trivial things about their beloved, but this has not yet been tested empirically. In two studies, we tested whether infatuated individuals have increased attention and memory for beloved-related information. In a passive viewing task (Study 1), the late positive potential, an event-related potential (ERP) component reflecting motivated attention, was enhanced for beloved-related *vs* friend-related words/phrases. In a recognition task (Study 2), memory performance and the frontal and parietal ERP old/new effects, reflecting familiarity and recollection, respectively, were not enhanced for beloved-related compared with friend-related words/phrases. In free recall tasks in both studies, memory was better for beloved-related than friend-related words/phrases. This research reveals that attention and memory are enhanced for beloved-related information. These attention and memory biases for beloved-related information were not due to valence, semantic relatedness, or experience, but to arousal. To conclude, romantic love has profound effects on cognition that play a clear role in daily life.

Keywords: romantic love; attention; memory; LPP; old/new effect

INTRODUCTION

Do you remember what your beloved ordered on your first dinner date together? Infatuated individuals report to remember trivial things that their beloved said or did (Fisher *et al.*, 2002). But because self-reports suffer from memory and social desirability biases, and demand characteristics (Orne, 1962; Stone *et al.*, 2009), it is unclear whether infatuation is truly associated with increased memory for beloved-related information. This is a significant gap in our knowledge, because virtually everyone falls in love at least once (Carver *et al.*, 2003), and falling in love has an enormous impact. The effect of infatuation on cognition thus requires thorough scientific investigation.

It is well established that emotional information is better perceived and attended than neutral information (Compton, 2003), which increases the chance that it is subsequently remembered. The emotional arousal of information also boosts memory-specific processes, such as encoding, (re)consolidation and retrieval (Hamann, 2001; Phelps, 2004). The result is that emotional information is better and/or more vividly remembered than neutral information. The extent to which information is emotionally salient differs between individuals. For example, depressed individuals show particularly enhanced attention to and memory for negative information (Everaert *et al.*, 2012), and people with social phobia display enhanced attention to and memory for socially threatening information (Musa and Lépine, 2000). Likewise, information that is related to the beloved is highly salient for the infatuated individual, so it is likely that this information is preferentially attended and remembered.

In two previous event-related potential (ERP) studies focusing on the positive ERP component that emerges after 300 ms after stimulus onset and that is maximal over the centroparietal scalp, we have demonstrated that infatuation is associated with increased attention for the beloved (Langeslag *et al.*, 2007, 2008). The exact onset and duration of this positive ERP component depend on factors such as stimulus duration and task. This component has been called the P300, P3, P3b, or late positive potential (LPP) depending on the context (Bledowski *et al.*, 2006; Langeslag *et al.*, 2008, 2009; Olofsson *et al.*, 2008; Langeslag and Van Strien, 2009; Hajcak *et al.*, 2010). In this article, we use the term LPP to refer to this ERP component. The LPP is typically enhanced for emotional compared with neutral information and reflects motivated attention (Schupp *et al.*, 2006; Olofsson *et al.*, 2008). Because the LPP was enhanced for pictures of the beloved's face compared with pictures of other people that the participant knew and liked (i.e. friends and beautiful strangers), we concluded that infatuated individuals pay increased attention to their beloved (Langeslag *et al.*, 2007, 2008). It is unclear whether this increased attention for a picture of the beloved generalizes to information that is related to the beloved. It seems likely, for example, that an infatuated individual will have enhanced attention for a passing car that looks like the car of his/her beloved, to a song on the radio by the beloved's favorite artist and to a newspaper article about the beloved's favorite sports team. The first research question of this study was whether infatuation is associated with increased attention for beloved-related information, which will be measured using the LPP.

Furthermore, it has not been experimentally examined whether infatuation is associated with enhanced memory for information that is related to the beloved. Emotional information is typically remembered better than neutral information in various memory tasks, including free recall and recognition tasks (Kensinger, 2008; Weymar and Hamm, 2013). The retrieval components familiarity and recollection are thought to underlie memory performance. Familiarity is the mere sense of having seen a stimulus previously without being able to recall any details of the circumstances (e.g. someone looks familiar, but you do not recall where you have seen him/her before), whereas recollection refers to the explicit memory of a stimulus. Although familiarity is sufficient for recognition memory, recollection is required for recall memory (Mecklinger, 2000; Yonelinas, 2001). The second research

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Correspondence should be addressed to Sandra J. E. Langeslag, Department of Psychology, University of Maryland, 0125D Biology/Psychology Building, College Park, MD 20742, USA. E-mail: sjelang@umd.edu

question was whether infatuation is associated with increased memory for beloved-related information, which will be tested using free recall and recognition memory tasks.

In ERP studies of recognition memory, the occurrence of word old/new effects has been well established. Words that are correctly identified as presented for the second time (old) elicit a more positive ERP waveform from 300 ms after stimulus onset than words that are correctly identified as presented for the first time (new) (Mecklinger, 2000; Rugg and Allan, 2000). The ERP old/new effect comprises a frontal component related to familiarity and a parietal component related to recollection. The frontal old/new effect typically occurs earlier (300–500 ms) than the parietal old/new effect (500–800 ms), but they sometimes overlap temporally (Mecklinger, 2000). Both old/new effects have been found to be larger for emotional than for neutral words (Dietrich *et al.*, 2001; Inaba *et al.*, 2005). The final research question is whether beloved-related information boosts the familiarity and/or the recollection component, which will be measured using ERP old/new effects.

In this study, the experimental stimuli were words, which are typically less arousing than pictorial information (Keil, 2006). Memory is prototypically enhanced for arousing stimuli, but is enhanced for low arousing emotional information as well, because that undergoes increased autobiographical and semantic elaboration. Specifically, emotional words are more likely to be associated with autobiographical experiences and to be semantically related to other emotional memoranda than neutral words (Kensinger, 2004; Talmi and Moscovitch, 2004). Therefore, we compared attention and memory for beloved-related information with attention and memory for friend-related and control information. The friend-related information was included to control for experience (i.e. frequency and/or association with autobiographical experiences), positive valence and semantic relatedness. That is, like beloved-related information, friend-related information is associated with a familiar, appealing person. In addition, like beloved-related information, friend-related information is semantically related because it is associated with a single person. The control information was included to control for semantics, including word imagery and concreteness. For example, when 'purple' was the favorite color of the beloved, 'yellow' was used as a control stimulus for that participant. Or when the beloved was a fan of 'Brad Pitt', 'Tom Cruise' was used as a control stimulus.

