Encoding In Social Context Enhances And Biases Long-Term Recognition Memory: Behavioral And Electrophysiological Evidence

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Abstract

Encoding often occurs in social contexts, yet research has hardly addressed their role in verbal memory. In three experiments, we investigated the behavioral and neural effects of encoding context on memory for positive, negative, and neutral adjectives, contrasting a social-feedback group ($N=24$) with an explicit verbal-learning ($N=24$) and a levels-of-processing group ($N=24$). Participants in the social-feedback group were not aware of a recognition session one week later, but their memory was better than the explicit learning or the levels-of-processing groups'. However, they also exhibited the strongest response bias, particularly for positive words. Brain event-related potentials (ERPs) revealed largest early negativities (EPN) and late positivities (LPP) in the social-feedback group. Only in the subsequent slow-wave did the explicit learning group show higher amplitudes than the other two groups, suggesting reliance on strategic rather than automatic processes. Still, context-driven incidental encoding outweighed explicit instructions, specifying a decisive role of social factors in memory.

Introduction

Humans are a social species. Therefore, human memory formation, as much other cognitive activity, often occurs in social contexts. Yet, scientific memory research has paid limited attention to the social situatedness of memory encoding, taking memory operations devoid of contextual embedding as its point of departure (Ebbinghaus (1885, 2013), thereby delineating many key principles. Meanwhile, contextual binding in space and time has proven crucial for successful episodic memory formation (Yonelinas et al., 2019). The social encoding context has, by comparison, received little attention, although recently social influences on memory systems have attracted scientific interest. These range from investigations into brain mechanisms of social memory conformity (Edelson et al., 2011) to the finding that the hippocampus, a critical region for spatial navigation and episodic memory formation, also represents a "social space" of relationships (Tavares et al., 2015). Such findings lend momentum to the hypothesis that the social context in which items are encoded affects their subsequent remembering.

Memory research also initially focused on content-general mechanisms. However, human memory does not treat all contents equally. Ample evidence indicates that emotionally relevant material is remembered differently and often better than neutral material (Dolcos & Cabeza, 2002; Dolcos et al., 2017), which may be due to both higher accuracy and response bias (Kensinger & Corkin, 2003; Ochsner, 2000). Emotion effects may be driven by arousal, equally affecting positive and negative contents, or by positive or negative valence (Dolcos & Cabeza, 2002; Kensinger & Corkin, 2004).

The content's self-reference also affects memory (Rogers, 1977; Sui & Humphreys, 2015). Self-referential processing is experimentally induced by a corresponding processing instruction on individually presented words, which enhances recognition or recall. This "self-reference effect" is attributed to elaborative stimulus processing and deep encoding (Symons & Johnson, 1997), similar to other levels of processing manipulations, such as concreteness decisions (Craik & Lockhart, 1972). Setting self-referential processing apart from other encoding manipulations, recent theories propose that the "self" acts as a hub, enabling efficient integration and storage of self-relevant information (Sui & Humphreys, 2015). Self-referential processing in social contexts is so far hardly understood. However, being confronted with social evaluations from somebody else likely creates a powerful social context, inducing self-referential updating to detect discrepancies with one's self-concept, adapt

it, or reject the information (see Shrauger & Schoeneman, 1979). In healthy people, such updating processes are often positively-biased, inducing more elaborative processing of self-serving (rather than merely self-relevant) information (Sharot & Garrett, 2016). Self-reference and emotion appear to interact and engage at least partly overlapping neural systems (Gutches & Kensinger, 2018).

Event-related brain potentials have been used to study stimulus encoding under various processing demands, ranging from free viewing and incidental encoding (Kissler et al., 2007), over levels of processing instructions (Rugg & Curran, 2007), and stimulus appraisals (Dolcos & Cabeza, 2002), to self-referential processing (Herbert et al., 2011) or processing in evaluative social contexts (Schindler et al., 2015). Early posterior negative (EPN) potentials appearing over visual cortex around 200 ms post-stimulus generally index feature-based attention and conceptual stimulus encoding, which can gate episodic encoding (Schupp et al., 2006). EPN potentials have been found to co-vary with task-driven attention deployment (Schupp et al., 2007), emotionally motivated attention (Junghöfer et al., 2001), self-reference (Herbert et al., 2011), but also contextually induced social relevance (Schindler et al., 2015). A series of later surface-positive potentials occurring over frontal and parietal brain areas index episodic memory encoding proper (e.g., see Friedman & Johnson, 2000). The parietal part of these effects, typically known as late positive potential (LPP) and occurring from about 400 ms post stimulus-onset, is also sensitive to explicit emotional appraisal (Dolcos and Cabeza, 2002) and self-reference (Herbert et al., 2011). Fronto-parietal slow waves after about 800 ms are generally assumed to reflect strategic verbal memory encoding (e.g., see Bosch et al., 2001).

Social evaluative contexts have been shown to considerably enhance both early negative and late positive brain potentials when identical trait adjectives are presented as personality feedback in virtual interaction setups, with larger EPN and LPP brain potentials and higher appropriateness ratings when feedback seems to come from more relevant interaction partners (e.g., see Schindler et al., 2015, 2019). However, no previous studies investigated possible long-term memory consequences.

The present research aims to fill this gap within the larger context of social memory formation. We study the effects of a social-evaluative encoding context on long-term recognition memory of positive, negative, and neutral trait adjectives. We present the exact same word lists in three different encoding contexts, measuring event-related brain potentials at encoding and recognition memory one week later. Specifically, we compare incidental encoding in a social-evaluative feedback context with intentional learning and incidental encoding via self-referential or semantic processing. We expect recognition memory and EPN and LPP amplitudes to be enhanced for emotional content and self-reference to be positively biased and specifically examine how recognition memory and ERPs are affected by the encoding context.

