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When I relive a positive me: Vivid autobiographical memories facilitate autonoetic brain activation and enhance mood

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Abstract

Autobiographical memory is vital for our well-being and therefore used in therapeutic interventions. However, not much is known about the (neural) processes by which reliving memories can have beneficial effects. This study investigates what brain activation patterns and memory characteristics facilitate the effectiveness of reliving positive autobiographical memories for mood and sense of self. Particularly, the role of vividness and autonoetic consciousness is studied. Participants (N= 47) with a wide range of trait self-esteem relived neutral and positive memories while their bold responses, experienced vividness of the memory, mood, and state self-esteem were recorded. More vivid memories related to better mood and activation in amygdala, hippocampus and insula,indicative of increased awareness of oneself (i.e., prereflective aspect of autonoetic con-sciousness). Lower vividness was associated with increased activation in the occipital lobe, PCC, and precuneus, indicative of a more distant mode of reliving. While individuals with lower trait self-esteem increased in state self-esteem, they showed less deacti-vation of the lateral occipital cortex during positive memories. In sum, the vividness of the memory seemingly distinguished a more immersed and more distant manner of memory reliving. In particular, when reliving positive memories higher vividness facilitated increased prereflective autonoetic consciousness, which likely is instrumental in boosting mood.

Keywords

me:, positive, relive, i, when, activation, brain, autonoetic, mood, facilitate, enhance, memories, autobiographical, vivid

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When I relive a positive me: Vivid autobiographical memories facilitate autonoetic brain activation and enhance mood

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Abstract

Autobiographical memory is vital for our well-being and therefore used in therapeutic interventions. However, not much is known about the (neural) processes by which reliving memories can have beneficial effects. This study investigates what brain activation patterns and memory characteristics facilitate the effectiveness of reliving positive autobiographical memories for mood and sense of self. Particularly, the role of vividness and autonoetic consciousness is studied. Participants ($N = 47$) with a wide range of trait self-esteem relived neutral and positive memories while their bold responses, experienced vividness of the memory, mood, and state self-esteem were recorded. More vivid memories related to better mood and activation in amygdala, hippocampus and insula, indicative of increased awareness of oneself (i.e., prereflective aspect of autonoetic consciousness). Lower vividness was associated with increased activation in the occipital lobe, PCC, and precuneus, indicative of a more distant mode of reliving. While individuals with lower trait self-esteem increased in state self-esteem, they showed less deactivation of the lateral occipital cortex during positive memories. In sum, the vividness of the memory seemingly distinguished a more immersed and more distant manner of memory reliving. In particular, when reliving positive memories higher vividness facilitated increased prereflective autonoetic consciousness, which likely is instrumental in boosting mood.

KEYWORDS
autonoetic consciousness, fMRI, hippocampus, insula, positive autobiographical memories, self-esteem, vividness

1 | INTRODUCTION

Mental well-being is supported by autobiographical memory (Pillemer, 2001; Waters, 2014). Reliving autobiographical memories (AM) serves emotion regulation and identity functions (Bluck, Alea, Habermas, & Rubin, 2005) such as improving current mood states and maintaining a coherent identity (Harris, Rasmussen, & Berntsen, 2014; Josephson, 1996; Pillemer, 2003). Typically, research focuses on neutral or aversive autobiographical memories or the valence of memories is not distinguished. Even though, positive memories are spontaneously used in daily life (Josephson, 1996; Philippe, Lecours, & Beaulieu-Pelletier, 2009) and in various therapeutic interventions (Hitchcock et al., 2015; Korrelboom, Marissen, & van Assendelft, 2011), there is a dearth of (neuroimaging) research on how positive memories are relived and can generate beneficial outcomes. Moreover, there are individual variations, with some people having difficulties to use positive AM to boost mood and self-evaluation, even when these memories are accessible (Foland-Ross, Cooney, Joormann, Henry, & Gotlib, 2014; Joormann, Siemer, & Gotlib, 2007). Identifying the neural processes involved in the effectiveness of reliving positive AM and the factors that facilitate or obstruct it, may hence inform our basic understanding of autobiographical memory and memory based clinical interventions. This study investigates the neural regions involved in reliving positive versus neutral AM, and aims to clarify whether the vividness of memories and trait self-esteem affect consequent mood states, state self-esteem, and neural activation.