In Study 1, we examined whether infatuated individuals pay increased attention to beloved-related information. The LPP amplitude was taken as an index of attention allocation, and it was hypothesized that the LPP amplitude would be enhanced for beloved-related stimuli compared with friend-related and control stimuli. In Studies 1 and 2, we examined whether infatuated individuals have enhanced memory for beloved-related information. In both studies, participants performed free recall tasks, and in Study 2, participants also performed a recognition task. It was expected that free recall and recognition memory would be enhanced for beloved-related stimuli compared with friend-related and control stimuli. Specifically, discrimination between old and new stimuli was expected to be better, and/or reaction times (RTs) to be shorter, for beloved-related than friend-related and control stimuli. In Study 2, we examined whether familiarity and/or recollection are boosted for beloved-related information. Observing an enhanced frontal ERP old/new effect for beloved-related compared with friend-related and control stimuli would indicate that familiarity is boosted for beloved-related information. Observing an enhanced parietal ERP old/new effect for beloved-related compared with friend-related and control stimuli would indicate that recollection is boosted for beloved-related information. Finally, in Study 2 we collected additional information about the relationships with the beloved and the friend to assess the effect of experience.

STUDY 1

Methods

Participants

Twenty students of the Erasmus University Rotterdam provided useable data. (See Table 1 for participant characteristics.) Two other participants were excluded because of missing electroencephalogram (EEG), rating and free recall data. Because infatuation decreases over time and is assumed to last up to 1.5 years (Fisher *et al.*, 2002; Langeslag *et al.*, 2013), only participants who had been in love for <1 year were included. Other inclusion criteria were normal or corrected-to-normal vision, no mental disorders and no use of medication known to affect the central nervous system. All participants were right-handed as determined by a hand preference questionnaire (Van Strien, 1992), and experienced high levels of romantic love as indicated by the Passionate Love Scale (PLS) (Hatfield, 1998). (See Table 1 for the love characteristics.) The study was conducted in accordance with the guidelines of the local ethics committee. Participants' consent was obtained according to the Declaration of Helsinki. Participants were remunerated with course credit or 10 euros.

Stimuli

The stimuli were 30 beloved-related, 30 friend-related and 30 control words/phrases. Participants gave the experimenter permission to contact the beloved and a friend by telephone or email. The experimenter asked the beloved and the friend in a semi-structured interview to provide 30 words or short phrases that had to do with themselves, such as hobbies and favorite color/foods/drink/movies/artists. If a category was not applicable (e.g. they had no favorite color), it was skipped. Also, beloveds and friends could come up with multiple words/phrases per category and with words/phrases that did not fit any of these categories. For each participant, a list of control stimuli was composed that resembled the beloved-related stimuli in semantics. Beloved-related and friend-related stimuli did not differ in length (Supplementary Data). The stimuli were presented in white font on a black background.

Tasks

The participants passively viewed the stimuli while their EEG was recorded. The task was divided into two blocks. Each stimulus was presented twice (once in each block, in random order) to increase the number of trials per condition. The effect of the different conditions on the ERP amplitude was constant throughout both blocks (Supplementary Data). Trial structure was as follows: fixation cross for 600–1000 ms (pseudorandom duration), stimulus for 250 ms, fixation cross for 1000 ms and a blank screen for 1000 ms.

Next, the participants completed a surprise free recall task that involved writing down all stimuli that the participant remembered. Subsequently, the participants rated the valence and arousal of the stimuli on 9-point Likert scales using the Self-Assessment Manikin (Bradley and Lang, 1994). They also rated how much each stimulus was associated with their beloved and with their friend, on 5-point Likert scales.

EEG recording and processing

The EEG was recorded using a 32-channel amplifier and data acquisition software (ActiveTwoSystem, BioSemi). The 32 Ag-AgCl active electrodes were placed upon the scalp by means of a head cap (BioSemi), according to the 10–20 International System. Vertical electro-oculogram and horizontal electro-oculogram were recorded by attaching additional electrodes (UltraFlat Active electrodes, BioSemi) above and below the left eye, and at the outer canthi of both eyes.

Table 1 Participant, love and friendship characteristics [counts or means (ranges in parentheses)]

	Study 1	Study 2
Age [years]	21.1 (18–28)	20.9 (18–26)
Gender	5 men, 15 women	3 men, 15 women
Gender beloved	—	17 opposite, 1 same
PLS score [1–9]	7.7 (5.9–8.8)	6.8 (4.6–8.3)
IAS infatuation score [1–9]	—	3.2 (1.4–5.1)
IAS attachment score [1–9]	—	5.7 (3.3–7.0)
Love duration [months]	6.9 (1.0–11.0)	7.3 (2.0–17.5)
Involved in romantic relationship	19 yes, 1 no	17 yes, 1 no
Relationship duration [months]	6.1 (1.0–12.0)	6.5 (0.5–16.0)
Relationship quality [1–9]	—	7.8 (5–9)
Gender friend	—	2 opposite, 16 same
Friendship duration [months]	—	53.3 (9.0–204.0)
Friendship quality [1–9]	—	7.9 (6–9)
Duration known beloved [months]	—	25.4 (2.8–76.5)
Duration known friend [months]	—	59.0 (9.0–204.0)
Well known beloved [1–9]	—	7.7 (7–9)
Well known friend [1–9]	—	8.2 (6–9)

—, Data not collected.

Another two electrodes were attached to the left and right mastoids. An active electrode (common mode sense) and a passive electrode (driven right leg) were used to comprise a feedback loop for amplifier reference. All signals were digitized with a sampling rate of 512 Hz, a 24 bit A/D conversion and a low pass filter of 134 Hz.