Results

Behavior during the encoding task

Social-feedback group (feedback acceptance). A main effect of emotional content ($F_{(2,46)} = 62.99, p < .001, \eta_p^2 = .733$) showed that positive feedback was most likely accepted, while negative feedback was least often accepted ($ps < .001$). A smaller main effect of feedback sender ($F_{(1,23)} = 5.12, p = .033, \eta_p^2 = .182$) revealed that

participants were more likely to accept feedback from the more relevant (“human”) sender. No interaction was found ($F_{(2,46)} = 0.48, p = .622, \eta_p^2 = .020$).

Levels-of-processing group (self-descriptiveness and concreteness). Here, effects of task ($F_{(1,23)} = 21.22, p < .001, \eta_p^2 = .480$), emotion ($F_{(2,46)} = 16.25, p < .001, \eta_p^2 = .414$), and their interaction were observed ($F_{(2,46)} = 23.31, p < .001, \eta_p^2 = .503$). For the self-reference task, an emotion effect was found ($F_{(2,46)} = 30.61, p < .001, \eta_p^2 = .571$), with participants selecting significantly more positive than both neutral ($p < .001$) and negative ($p < .001$) words as self-descriptive, neutral and negative words not differing ($p = 1.0$). In the concreteness task, there was no effect of emotional content on concrete/abstract decisions ($F_{(2,46)} = 1.05, p = .359, \eta_p^2 = .044$).

Recognition Memory (one week later)

Recognition memory data are shown in Fig. 1 and further detailed in Table 1 and Supplement A.

Discrimination accuracy

As shown in Fig. 1, experimental groups differed in discrimination accuracy ($F_{(2,65)} = 7.57, p = .001, \eta_p^2 = .189$). The social-feedback group was significantly more accurate than both the verbal-learning ($p = .007$) and the levels-of-processing group ($p < .001$). The latter did not differ ($p = .403$). Group and emotion did not interact ($F_{(4,130)} = 0.45, p = .776, \eta_p^2 = .014$), but a three-way interaction between group, encoding condition, and emotion ($F_{(4,130)} = 20.53, p < .001, \eta_p^2 = .387$) indicated that depending on the experiment, emotion effects differed between conditions (see Table 1). Within the levels-of-processing group, positive ($p = .003$) but not negative words ($p = .113$) from the self-descriptiveness task were recognized more accurately, while from the concreteness task neutral words ($p = .001$) were recognized best, whereas emotion effects did not depend on “sender” or “block” in the other two groups.

Response bias

Again, a main effect of group occurred ($F_{(2,65)} = 10.31, p < .001, \eta_p^2 = .241$; see Fig. 1, right panel). Both the social-feedback and the verbal-learning group responded more liberally than the levels-of-processing group ($p < .001$ and $p = .002$, respectively). Group further interacted with emotion ($F_{(4,130)} = 9.09, p < .001, \eta_p^2 = .218$; see Table 1), suggesting specific bias differences between the groups. Investigating positive-negative bias differences between groups ($F_{(2,65)} = 12.55, p < .001, \eta_p^2 = .279$), we found a larger positive bias for the social feedback group compared to both other groups ($ps < .001$), whereas the verbal-learning and levels-of-processing group did not differ ($p = .351$). For positive-neutral differences ($F_{(2,65)} = 6.33, p = .003, \eta_p^2 = .163$), a larger positive bias for the social feedback group was found compared to the levels-of-processing group ($p = .001$), but not compared to the instructed learning group ($p = .247$) who had a larger positive-bias than the levels-of-processing group ($p = .029$). Bias differences between negative and neutral words were similar across groups ($F_{(2,65)} = 3.10, p = .052, \eta_p^2 = .087$). Finally, a three-way interaction between group, condition, and emotion ($F_{(4,130)} = 6.42, p = .001, \eta_p^2 = .165$) revealed for the social-feedback group no significant “sender”-differences for positive words ($p = .882$), but more liberal responding to neutral ($p = .032$) and in tendency also negative ($p = .053$) words from a the more relevant sender. For the levels-of-processing group, more liberal responding to positive ($p = .004$) and negative words ($p = .019$) occurred for the self-relevance compared to the concreteness task (see Table 1).

Table 1
Memory data for the three groups

social-feedback group (N= 24)									
				human feedback			computer feedback		
	condition	emotion	interaction	negative	neutral	positive	negative	neutral	positive
	$F_{(1,23)}$	$F_{(2,46)}$	$F_{(2,46)}$						
P _r	1.12	3.53*	2.17	.32 (0.25)	.35 (0.30)	.24 (0.21)	.24 (0.29)	.29 (0.35)	.22 (0.27)
B _r	3.00	47.70***	4.58*	.50 (0.25)	.57 (0.23)	.71 (0.17)	.44 (0.22)	.48 (0.25)	.72 (0.19)
verbal-learning group (N= 21)									
				block A			block B		
	condition	emotion	interaction	negative	neutral	positive	negative	neutral	positive
	$F_{(1,20)}$	$F_{(2,40)}$	$F_{(2,40)}$						
P _r	0.07	0.83	0.57	.13 (0.15)	.14 (0.20)	.09 (0.19)	.14 (0.20)	.13 (0.22)	.10 (0.18)
B _r	0.47	23.48***	0.09	.48 (0.17)	.48 (0.15)	.60 (0.15)	.50 (0.17)	.49 (0.17)	.61 (0.16)
levels-of-processing group (N= 23)									
				self-reference task			semantic task		
	condition	emotion	interaction	negative	neutral	positive	negative	neutral	positive
	$F_{(1,22)}$	$F_{(2,44)}$	$F_{(2,44)}$						
P _r	0.04	3.53*	30.06***	.13 (0.19)	.00 (0.22)	.11 (0.20)	.05 (0.21)	.21 (0.18)	– .05 (0.25)
B _r	1.39	8.75**	6.80**	.36 (0.18)	.33 (0.09)	.45 (0.16)	.31 (0.14)	.40 (0.20)	.38 (0.11)
Note: * = $p < 0.05$, ** = $p < 0.01$, *** = $p < 0.001$. Standard deviations appear in parentheses. P _r = discrimination accuracy, B _r = recognition bias.									