A broad fronto-temporo-parietal brain network is engaged when reliving autobiographical memories, with the medial prefrontal cortex (mPFC) and the insula as key players in the subjective experience of emotional memories (Levine, 2004; Pais-Vieira, Wing, & Cabeza, 2016; Svoboda, McKinnon, & Levine, 2006). The subjective experience of the self in another time is coined autonoetic consciousness (Fivush, 2011; Klein, 2016). Two modes of autonoetic consciousness can be distinguished. Prereflective awareness indicates that one is at the moment re-experiencing the event and reflective awareness indicates a meta-conscious experience where one takes more distant from the event (Libby & Eibach, 2002; Prebble, Addis, & Tippett, 2013). Some of the key areas for prereflective awareness are the ventral mPFC (Esslen, Metzler, Pascual-Marqui, & Jancke, 2008; Levine, 2004; Speer, Bhanji, & Delgado, 2014), insula (Craig, 2011; Prebble et al., 2013), and medial-temporal lobe (MTL; hippocampus and amygdala in particular) (Addis, Moscovitch, Crawley, & McAndrews, 2004; Cabeza & St Jacques, 2007). For reflective awareness, the dorsal mPFC (Esslen et al., 2008), and for more distant reliving through a third person perspective, the precuneus, and temporo-parietal junction (TPJ) (Grol, Vingerhoets, & De Raedt, 2017) are crucial brain regions. Importantly, to facilitate the emotional benefits of reliving, particularly prereflective awareness during vivid positive AM reliving is expected to bring positive emotional feelings back to the present (M.A. Conway & Pleydell-Pearce, 2000; M.A. Conway, Singer, & Tagini, 2004; Greenberg & Knowlton, 2014; Vannucci, Pelagatti, Chiorri, & Mazzoni, 2016). Vivid memories that contain rich perceptual-sensory information can elicit autonoetic consciousness (Holmes, Mathews, Dalgleish, & Mackintosh, 2006; Jacob et al., 2011; Korrelboom et al., 2011), typically a state of prereflective awareness. Increasing the availability of the contextual and affective details (vividness) associated with a past event can better inform present feelings, thoughts, and actions (Pillemer, 2003).

Previous research has related the vividness of imagined future positive events to the pleasantness of the imagination (Holmes, Lang, Moulds, & Steele, 2008; Jing, Madore, & Schacter, 2016; Morina, Deeprose, Pusowski, Schmid, & Holmes, 2011). Research in clinical populations have mostly focused on the specificity of AM, showing lowered specificity of positive memories across diverse clinical populations (Ono, Devilly, & Shum, 2016). While it is generally assumed that specific memories (i.e., bound to place and 24 hr time frame) are also more vivid, and hence may improve mood, this is not always the case (Habermas & Diel, 2013; Kyung, Yanes-Lukin, & Roberts, 2016). A specific memory may not be relived in a vivid way. Vividness may thus be important for mood enhancement, but so far, studies on the impact of vividness of positive AM on brain functioning and mood enhancement are scarce.