The EEG data were analyzed with BrainVision Analyzer 2 (Brain Products, Gilching, Germany). Offline, a mathematically linked mastoids reference was applied and the data were filtered using a 0.15–30 Hz band pass filter (phase shift-free Butterworth filters; 24 dB/octave slope). Data were segmented in epochs from 100 ms pre-stimulus until 1000 ms post-stimulus onset. Ocular artifact correction was applied according to the Gratton and Coles algorithm (Gratton *et al.*, 1983). The mean 100 ms pre-stimulus period was used for baseline correction. Artifact rejection was performed at individual electrodes with the criterion minimum and maximum baseline-to-peak −100 to +100 μV. The mean number of accepted epochs per participant per condition per electrode was 58.3 (range = 38–60).

Analyses

The free recall and rating data were analyzed using repeated measures analyses of variance (rmANOVAs) with the factor Condition (beloved-related, friend-related, control). Visual inspection of the ERP data revealed that the LPP was maximal between 500 and 800 ms after stimulus onset (Figure 1). The LPP was therefore defined as the mean ERP activity in the 500–800 ms time window after stimulus onset, and was tested at electrodes F3/z/4, C3/z/4 and P3/z/4 using rmANOVAs with the factors Condition, Caudality (frontal, central, parietal) and Laterality (left, midline, right). Only significant effects involving the factor Condition are reported. When applicable, the degrees of freedom were corrected using the Greenhouse–Geisser correction. The *F*-values, uncorrected degrees of freedom, the ε-values and corrected probability values were reported. Significant effects were followed up by paired samples *t*-tests.

To assess the contributions of valence and arousal to increased attention and memory for beloved-related information, Pearson correlation coefficients were computed between the valence and arousal differences between beloved-related and friend-related stimuli, and the LPP amplitude (mean amplitude at electrodes P3/z/4) and free recall performance differences between beloved-related and friend-related stimuli.

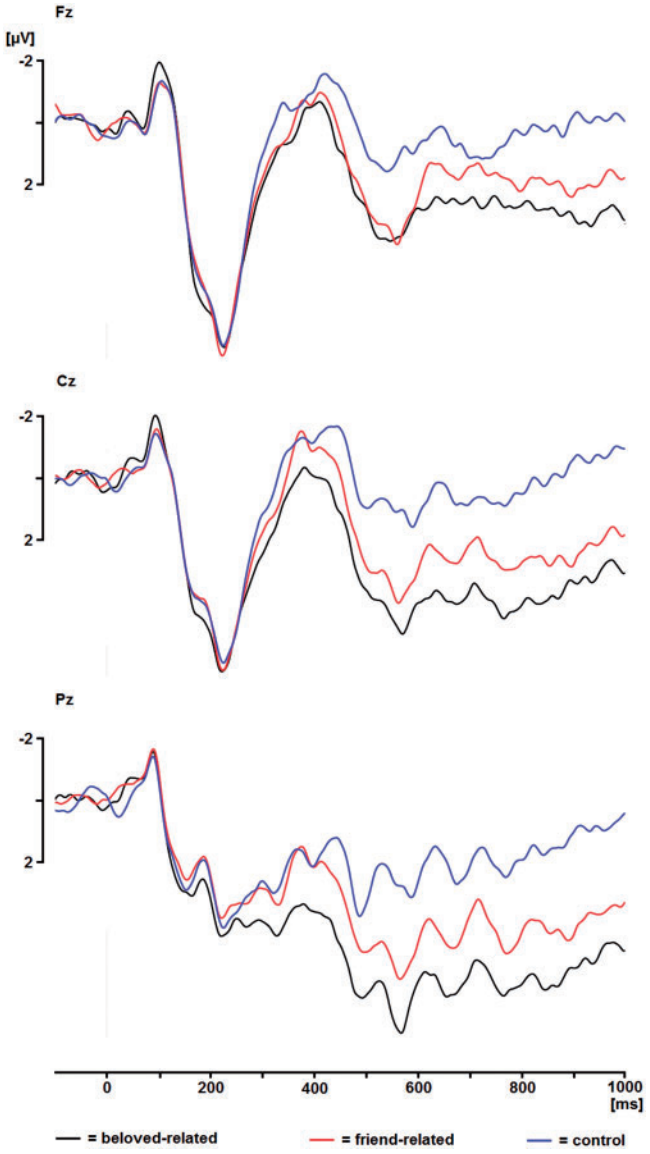

Fig. 1 Grand-average ERPs at electrodes Fz, Cz and Pz for beloved-related, friend-related and control stimuli, positivity is down.

Results

Ratings

See Table 2 for the rating data. All ratings differed between conditions, all Fs(2,38) > 47.7, all εs > 0.79, all Ps < 0.001. Beloved-related and friend-related stimuli were more pleasant than control stimuli, both Ps < 0.001. The valence of the beloved-related and friend-related stimuli did not differ, $P = 0.32$. Beloved-related stimuli were most arousing, friend-related stimuli intermediately arousing, and control stimuli least arousing, all Ps < 0.009. Beloved-related stimuli were more applicable to the beloved than friend-related and control stimuli, both Ps < 0.001. The difference in applicability-to-beloved between friend-related and control stimuli did not reach significance, $P = 0.092$. Friend-related stimuli were more applicable to the friend than beloved-related and control stimuli, both Ps < 0.001. The difference in applicability-to-friend between beloved-related and control stimuli did not reach significance, $P = 0.071$.

Late positive potential

See Figures 1 and 2 for the ERP waveforms and scalp topographies. In the 500–800 ms time window, there was a significant main effect of

Condition, $F(2,38) = 6.5$, $\varepsilon = 0.97$, $P = 0.004$, which was modulated by a significant Condition × Caudality interaction, $F(4,76) = 5.7$, $\varepsilon = 0.61$, $P = 0.004$. At central electrodes, the ERP was more positive for beloved-related and friend-related stimuli than for control stimuli, both Ps < 0.049. At parietal electrodes, the ERP was most positive for beloved-related stimuli, intermediately positive for friend-related stimuli and least positive for control stimuli, all Ps < 0.050. Thus, the LPP amplitude was enhanced for beloved-related stimuli compared with friend-related and control stimuli, as well as for friend-related compared with control stimuli.