Encoding ERPs

Early EPN (200–300)

For the early EPN, an effect of experimental group was found ($F_{(2,69)} = 9.47, p < .001, \eta_p^2 = .215$; see Fig. 2a). The social-feedback group had a larger EPN than both the verbal learning ($p < .001$) and the levels-of-processing group ($p = .037$). The latter also showed a larger EPN than the verbal-learning group ($p = .029$). A main effect of emotion ($F_{(2,138)} = 5.90, p = .003, \eta_p^2 = .079$; see Fig. 3b) was due to larger EPN for positive ($p = .002$) and negative ($p = .028$) words compared to neutral ones. Positive and negative words did not differ ($p = .179$). No further interactions emerged ($F_s < 0.93, p_s > .398$).

Late EPN (300–400)

For the later part of the EPN, again, an effect of experimental group occurred ($F_{(2,69)} = 4.81, p = .011, \eta_p^2 = .122$; see Fig. 3a). The social-feedback group ($p = .014$) and the levels-of-processing group ($p = .006$) showed a larger EPN than the verbal-learning group, the former not differing from each other ($p = .762$). Further, a main effect of emotion was observed ($F_{(2,138)} = 7.39, p = .001, \eta_p^2 = .097$; see Fig. 2b), with a larger EPN for positive compared to neutral ($p = .003$) and negative words ($p = .001$). Negative and neutral words did not differ ($p = .698$). There were no further interactions ($F_s < 0.93, p_s > .398$).

LPP (400–800 ms)

Experimental groups differed again for the LPP ($F_{(2,69)} = 5.65, p = .005, \eta_p^2 = .141$; see Fig. 3a). The social-feedback group had much larger LPP amplitudes than the verbal-learning ($p = .001$), and somewhat larger ones than the levels-of-processing group ($p = .070$), the latter groups did not differ ($p = .134$). A main effect of emotion ($F_{(2,138)} = 3.71, p = .027, \eta_p^2 = .051$; see Fig. 3b) showed a larger LPP for positive compared to neutral ($p = .031$) and negative words ($p = .019$), the latter not differing ($p = .908$). An interaction of emotion and channel group ($F_{(4,138)} = 4.50, p = .002, \eta_p^2 = .115$) revealed that the emotion effect was more pronounced parietally ($F_{(2,138)} = 3.88, p = .023, \eta_p^2 = .103$) than frontally ($F_{(2,138)} = 2.53, p = .083, \eta_p^2 = .035$). Similar to the global emotion effect, for the parietal cluster a larger LPP for positive than negative words ($p = .007$) was found. Neither positive ($p = .180$) nor negative words ($p = .156$) differed from neutral ones.

A further four-way interaction occurred ($F_{(4,138)} = 3.48, p = .010, \eta_p^2 = .092$) which is resolved and illustrated in the Supplement – Section C.

Slow-wave (800–1200 ms)

In the slow-wave window, a main effect of experimental group was also found ($F_{(2,69)} = 3.57, p = .033, \eta_p^2 = .094$; see Fig. 3a). Here, the verbal-learning group had a larger positive-going slow-wave than the social-feedback ($p = .021$) and the levels-of-processing groups ($p = .026$), who did not differ ($p = .933$). No other main effects ($F_{(2,138)} = 1.08, p = .342, \eta_p^2 = .015$) or any significant interactions emerged ($F_s < 2.10, p_s > .084$).

Run 2 / passive viewing re-presentation of word stimuli

After debriefing, there were no effects of group, condition, emotion, or any interactions between these factors for early and late parts of the EPN and early and late parts of the LPP ($F_s < 1.40, p_s > .236$).

Discussion

Humans typically acquire information in social contexts. Therefore, we investigated its role for long-term recognition memory and encoding ERPs for positive, negative, and neutral words. We compared a group for whom a social context was induced via a self-introduction followed by evaluative feedback (“social-feedback” group) with a verbal-learning and a standard levels-of-processing group. Although the social-feedback group was not aware of the recognition session one week later, this group showed superior recognition accuracy, but also an increased response bias, particularly for positive adjectives. Encoding ERPs revealed the highest EPN and LPP amplitudes in the social-feedback group. Only in the slow-wave window were ERPs most positive-going in the verbal-learning group. ERPs from the levels-of-processing group fell in between the other two. Together, these findings reveal a distinct effect of evaluative social context, enhancing long-term recognition memory and encoding ERPs beyond both explicit learning and standard levels of processing manipulations, while also inducing specific biases.

The highest memory accuracy in the social feedback group indicates that the social context facilitated memory encoding, likely via elaborative stimulus processing which is known to enhance memory (Fisher & Craik, 1977; Sui & Humphreys, 2015; Symons & Johnson, 1997). Since explicit learning tasks are typically easier and result in better memory than incidental ones (Rugg et al., 1998; Wang, 2020), these findings highlight the power of social context to increase stimulus encoding.

Groups also differed in their response bias, with less conservative responses in the social-feedback and the verbal learning groups. Moreover, the social-feedback group was specifically biased towards classifying positive words as “old”. Healthy participants are known to have optimistic feedback expectations (Hepper et al., 2011), leading to distorted memory when information is incongruent with their positive self-view (Story, 1998). In fact, better than expected evaluations induce positively biased self-updating (Korn et al., 2012) as well as a specific feedback-related positivity (Schindler et al., 2021). Self-serving tendencies also occurred in feedback acceptance (social-feedback group) and self-descriptiveness decisions (levels-of-processing group), the highest acceptance rates for positive adjectives corresponding with positive self-views of healthy participants (e.g., see Sharot & Garrett, 2016).

Concerning ERPs, words in the social feedback context elicited the largest EPN and LPP amplitudes, followed by levels-of-processing and, finally, instructed learning. Per se, these ERP modulations are broadly in line with findings of increased EPN and LPP amplitudes for various manipulations of self-reference and social feedback (e.g., see Bayer et al., 2017; Fields & Kuperberg, 2012; Herbert et al., 2011; Schindler et al., 2015). Given the EPN’s role in early attentional selection (Schupp et al., 2007), results show a rapid prioritizing role of social-evaluative context beyond mere task-relevance. The highest LPP in the social feedback group accords with this component indexing successful memory encoding (Dolcos & Cabeza, 2002).

Finally, only in the slow-wave window were ERPs more positive-going in the verbal-learning group than in the other two groups. Given the role of positive-going slow waves in strategic verbal memory encoding (Bosch et al., 2001), this finding might explain why the verbal-learning group had similar recognition accuracy (and even more hits) than the levels-of-processing group, despite having smaller amplitudes on the earlier ERPs. Therefore, encoding in the social feedback and levels-of-processing groups seems to have relied more on automatic mechanisms, whereas the verbal-learning group recruited more strategic processes—exploratory correlations accord with this interpretation (see Supplementary Materials Section B).

As expected, significant emotion effects on brain potentials were also observed, although they were smaller than the context-effects. Emotion sensitivity of EPN and LPP components aligns with much previous research (e.g., see Hinojosa et al., 2010; Kissler et al., 2007; Rohr & Abdel Rahman, 2018; Schacht & Sommer, 2009). Largest amplitudes for positive words have also been reported before (e.g., Herbert et al., 2008). Self-referential processing might have contributed to a more substantial increase for positive content, whereas in other situations a bias towards negative material might occur (e.g., see Hinojosa et al., 2010; Schacht & Sommer, 2009).

Overall, we show that social context during encoding enhances long-term recognition memory beyond explicit learning or typical deeper incidental encoding tasks (self-descriptiveness or concreteness decisions). Notably, although both the social feedback and self-descriptiveness task probably recruited self-referential processing, effects in the feedback condition, where any self-reference was socially contextualized, by far exceeded those of task-driven self-referential processing alone. Although the retention interval leaves ample time for consolidation or spontaneous rehearsal, which we cannot directly assess, the immediate repetition run revealed no significant effects, suggesting that effects were either due to initial encoding, where corresponding ERP modulations occurred, or arose considerably later.

Our focus was on the between-groups analysis, which de-emphasizes potentially interesting effects in individual conditions. Still, in Experiment 1, some “sender” differences occurred at encoding (see Supplement C), replicating previous research (e.g., see Schindler et al., 2019). However, these had little effect on long-term recognition, suggesting that participants integrated both blocks from experiment 1 into one episode whose items were considerably more memorable than those from the other two experiments. Interactions in the levels-of-processing group indicate that encoding task modulates emotion effects in long-term recognition memory, only self-descriptiveness and not concreteness decisions resulting in an emotion effect on recognition accuracy, in line with the suggestion of interacting memory effects of self and emotion (see Gutchess & Kensinger, 2018).

In sum, although we used identical stimuli and presentation parameters across three experiments, the psychological encoding contexts elicited pronounced between-group differences in recognition memory and ERPs: The social-feedback context enhanced recognition memory beyond both explicit verbal-learning and self-descriptiveness/concreteness judgments. It also induced the largest EPN and LPP amplitudes, followed by levels-of-processing and verbal learning. The most positive-going slow wave amplitudes in the verbal learning group suggest that this group might have relied particularly on strategic memory processes. Our findings specify some important social factors in human long-term memory. They resonate with the fact that humans typically acquire information in social contexts (e.g., see Light & Perret-Clermont, 1991), social evaluation being a particularly salient factor in human life (e.g., see Moor et al., 2010). Finally, these results have implications for memory formation in educational settings or memory assessment in legal contexts, where the extent to which individuals were exposed to an evaluative social context will affect their memory for elements of the initial episode.

Methods

Participants

Three groups of twenty-four participants each were recruited at Bielefeld University. Participants provided written informed consent and received 10 Euros per hour for participation. The Ethics Committee at Bielefeld University approved the study and the study was performed in accordance with the regulations of the Declaration of Helsinki. All subjects were right-handed, had normal or corrected-to-normal vision, and were free from a self-reported neurologic or psychiatric disorder. They were tested twice with a lag of about one week (T1-T2 difference $M = 7.13$ days, $Min = 6$ days, $Max = 9$ days, see Table 1).

Table 2
Demographic information for the participants in each experiment

Variable	social-feedback group ($N = 24$)	verbal-learning group ($N = 24$)	levels-of-processing group ($N = 24$)
Gender female/male	14/10	19/5	18/6
Age	24.13 (2.54)	25.48 ^a (4.71)	24.36 ^b (3.08)
BDI Score*	4.87 (5.31)	4.61 ^a (3.93)	4.91 (5.27)
STAI state**	33.92 (6.97)	35.48 ^a (4.21)	32.54 (6.82)
STAI trait**	33.92 (6.97)	35.48 ^c (4.21)	32.54 (6.82)
T1-T2 difference	7.13 (0.61)	7.00 ^b (0.31)	7.61 ^a (0.66)
Note: a) information is missing from one b) missing from two c) missing from three participants. *BDI: Beck's Depression Inventory (Hautzinger et al., 2006). **STAI: State-Trait Anxiety Inventory (Spielberger et al., 1999)			

Stimuli

The stimulus set had been rated by 22 other students on nine-point Likert-type scales in terms of valence and arousal using the Self-Assessment Manikin (Bradley & Lang, 1994) and a similarly constructed concreteness scale. The selected 270 adjectives (90 negative, 90 neutral, 90 positive) were assigned to three separate lists. Neutral adjectives were allowed to deviate from emotional adjectives on both arousal and concreteness since truly neutral trait adjectives are rare in an interpersonal evaluative contexts. The three lists did not differ in relevant emotional and lexical properties, and the list-condition assignment was counterbalanced (see Table 3).