The LPP amplitude difference between beloved-related and friend-related stimuli was not correlated with valence, $r(18) = -0.13$, $P = 0.59$, or arousal, $r(18) = -0.11$, $P = 0.66$, differences between beloved-related and friend-related stimuli.

Recall

On average, participants recalled 34.4 (range = 21–59) of the 90 stimuli. The number of recalled stimuli differed between conditions, $F(2,38) = 44.8$, $\varepsilon = 0.99$, $P < 0.001$. Beloved-related stimuli were remembered best, followed by friend-related stimuli, and control stimuli were remembered worst, all Ps < 0.004 (Figure 3).

Table 2 Mean ratings (standard deviations in parentheses)

		Study 1	Study 2
Valence [1–9]	Beloved-related	6.8 (0.9)	7.1 (0.6)
	Friend-related	6.6 (0.9)	7.0 (0.8)
	Control	5.2 (1.1)	5.7 (0.7)
Arousal [1–9]	Beloved-related	5.2 (1.8)	5.3 (1.1)
	Friend-related	4.7 (1.8)	4.9 (1.5)
	Control	3.3 (1.5)	3.4 (0.9)
Applicability-to-beloved [1–5]	Beloved-related	4.4 (0.3)	4.6 (0.2)
	Friend-related	2.1 (0.6)	2.0 (0.5)
	Control	2.3 (0.6)	2.3 (0.7)
Applicability-to-friend [1–5]	Beloved-related	2.0 (0.5)	1.9 (0.5)
	Friend-related	4.2 (0.4)	4.5 (0.3)
	Control	2.2 (0.6)	2.2 (0.6)

For the valence ratings, 1 = negative, 9 = positive. For the arousal ratings, 1 = calming, 9 = arousing. For the applicability ratings, 1 = not applicable, 5 = applicable.

The valence difference between beloved-related and friend-related stimuli was not correlated with free recall performance differences between beloved-related and friend-related stimuli, $r(18) = 0.32$, $P = 0.17$. In contrast, the arousal difference between beloved-related and friend-related stimuli was significantly positively correlated with free recall performance differences between beloved-related and friend-related stimuli, $r(18) = 0.57$, $P = 0.009$.

STUDY 2

Methods

The methods of Study 2 were similar to Study 1, with the following exceptions.

Participants

Eighteen participants that did not participate in Study 1 provided useable data. (See Table 1 for participant characteristics.) Two other participants had to be excluded because of bad EEG registration from one of the mastoids and poor performance on the recognition task (98% 'old' responses). Because participant recruitment was difficult, we stretched the inclusion criterion to romantic love duration <1.5 year. All participants experienced high levels of romantic love as indicated by the PLS and Infatuation and Attachment Scales (IAS) (Langeslag *et al.*, 2013) (Table 1). Monetary reimbursement was 15 euros.

Tasks

The continuous recognition task was divided into three blocks that contained 60 experimental trials each, evenly distributed across the conditions (Langeslag and Van Strien, 2008). The stimuli were presented in a pseudorandom order, with no more than three stimuli of the same condition succeeding each other. Each stimulus was presented twice and both presentations took place within the same block, at least four and at most 30 stimuli apart. The distances between the first and second presentations were balanced between the three different conditions across the three blocks. At the beginning and at the end of each block, three neutral filler words that could be new or old were presented to reduce primacy and recency effects. Trial structure was as follows: fixation cross for 400–600 ms (pseudorandom duration), stimulus for 1000 ms, fixation cross for 1000 ms and a blank screen for 1500 ms. Participants were instructed to press a button with their right index or middle finger to indicate whether the stimulus was presented for the first (new) or the second time

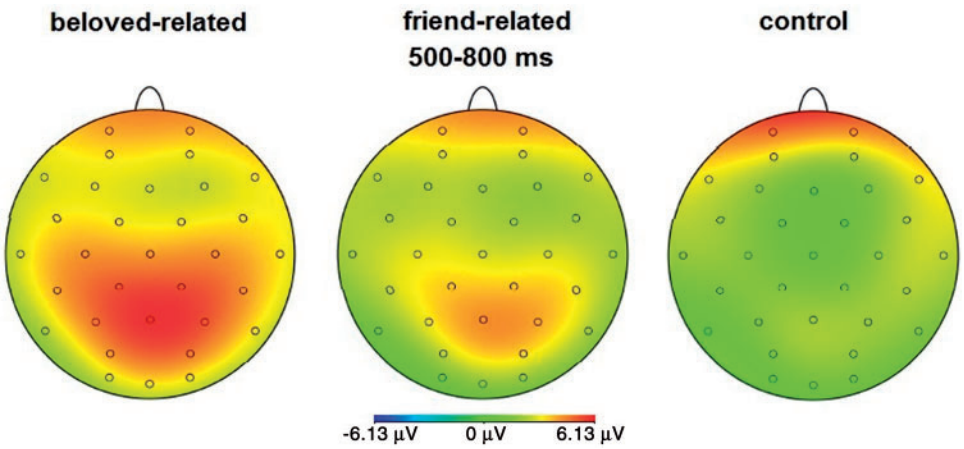

Fig. 2 Voltage scalp distributions for the beloved-related, friend-related and control stimuli, between 500 and 800 ms.

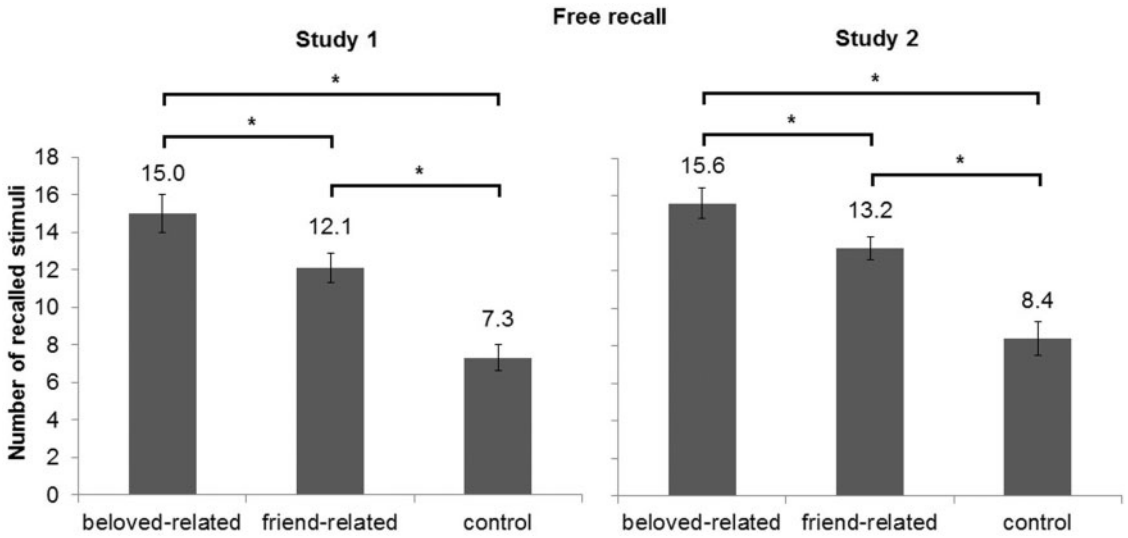

Fig. 3 Free recall performance, *significantly different, all *Ps* < 0.024.

(old), as accurately and fast as possible. Response mapping was counterbalanced between participants. Only responses between 150 and 2000 ms after stimulus onset were recorded. After the recognition task, participants completed the surprise free recall task and the ratings.

EEG recording and processing

The mean number of accepted epochs per participant per condition per electrode was 25.9 (range = 16–30).

Analyses

Differences between the love and friendship characteristics were analyzed with paired *t*-tests. In the recognition task, hit rates (*H*, i.e. proportion 'old' responses to old stimuli) and false alarm rates (FA, i.e. proportion 'old' responses to new stimuli) were computed. Recognition performance was represented by the discrimination index Pr = *H* − FA (Snodgrass and Corwin, 1988), which was tested with rmANOVAs with the factor Condition. Median RTs for correct responses were analyzed with an rmANOVA with factors Condition and Old/new status (new, old).

The ERP waveforms for correct responses were quantified by mean amplitude measures in 350–450 and 500–800 ms time windows at the electrodes F3/z/4, C3/z/4 and P3/z/4 to capture the frontal and parietal word old/new effects (Van Strien *et al.*, 2005, 2007). rmANOVAs were performed with the factors Condition, Old/new status, Caudality and Laterality. Only significant effects involving the factor Condition and/or Old/new status are reported.

Results

Love and friendship characteristics

See Table 1 for love and friendship characteristics. Participants had known their friend longer than their beloved, $t(17) = 2.4$, $P = 0.028$. They correspondingly knew their friend better than their beloved, although this difference was not significant, $t(17) = 1.4$, $P = 0.16$.

Ratings

See Table 2 for the rating data. All ratings differed between conditions, all Fs$(2,34) > 29.7$, all $\varepsilon > 0.82$, all Ps< 0.001. Beloved-related and friend-related stimuli were more pleasant than control stimuli, both Ps< 0.001. The valence of beloved-related and friend-related stimuli did not differ, $P = 0.40$. Beloved-related and friend-related stimuli were more arousing than control stimuli, both Ps< 0.001. Beloved-related stimuli were more arousing than friend-related stimuli, but this difference did not reach significance, $P = 0.10$. Beloved-related stimuli were most applicable, control stimuli intermediately applicable, and friend-related stimuli least applicable to the beloved, all Ps< 0.012. Friend-related stimuli were most applicable, control stimuli intermediately applicable, and beloved-related stimuli least applicable to the friend, all Ps< 0.004.

Recognition

Mean accuracy on the recognition task was very high ($M = 94\%$, range = 78–99). The discrimination index Pr (beloved-related: $M = 0.88$, s.d. = 0.05; friend-related: $M = 0.88$, s.d. = 0.07; control: $M = 0.90$, s.d. = 0.06) did not differ between conditions, $F < 1$, ns. The median RTs for correct responses showed a significant Condition × Old/new status interaction, $F(2,34) = 8.9$, $\varepsilon = 0.95$, $P = 0.001$. For new stimuli, RTs were longer for beloved-related and friend-related stimuli than for control stimuli, both Ps< 0.016. For old stimuli, however, RTs were shorter for beloved-related than control stimuli, $P = 0.013$ (Figure 4).

Old/new effects

See Figures 5 and 6 for the ERP waveforms and scalp topographies. In the 350–450 ms time window, the significant main effect of Old/new status, $F(1,17) = 28.6$, $P < 0.001$, and Old/new status × Caudality interaction, $F(2,34) = 12.9$, $\varepsilon = 0.69$, $P = 0.001$, were modulated by a significant Condition × Old/new status × Caudality interaction, $F(4,68) = 3.0$, $\varepsilon = 0.70$, $P = 0.041$. For beloved-related and friend-related stimuli, the ERP was more positive for old than new stimuli at frontal, central and parietal electrodes, all Ps< 0.015. For control stimuli, the ERP was more positive at parietal electrodes only, $P = 0.032$. At frontal electrodes, the old/new effect was larger for beloved-related and friend-related than control stimuli, all Ps< 0.026. At central electrodes, the old/new effect was larger for beloved-related than control stimuli, $P = 0.025$. At parietal electrodes, the old/new effect did not differ between the three conditions, all Ps> 0.15. In addition, there was a significant Old/new status × Laterality interaction, $F(2,34) = 10.0$, $\varepsilon = 0.98$, $P < 0.001$. The ERP was more positive

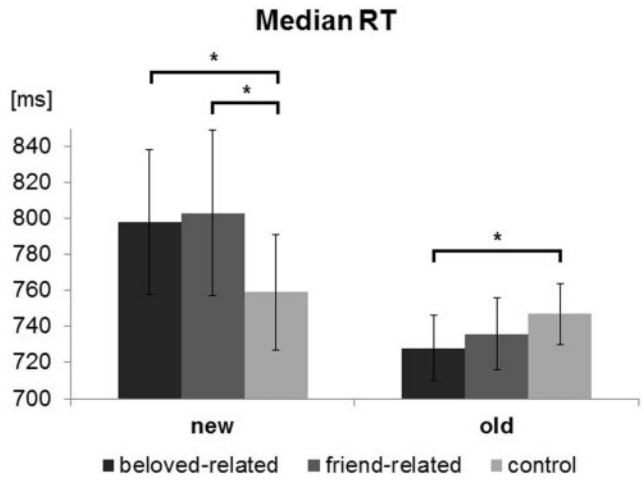

Fig. 4 Median RTs for correct responses for new and old beloved-related, friend-related and control stimuli, *significantly different, all *Ps* < 0.016.

for old than new stimuli at left, midline and right electrodes, all *Ps* < 0.001. However, the old/new effect was larger at left and midline than at right electrodes, both *Ps* < 0.003.