Table 3

Comparisons of negative, neutral, and positive adjectives for three separate lists by One-Way-ANOVAs

Variable	Negative adjectives each list ($N=30$)	Neutral adjectives each list ($N=30$)	Positive adjectives each list ($N=30$)
Valence: Main effect emotion $F_{(2,270)} = 1182.37^{***}$, Interaction Emotion*List $F_{(4,270)} = 1.24$			
List 1	2.83 ^a (0.64)	4.58 ^b (0.64)	7.44 ^c (0.72)
List 2	2.78 ^a (0.57)	4.84 ^b (0.50)	7.32 ^c (0.70)
List 3	2.70 ^a (0.56)	4.84 ^b (0.55)	7.27 ^c (0.77)
Arousal: Main effect emotion $F_{(2,270)} = 121.80^{***}$, Interaction Emotion*List $F_{(4,270)} = 0.25$			
List 1	4.95 ^a (0.89)	3.42 ^b (0.98)	4.79 ^a (0.75)
List 2	4.96 ^a (0.71)	3.20 ^b (0.68)	4.71 ^a (0.73)
List 3	4.98 ^a (0.85)	3.20 ^b (0.78)	4.69 ^a (0.63)
Concreteness: Main effect emotion $F_{(2,270)} = 73.15^{***}$, Interaction Emotion*List $F_{(4,270)} = 0.19$			
List 1	3.61 ^a (0.93)	5.32 ^b (1.67)	3.15 ^a (1.22)
List 2	3.62 ^a (0.96)	5.49 ^b (1.36)	3.38 ^a (1.20)
List 3	3.40 ^a (0.91)	5.03 ^b (1.42)	3.17 ^a (1.13)
Word length: Main effect of emotion $F_{(2,270)} = 0.29$, Interaction Emotion*List $F_{(4,270)} = 0.07$			
List 1	8.93 ^a (2.12)	8.97 ^a (1.92)	9.20 ^a (2.48)
List 2	8.93 ^a (2.52)	9.13 ^a (2.57)	9.03 ^a (3.17)
List 3	8.80 ^a (2.63)	9.03 ^a (2.54)	9.30 ^a (2.65)
Frequency (per million): Main effect of emotion $F_{(2,270)} = 0.11$, Interaction Emotion*List $F_{(4,270)} = 0.01$			
List 1	375.03 ^a (482.35)	393.37 ^a (517.83)	344.80 ^a (485.97)
List 2	396.33 ^a (589.39)	397.80 ^a (526.32)	367.07 ^a (490.14)
List 3	359.97 ^a (580.87)	383.83 ^a (535.67)	356.80 ^a (466.75)
Note: *** = $p \leq 0.001$. Cells provide the means for the different word attributes with standard deviations in parentheses; means for the same List not sharing subscripts differ at $p \leq 0.05$ based on LSD test post-hoc comparisons.			

Procedure

An outline of the experimental setup for the three groups is presented in Fig. 4.

Social-feedback group. Upon arrival, participants were told that another, unknown person, would evaluate them based on their self-presentation. In a second condition, a randomly operating computer algorithm was supposedly going to give them feedback. All subjects underwent both “sender” conditions. Condition sequence and word lists were counterbalanced. Importantly, random feedback was presented in both conditions. Participants were instructed to briefly describe themselves in a structured interview in front of a camera. They were informed that the video of their self-description would be presented to another person. During EEG preparation, participants completed a demographic questionnaire and the BDI (Hautzinger et al., 2006) and STAI (Spielberger et al., 1999) to characterize the sample. A research assistant left the testing room 15 minutes ahead of the fictitious feedback to ensure face validity, guiding an “unknown person” to a laboratory room next to the testing room.

Stimuli were presented by software described as “Interactional Behavioral Systems”, supposedly allowing instant online communication. Participants were told that the unknown other person would select adjectives describing the participant, which would be subsequently presented. In the other condition, feedback was denoted as random computer feedback. Feedback-adjectives were presented for 1500 ms, after which the participants had to indicate via button-press whether or not they agree with this evaluation. After the response, a fixation cross was presented for 2000 to 3500 ms. For each sender, 30 negative, 30 neutral, and 30 positive adjectives (one of the three lists, see Table 2) were presented twice. The desktop environment and stimulus presentation were created using Presentation (www.neurobehavioralsystems.com). Afterwards, participants were debriefed that no social evaluation had taken place and presented a passive viewing run of all 60 negative, 60 neutral, and 60 positive adjectives again to test for any immediate post-processing effects of the manipulation.

Participants were informed that an unrelated test would be conducted in a second session one week later, where an unexpected recognition test took place. All adjectives from the first session and a set of new items were shown for 1500 ms each, followed by an old/new decision and a fixation cross for 1500 to 2000 ms.

Verbal-learning group. The very same stimuli and presentation parameters were used. In order to keep the visual input constant, the same background presentation setup (Interactive Behavioral Systems) was used but never referred to. The self-introduction phase was omitted, and no social significance was assigned to the stimulation. Instead, participants were instructed to memorize all adjectives for recognition testing in the next session one week later. Adjectives were presented for 1500 ms, followed by a variable fixation cross presented for 2000 to 3500 ms. To mimic the “social-feedback” experiment, two counterbalanced conditions were presented (block “A” and block “B”), using the same material and number of repetitions (see Fig. 4b, Fig. 4d, Table 2). Condition order was counterbalanced. A passive viewing run finished the experimental session.

Levels-of-processing group. The same materials and presentation parameters as in the previous two experiments were used. As in experiment 1, active word evaluation was instructed, but no social context was created. Participants were told to either decide via button press on the self-descriptiveness of the presented words or, in condition two, perform a binary concreteness judgment on the words, classifying them as either abstract or concrete. This closely reflected the encoding trial structure for the social-feedback group. Adjectives were presented for 1500 ms, after which the binary decision was requested. Material and experimental parameters were the same as in the social feedback group (see Fig. 4c, Fig. 4d, Table 2). Again, the session was finished with a passive viewing run.

EEG recording and analyses

EEG was recorded from 128 BioSemi active electrodes (www.biosemi.com) at 1024Hz. Two separate electrodes were used as ground electrodes, a Common Mode Sense active electrode (CMS) and a Driven Right Leg passive electrode (DLR), which form a feedback loop to measure the average potential close to the reference in the A/D-box (www.biosemi.com/faq/cms&drl.htm). Four additional electrodes (EOG) measured horizontal and vertical eye movement.

Pre-processing and statistical analyses were performed using BESA (www.besa.de) and EMEGS (Peyk et al., 2011). Offline, data was re-referenced to an average reference and filtered with a high-pass forward filter of 0.16 (6 db/oct) and a 30 Hz low-pass zero-phase filter (24 db/oct). Filtered data were segmented from 200 ms before word onset until 1500 ms after stimulus presentation. The 200 ms before stimulus onset were used for baseline correction. Eye-movements were corrected using the automatic correction method implemented in BESA (Ille et al., 2002). Remaining artifacts were rejected based on an absolute threshold ($< 120 \mu\text{V}$), signal gradient ($< 75 \mu\text{V}/\partial\text{T}$), and low signal (i.e., the *SD* of the gradient, $> 0.01 \mu\text{V}/\partial\text{T}$). Noisy EEG sensors were interpolated using a spline interpolation procedure.

Statistical analyses

For all data, we calculated three (group: social-feedback, verbal-learning, levels-of-processing) by two (condition: human sender/block A /self-reference, computer sender/block B /concreteness) by three (emotion: positive, negative, neutral) repeated-measures ANOVAs. For memory data, the discrimination index (P_r = hits-false alarms), and the response bias (B_r = false alarms/(1- P_r)) were calculated according to Snodgrass and Corwin's two-high-threshold model (1988). B_r values of 0.5 indicate no response bias, while higher values indicate a liberal and lower values a conservative response strategy. Raw data are presented in Supplementary Materials Section A. Furthermore, for the social-feedback and levels-of-processing groups, decision rates (agreement, self-descriptiveness, concreteness) were assessed.

ERP data were analyzed and visualized with EMEGS (Peyk et al., 2011) and in-house Matlab scripts. Effect sizes were estimated as partial eta-squared (η_p^2 , see Cohen, 1988). When Mauchly's test indicated a violation of sphericity, degrees of freedom were corrected according to Greenhouse-Geisser. We report uncorrected degrees of freedom but corrected *p*-values and effect sizes. Time windows of interest were segmented from 200 to 300 ms for early and from 300 to 400 for late EPN. The LPP was scored from 400 to 800 ms and the slow-wave from 800 to 1,200ms. For the EPN, a parieto-occipital cluster of eighteen electrodes was examined (P9, P9h, P7, P09, P09h, P07, I1, O11, O1, P10, P10h, P8, P010, P010h, P08, I2, O12, O2). The LPP and the slow-wave were measured at a frontal and a posterior cluster of seventeen electrodes each (frontal: F1, Fz, F2, FFC1, FFC1h, FFCz, FFC2h, FFC2, FC3h, FC1, FC1h, FCz, FC2h, FC2, FC4h, FCC1h, FCC2h; parietal: CCPz, CP3h, CP1, CP1h, CPz, CP2h, CP2, CP4h, CPP1, CPPz, CPP2, P1, Pz, P2, PPO1, PPOz, PPO2). Exploratory correlations between ERP amplitudes during encoding and memory performance are reported in Supplementary Materials Section B.

Declarations

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Author disclosure

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References

1. Bayer, M., Ruthmann, K., & Schacht, A. (2017). The impact of personal relevance on emotion processing: Evidence from event-related potentials and pupillary responses. *Social Cognitive and Affective Neuroscience*, *12*(9), 1470–1479. <https://doi.org/10.1093/scan/nsx075>
2. Gutchess, A. & Kensinger, E. A. Shared Mechanisms May Support Mnemonic Benefits from Self-Referencing and Emotion. *Trends in Cognitive Sciences*, *22* (8), 712–724 <https://doi.org/10.1016/j.tics.2018.05.001> (2018).
3. Hautzinger, M., Keller, F. & Kühner, C. *Beck depressions-inventar (BDI-II)* (Harcourt Test Services, 2006).
4. Hepper, E. G., Hart, C. M., Gregg, A. P. & Sedikides, C. Motivated expectations of positive feedback in social interactions. *The Journal of Social Psychology*, *151*, 455–477 (2011).
5. Herbert, C., Junghöfer, M. & Kissler, J. Event related potentials to emotional adjectives during reading., *45*, 487–498 (2008).
6. Herbert, C., Pauli, P. & Herbert, B. M. Self-reference modulates the processing of emotional stimuli in the absence of explicit self-referential appraisal instructions. *Social Cognitive and Affective Neuroscience*, *6*, 653–661 (2011).
7. Hinojosa, J. A., Albert, J., López-Martín, S. & Carretié, L. Temporospatial analysis of explicit and implicit processing of negative content during word comprehension. *Brain and Cognition*, *87*, 109–121 <https://doi.org/10.1016/j.bandc.2014.03.008> (2014).
8. Hinojosa, J. A., Méndez-Bértolo, C. & Pozo, M. A. Looking at emotional words is not the same as reading emotional words: Behavioral and neural correlates., *47* (4), 748–757 (2010).
9. Ille, N., Berg, P. & Scherg, M. Artifact Correction of the Ongoing EEG Using Spatial Filters Based on Artifact and Brain Signal Topographies. *Journal of Clinical Neurophysiology*, *19* (2), 113–124 (2002).
10. Junghöfer, M., Bradley, M. M., Elbert, T. R. & Lang, P. J. Fleeting images: A new look at early emotion discrimination., *38* (2), 175–178 <https://doi.org/10.1111/1469-8986.3820175> (2001).
11. Kanske, P. & Kotz, S. A. Concreteness in emotional words: ERP evidence from a hemifield study. *Brain Res*, *1148*, 138–148 Epub 2007 Feb 27. (2007).
12. Kensinger, E. A. & Corkin, S. Memory enhancement for emotional words: Are emotional words more vividly remembered than neutral words? *Mem. Cognit*, *31* (8), 1169–1180 <https://doi.org/10.3758/BF03195800>

(2003).