In the 500–800 ms time window, the main effect of Old/new status, $F(1,17) = 16.6$, $P = 0.001$, was modulated by significant Old/new status × Caudality, $F(2,34) = 19.9$, $\varepsilon = 0.79$, $P < 0.001$, and Old/new status × Laterality, $F(2,34) = 5.9$, $\varepsilon = 0.86$, $P = 0.010$, interactions. The ERP was more positive for old than new stimuli at central and parietal electrodes, both *Ps* < 0.001, and the old/new effect was larger at central and parietal than at frontal electrodes, both *Ps* < 0.001. Moreover, the ERP was more positive for old than new stimuli at left, midline and right electrodes, all *Ps* < 0.004. However, the old/new effect was larger at midline and right electrodes than at left electrodes, both *Ps* < 0.017. None of the effects involving the factor Condition was significant, all *Fs* < 3.0, all *Ps* > 0.26.

In summary, the frontal old/new effect occurred for beloved-related and friend-related stimuli only. The parietal old/new effect, in contrast, did not differ between conditions.

Recall

On average, participants recalled 37.1 (range = 28–52) of the 90 stimuli. The number of recalled stimuli differed between conditions, $F(2,34) = 34.7$, $\varepsilon = 0.95$, $P < 0.001$. Beloved-related stimuli were remembered best, followed by friend-related stimuli, and control stimuli were remembered worst, all *Ps* < 0.024 (Figure 3).

The valence difference between beloved-related and friend-related stimuli was not correlated with free recall performance differences between beloved-related and friend-related stimuli, $r(16) = 0.34$, $P = 0.17$. In contrast, the arousal difference between beloved-related and friend-related stimuli was significantly positively correlated with free recall performance differences between beloved-related and friend-related stimuli, $r(16) = 0.50$, $P = 0.034$.

DISCUSSION

We examined whether infatuation is associated with increased attention and memory for beloved-related information. Participants performed passive viewing, free recall and recognition tasks with beloved-related, friend-related and control stimuli. Participants were initially unaware of these three conditions, as the stimuli were obtained from the beloveds and friends. Nevertheless, ratings afterwards showed that participants attributed the beloved-related stimuli to their beloved

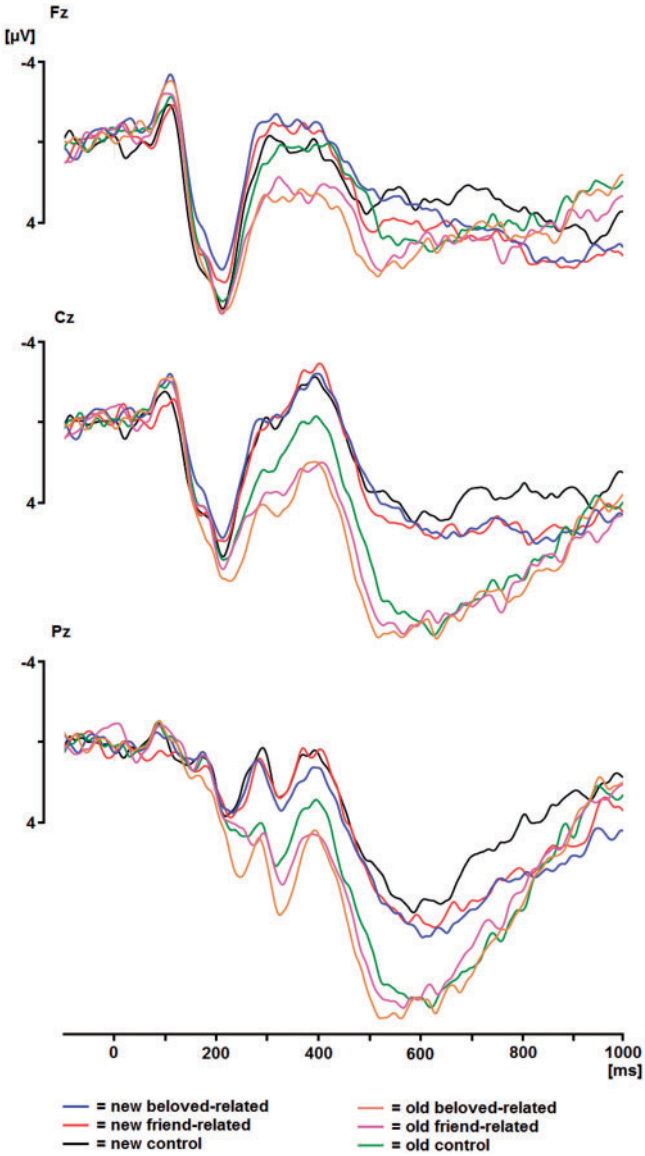

Fig. 5 Grand-average ERPs at electrodes Fz, Cz and Pz, for new and old beloved-related, friend-related and control stimuli, positivity is down.

and not to their friend, and the friend-related stimuli to their friend and not to their beloved, so our manipulation was effective. In accordance with our hypotheses, the LPP amplitude and free recall performance were enhanced for beloved-related information specifically. In contrast to our hypotheses, recognition memory performance and the ERP old/new effects were not enhanced for beloved-related compared with friend-related information.