13. Kensinger, E. A. & Corkin, S. (2004). Two routes to emotional memory: Distinct neural processes for valence and arousal. *Proceedings of the National Academy of Sciences*, *101*(9), 3310–3315.
<https://doi.org/10.1073/pnas.0306408101>
14. Kissler, J., Herbert, C., Peyk, P. & Junghofer, M. Buzzwords: Early cortical responses to emotional words during reading. *Psychol. Sci*, *18*, 475–480 (2007).
15. Korn, C. W., Prehn, K., Park, S. Q., Walter, H. & Heekeren, H. R. Positively biased processing of self-relevant social feedback. *The Journal of Neuroscience*, *32*, 16832–16844 (2012).
16. Light, P. & Perret-Clermont, A. N. (1991). Social context effects in learning and testing. *Learning to Think*, 136–149.
17. Moor, B. G., van Leijenhorst, L., Rombouts, S. A. R. B., Crone, E. A. & Van der Molen, M. W. Do you like me? Neural correlates of social evaluation and developmental trajectories. *Soc. Neurosci*, *5*, 461–482 (2010).
18. Ochsner, K. N. Are affective events richly recollected or simply familiar? The experience and process of recognizing feelings past. *Journal of Experimental Psychology: General*, *129* (2), 242–261
<https://doi.org/10.1037/0096-3445.129.2.242> (2000).
19. Peyk, P., De Cesarei, A. & Junghöfer, M. (2011). Electro Magneto Encephalography Software: Overview and integration with other EEG/MEG toolboxes. *Computational Intelligence and Neuroscience*, Volume 2011, Article ID 861705(2011:861705), 1–11. <https://doi.org/10.1155/2011/861705>
20. Rogers, T. B. Self-reference in memory: Recognition of personality items. *Journal of Research in Personality*, *11* (3), 295–305 [https://doi.org/10.1016/0092-6566\(77\)90038-1](https://doi.org/10.1016/0092-6566(77)90038-1) (1977).
21. Rohr, L. & Abdel Rahman, R. Loser! On the combined impact of emotional and person-descriptive word meanings in communicative situations., <https://doi.org/10.1111/psyp.13067> (2018). /a-n/a
22. Rugg, M. D. & Curran, T. Event-related potentials and recognition memory. *Trends in Cognitive Sciences*, *11* (6), 251–257 <https://doi.org/10.1016/j.tics.2007.04.004> (2007).
23. Rugg, M. D. *et al.* Dissociation of the neural correlates of implicit and explicit memory. *Nature*, *392* (6676), 595–598 <https://doi.org/10.1038/33396> (1998).
24. Schacht, A. & Sommer, W. Time course and task dependence of emotion effects in word processing. *Cogn. Affect. Behav. Neurosci*, *9*, 28–43 <https://doi.org/10.3758/CABN.9.1.28> (2009).
25. Schindler, S., Höhner, A., Moeck, R., Bruchmann, M. & Straube, T. Let's Talk About Each Other: Neural Responses to Dissenting Personality Evaluations Based on Real Dyadic Interactions. *Psychol. Sci*, 0956797621995197 <https://doi.org/10.1177/0956797621995197> (2021).
26. Schindler, S., Miller, G. A. & Kissler, J. Attending to Eliza: Rapid brain responses reflect competence attribution in virtual social feedback processing. *Social Cognitive and Affective Neuroscience*, *14* (10), 1073–1086 <https://doi.org/10.1093/scan/nsz075> (2019).
27. Schindler, S., Wegrzyn, M., Steppacher, I. & Kissler, J. Perceived Communicative Context and Emotional Content Amplify Visual Word Processing in the Fusiform Gyrus. *The Journal of Neuroscience*, *35* (15), 6010–6019 <https://doi.org/10.1523/JNEUROSCI.3346-14.2015> (2015).
28. Schupp, H. T., Flaisch, T., Stockburger, J. & Junghofer, M. Emotion and attention: Event-related brain potential studies. *Progress in Brain Research*, *156*, 31–51 [https://doi.org/10.1016/S0079-6123\(06\)56002-9](https://doi.org/10.1016/S0079-6123(06)56002-9) (2006).