In the passive viewing task in Study 1, the ERP at parietal electrodes between 500 and 800 ms was more positive for beloved-related information than for friend-related and control information. The latency and scalp topography of this effect are in accordance with the typical emotional modulation of the LPP (Schupp *et al.*, 2006). Moreover, it concurs with the previously observed enhanced LPP amplitude for a picture of the beloved compared with pictures of a friend or beautiful stranger (Langeslag *et al.*, 2007, 2008). Interpreting the LPP as reflecting motivated attention (Schupp *et al.*, 2006), this study shows that, in addition to increased attention for the beloved (Langeslag *et al.*, 2007, 2008), infatuation is also associated with increased attention for information that is associated with the beloved. This resembles the general

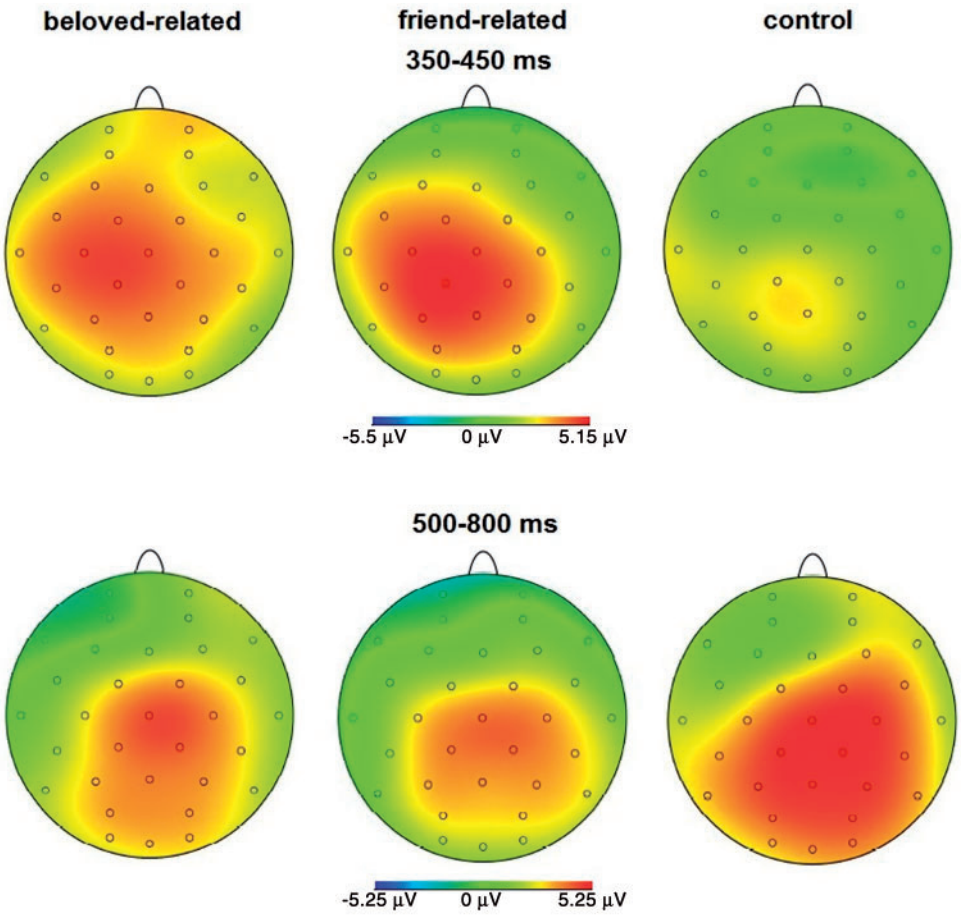

Fig. 6 Scalp topographies of the old/new effect in the 350–450 ms and 500–800 ms time windows for beloved-related, friend-related and control stimuli.

enhanced attention for emotional information (Compton, 2003) and the attention biases associated with mental disorders such as depression and anxiety (Musa and Lépine, 2000; Everaert *et al.*, 2012).

In free recall tasks in both studies, participants remembered more beloved-related information than friend-related or control information. Because this is the first experimental demonstration of enhanced memory for beloved-related information, it is important that it was observed in two independent samples. This infatuation enhancement effect on memory occurred under incidental encoding conditions in Study 1, and intentional encoding conditions (albeit for the recognition, not for the free recall task) in Study 2. Enhanced free recall of beloved-related information is in accordance with the perception of infatuated individuals that they remember trivial things that the beloved said or did (Fisher *et al.*, 2002). It also resembles the general emotion enhancement effect on memory (Hamann, 2001; Phelps, 2004), and the memory biases associated with mental disorders (Musa and Lépine, 2000; Everaert *et al.*, 2012).

Importantly, attention and free recall memory were better for beloved-related than friend-related information. The beloved-related and friend-related stimuli did not differ in length or in semantic relatedness, as all stimuli within a condition were associated with one person. In addition, beloved-related and friend-related information was equally positively valenced. Beloved-related information was, however, more arousing than friend-related information, although this difference did not reach significance in Study 2 (which was not due to the more lenient love duration inclusion criterion in Study 2; Supplementary Data). It is well known that arousing stimuli are better perceived, attended and remembered (Compton, 2003; Kensinger, 2004), and high arousal thus seems to be an important mechanism underlying the attention and memory biases for beloved-related information. Moreover, in both studies, the greater the arousal difference between beloved-related and friend-related information, the greater the difference in free recall performance for these types of information, providing additional evidence that beloved-related information is preferentially remembered because it is arousing. In contrast, an association between arousal ratings and LPP amplitude differences was not observed in Study 1. It is well known that the LPP is larger for high than low arousing stimuli (Schupp *et al.*, 2006; Olofsson *et al.*, 2008). Although some studies have revealed positive correlations between picture arousal ratings and the LPP amplitude (Cuthbert *et al.*, 2000; Yen *et al.*, 2010), many other publications do not report such analyses (Schupp *et al.*, 2000, 2004; Amrhein *et al.*, 2004). It might be that arousal ratings are the result of a deliberate evaluation process, whereas the LPP reflects an implicit stimulus evaluation process that differs between high and low arousing stimuli, but is not necessarily associated with the consciously experienced level of arousal. Alternatively, the absence of a relation between arousal ratings and the LPP amplitude could have been due to the use of relatively low arousing words, instead of higher arousing and evolutionary more relevant pictures (Keil, 2006). In any case, the current results suggest that arousal, and not positive valence or semantic relatedness, is the underlying source of the increased attention and memory for beloved-related information.