29. Schupp, H. T. *et al.* Selective visual attention to emotion. *The Journal of Neuroscience*, **27**, 1082–1089 <https://doi.org/10.1523/JNEUROSCI.3223-06.2007> (2007).
30. Sharot, T. & Garrett, N. Forming Beliefs: Why Valence Matters. *Trends in Cognitive Sciences*, **20** (1), 25–33 <https://doi.org/10.1016/j.tics.2015.11.002> (2016).
31. Shrauger, J. S. & Schoeneman, T. J. Symbolic interactionist view of self-concept: Through the looking glass darkly. *Psychol. Bull.*, **86** (3), 549 (1979).
32. Snodgrass, J. G. & Corwin, J. Pragmatics of measuring recognition memory: Applications to dementia and amnesia. *Journal of Experimental Psychology: General*, **117** (1), 34–50 <https://doi.org/10.1037/0096-3445.117.1.34> (1988).
33. Spielberger, C. D., Sydeman, S. J., Owen, A. E. & Marsh, B. J. (1999). Measuring anxiety and anger with the State-Trait Anxiety Inventory (STAI) and the State-Trait Anger Expression Inventory (STAXI). In M. E. Maruish (Ed.), *The use of psychological testing for treatment planning and outcomes assessment (2nd ed.)* (pp. 993–1021). Lawrence Erlbaum Associates.
34. Story, A. L. Self-Esteem and Memory for Favorable and Unfavorable Personality Feedback. *Personality and Social Psychology Bulletin*, **24** (1), 51–64 <https://doi.org/10.1177/0146167298241004> (1998).
35. Sui, J. & Humphreys, G. W. The Integrative Self: How Self-Reference Integrates Perception and Memory. *Trends in Cognitive Sciences*, **19** (12), 719–728 <https://doi.org/10.1016/j.tics.2015.08.015> (2015).
36. Symons, C. S. & Johnson, B. T. The self-reference effect in memory: A meta-analysis. *Psychol. Bull.*, **121** (3), 371–394 <https://doi.org/10.1037/0033-2909.121.3.371> (1997).
37. Tavares, R. M. *et al.* A Map for Social Navigation in the Human Brain., **87** (1), 231–243 <https://doi.org/10.1016/j.neuron.2015.06.011> (2015).
38. Wang, F. H. Explicit and implicit memory representations in cross-situational word learning., **205**, 104444 <https://doi.org/10.1016/j.cognition.2020.104444> (2020).
39. Yonelinas, A. P., Ranganath, C., Ekstrom, A. D. & Wiltgen, B. J. A contextual binding theory of episodic memory: Systems consolidation reconsidered. *Nature Reviews Neuroscience*, **20** (6), 364–375 <https://doi.org/10.1038/s41583-019-0150-4> (2019).
40. Schupp, H. T., Stockburger, J., Codispoti, M., Junghöfer, M., Weike, A. I., & Hamm, A. O. (2007). Selective visual attention to emotion. *The Journal of Neuroscience*, **27**, 1082–1089. <https://doi.org/10.1523/JNEUROSCI.3223-06.2007>
41. Sharot, T., & Garrett, N. (2016). Forming Beliefs: Why Valence Matters. *Trends in Cognitive Sciences*, **20**(1), 25–33. <https://doi.org/10.1016/j.tics.2015.11.002>
42. Shrauger, J. S., & Schoeneman, T. J. (1979). Symbolic interactionist view of self-concept: Through the looking glass darkly. *Psychological Bulletin*, **86**(3), 549.
43. Snodgrass, J. G., & Corwin, J. (1988). Pragmatics of measuring recognition memory: Applications to dementia and amnesia. *Journal of Experimental Psychology: General*, **117**(1), 34–50. <https://doi.org/10.1037/0096-3445.117.1.34>
44. Spielberger, C. D., Sydeman, S. J., Owen, A. E., & Marsh, B. J. (1999). Measuring anxiety and anger with the State-Trait Anxiety Inventory (STAI) and the State-Trait Anger Expression Inventory (STAXI). In M. E. Maruish (Ed.), *The use of psychological testing for treatment planning and outcomes assessment (2nd ed.)* (pp. 993–1021). Lawrence Erlbaum Associates.

45. Story, A. L. (1998). Self-Esteem and Memory for Favorable and Unfavorable Personality Feedback. *Personality and Social Psychology Bulletin*, 24(1), 51–64. <https://doi.org/10.1177/0146167298241004>

46. Sui, J., & Humphreys, G. W. (2015). The Integrative Self: How Self-Reference Integrates Perception and Memory. *Trends in Cognitive Sciences*, 19(12), 719–728. <https://doi.org/10.1016/j.tics.2015.08.015>

47. Symons, C. S., & Johnson, B. T. (1997). The self-reference effect in memory: A meta-analysis. *Psychological Bulletin*, 121(3), 371–394. <https://doi.org/10.1037/0033-2909.121.3.371>

48. Tavares, R. M., Mendelsohn, A., Grossman, Y., Williams, C. H., Shapiro, M., Trope, Y., & Schiller, D. (2015). A Map for Social Navigation in the Human Brain. *Neuron*, 87(1), 231–243. <https://doi.org/10.1016/j.neuron.2015.06.011>

49. Wang, F. H. (2020). Explicit and implicit memory representations in cross-situational word learning. *Cognition*, 205, 104444. <https://doi.org/10.1016/j.cognition.2020.104444>

50. Yonelinas, A. P., Ranganath, C., Ekstrom, A. D., & Wiltgen, B. J. (2019). A contextual binding theory of episodic memory: Systems consolidation reconsidered. *Nature Reviews Neuroscience*, 20(6), 364–375. <https://doi.org/10.1038/s41583-019-0150-4>

Figures

Figure 1

Behavioral data for the social-feedback, verbal-learning, and levels-of-processing group. Discrimination accuracy ($Pr = \text{Hits} - \text{False alarms}$) and response bias ($Br = \text{false alarms}/(1-Pr)$) are shown per emotional category and group. Error bars depict ± 1 Standard Error of the Mean.

Figure 2

EPN effects of A) experimental group and B) emotion. Scalp topographies depict the mean amplitude differences for the respective interval. ERPs show the time course averaged from highlighted sensors. Between-group difference potentials contain 95% bootstrap confidence intervals. Between-emotion difference-potentials contain 95% bootstrap confidence intervals of intra-individual differences. For bar charts, error bars show 95% confidence intervals.

Figure 3

LPP and slow-wave effects of A) experimental group and B) emotion. Scalp topographies depict the mean amplitude differences for the respective interval. ERPs show the time course from averaged highlighted sensors. Respective difference potentials contain 95% bootstrap confidence intervals of the group differences. Emotion difference waves contain 95% bootstrap confidence intervals of intra-individual differences. For bar charts, error bars show 95% confidence intervals.

Figure 4

Example experimental and main experiment trial structure for the a) social-feedback group, b) verbal-learning, and c) levels-of-processing group.

Supplementary Files

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