It is difficult to assess how experienced someone is with information related to his/her beloved and friend. People may be more experienced with their beloved, and the associated information, than with their

friend, because people typically spend more time with their beloved than with their friend. Conversely, people may be more experienced with their friend than their beloved, because infatuated individuals, who fell in love recently, may not have known their beloved for a long time, whereas they may have known their friend for years. Indeed, in Study 2, participants had known their friend for much longer than they had known their beloved and, if anything, they knew their friend better than their beloved. Thus, it is unlikely that the enhanced memory for beloved-related information is due to that information being more frequently encountered and/or more associated with autobiographical experiences than the friend-related information.

In the recognition task in Study 2, participants were equally good at discriminating between new and old stimuli of all three conditions (and displayed a similar response bias; Supplementary Data). Participants were slower to correctly classify beloved-related and friend-related than control stimuli as new, and were faster to correctly classify beloved-related than control stimuli as old. The latter behavioral finding suggests better recognition of beloved-related and friend-related information compared with control information and matches the observation of an enhanced frontal old/new effect for these types of information. Given that the frontal old/new effect reflects familiarity (Mecklinger, 2000), it seems that beloved-related and friend-related information was processed more fluently because it was experienced as more familiar than the control information. Importantly, there was no difference between beloved-related and friend-related information, so the enhanced frontal old/new effect may have been due to factors such as increased experience, semantic relatedness, positive valence, and/or arousal of beloved-related and friend-related information compared with control information. The parietal old/new effect, which reflects conscious recollection (Mecklinger, 2000), did not differ between the three conditions. In short, we did not find evidence that recognition memory or the retrieval components familiarity and recollection are enhanced for beloved-related compared with friend-related information.

The observed dissociation between free recall and recognition memory is interesting. Notably, the free recall task involves uncued retrieval, whereas the recognition task involves cued retrieval. Moreover, the free recall tasks were unexpected. Consequently, the recognition task was easier than the free recall task, as evident from the differences in performance levels (recognition: 94% accuracy, free recall: 38–41% retrieval). It may be that a ceiling effect in recognition performance prevented the observation of a love enhancement effect on recognition memory performance and old/new effects (Weymar and Hamm, 2013). Additionally, because emotion enhancement effects on memory are typically more pronounced with longer retention intervals, the short delay between encoding and retrieval in the recognition compared with the free recall task may have prevented the observation of a love enhancement effect on recognition memory performance and old/new effects (Weymar and Hamm, 2013). Nevertheless, free recall probably reflects everyday behavior better than recognition. When infatuated people reminisce about their beloved they will remember more details than when reminiscing about other people they know and like. It would be interesting to use a study-test recognition task with a longer retention interval to test whether infatuation does enhance recognition memory when there is no ceiling effect and a longer retention interval.

It is proposed that, in humans, romantic love consists of infatuation and attachment. Infatuation (or passionate love or attraction) concerns the overwhelming, amorous feeling for that one special person, while attachment (or companionate love) reflects the comforting feeling of emotional bonding with another individual (Sprecher and Regan, 1998; Fisher, 1998, 2000; De Boer *et al.*, 2012). Generally, infatuation decreases over time, whereas attachment increases over time (Fisher, 1998, 2000; Marazziti *et al.*, 1999; Fisher *et al.*, 2002; Marazziti and Canale, 2004; Langeslag *et al.*, 2013). Here, we focused on infatuation and recruited participants who had been in love for a relatively short period in time. However, these attention and memory biases might not be unique to infatuation. It seems likely that attached individuals, such as married individuals, also show attention and memory biases for beloved-related information, although the underlying mechanism may be different. That is, attachment is accompanied by lower arousal and greater experience with the beloved than infatuation (Gonzaga *et al.*, 2006), so spouse-related information may be preferentially remembered not because it is arousing, but because people are highly experienced with it. Indeed, in a previous study of ours we have observed an attention bias for the beloved in participants who had been in love for 2.5–36 months (Langeslag *et al.*, 2007). Unfortunately, arousal and experience ratings were not collected in that study. Additionally, a memory bias in free recall was observed in Study 2 despite the more lenient love duration inclusion criterion. It would be interesting to examine the dissociation between the effects of infatuation and attachment on cognition in future studies.

The participants of this study were young adults. Although we did not collect data regarding their previous experiences with infatuation and romantic relationships, a study among nearly 12 000 adolescents has revealed that more than 80% of people has been involved in at least one romantic relationship by the age of 18 (Carver *et al.*, 2003). It is therefore unlikely that the observed attention and memory biases are due to the novelty of being infatuated or being involved in a relationship.

A limitation of this study is that most participants were female, which likely results from the gender ratio of the population from which participants were sampled and from the greater willingness of women to participate in studies about love. There are gender differences in romantic love (Harris, 2002; Geary *et al.*, 2004; Meston and Buss, 2007; Langeslag *et al.*, 2012), emotional attention (Sabatinelli *et al.*, 2004; Sass *et al.*, 2010) and emotional memory (Canli *et al.*, 2002; Wang, 2013). It would therefore be interesting to examine gender differences in increased attention and memory for beloved-related information in future studies.

To conclude, this study greatly advances our knowledge of the effect of infatuation on cognition, which virtually everybody will experience at some point (Carver *et al.*, 2003). This study reveals that the attention bias of infatuated individuals for their beloved (Langeslag *et al.*, 2007, 2008) extends to information that is associated with their beloved. Moreover, this study is the first to show that infatuated individuals exhibit enhanced memory for information that is associated with their beloved. This infatuation enhancement effect on memory occurred under incidental and intentional encoding conditions, but only in free recall tasks. These attention and memory biases for beloved-related information were not due to positive valence, semantic relatedness, or experience, but to arousal instead. In daily life, infatuated individuals will for example have increased attention and memory for the beloved's favorite dish being listed on a restaurant menu or for an advertisement of a movie that features their beloved's favorite actor. Future studies could reveal whether the observed attention and memory biases are important for the maintenance of early-stage relationships when there is no social commitment (e.g. marriage) yet, or whether they are mere side effects of infatuation. In any case, it may be clear that romantic love has profound effects on cognition, which deserve full attention from the scientific community.

SUPPLEMENTARY DATA

Supplementary data are available at *SCAN* online.

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