Moreover, individual differences exist in the degree to which details of memories can be retrieved (Palombo, Sheldon, & Levine, 2018; Sheldon, Amaral, & Levine, 2017). When fewer details are available, it is more challenging to keep a memory in mind (Conway, Pleydell-Pearce, & Whitecross, 2001) and reliving positive memories could therefore have less beneficial effects. Positive memories may in particular be difficult to be relived by individuals with negative self-evaluations as past positive experiences are not congruent with how they typically feel about themselves (Joormann et al., 2007; Joormann & Siemer, 2004; Kohler et al., 2015; Rusting & DeHart, 2000; Watkins, 2008). Low trait self-esteem could therefore obstruct re-experiencing positive past feelings and dampen the beneficial effect of reliving positive memories (Rusting & DeHart, 2000). To the best of our knowledge no studies investigated the role of trait self-esteem in neural mechanisms of reliving positive memories. However, based on previous work, the temporal-occipital areas are thought to be relevant for holding a memory in mind (Conway et al., 2001).

Taken together, clinical memory-based interventions can benefit from knowledge about the factors that influence the effectiveness of reliving positive AM for improving mood and self-evaluation. In this study, we aim to investigate the beneficial effect of reliving positive memories together with an understanding of its related neural processes. Specifically, we examined whether higher vividness relates to mood enhancement and activation in the insula and hippocampus indicative of prereflective awareness and, whether lower trait self-esteem reduces the boosting effect of reliving of autobiographical memories on mood and sense of self-worth (i.e., state self-esteem). To this end, participants with a broad range of trait self-esteem relive positive and neutral AM in the scanner, after which mood, state self-esteem, and neural activation are assessed.

We hypothesize that positive compared to neutral memories increase mood and based on previous research engages the orbitofrontal cortex (OFC) and mPFC (Speer et al., 2014). Vivid memories are expected to relate to better mood and insula and hippocampal activity. Moreover, it is expected that the facilitative effect of vividness on reliving should be more evident in emotional memories rather than neutral memories. We will therefore also test the interaction of valence (positive vs. neutral) with vividness. Due to a dearth of neuroimaging studies on trait self-esteem in reliving positive memories, no clear expectations regarding the involvement of specific brain areas in individuals with low self-esteem could be stated. However, in general we expect lower effectiveness of reliving positive memories, which could be reflected in altered temporal-occipital activation.

2 | METHOD

2.1 | Participants

Female participants (N = 47) were recruited from the general population representing different ages and education level, and importantly self-esteem (RSES), see Table 1 and Figure S1. While current disorders were excluded, lifetime axis I disorders were reported by 11 participants, see Table 1. Lower trait self-esteem (RSES) score increased the

TABLE 1 Demographic information on total sample (*N* = 47)

Demographic	Specification	*M (SD)/N (%)/R*
Age		*M* = 29.36 (*SD* = 9.61)
Education	High school	*N* = 3 (6.4%)
	Vocational training	*N* = 23 (48.9%)
	Higher education	*N* = 21 (44.7%)
Self-esteem (RSES)		*M* = 20.27 (*SD* = 5.55) *R* = 8–29
Handedness	Total	*M* = 7.98 (*SD* = 5.08)
	Right-handed	*N* = 41 (87.2%)
	Ambidextrous	*N* = 4 (8.5%)
	Left-handed	*N* = 2 (4.3%)
Psychopathology Lifetime Axis I	Major depressive disorder	*N* = 7
	Panic disorder	*N* = 1
	Agoraphobia	*N* = 1
	Obsessive compulsive disorder	*N* = 1
	Post-traumatic stress disorder	*N* = 1
	Anorexia nervosa	*N* = 1
	Adjustment disorder	*N* = 1
Medication	Physical ailments	*N* = 3 (diabetes and asthma, thyroid and bronchitis, blood pressure and sleep medication)
	Psychotropic medication	*N* = 1 (SSRI—sertraline)

likelihood of having a lifetime axis I disorder (*OR* = 0.83, *95% CI*: 0.71–0.95). Trait self-esteem was neither related to age (*r* = –0.24, *p* = .104), nor education level (χ^2[3] = 6.87, *p* = .076). Three participants reported the use of medication for physical ailments and one participant reported a stable use of SSRI's, see Table 1. The sample reported an average ability to use imagery (see supplementary information).

Exclusion criteria were incompatibility with the MRI scanner, current axis I disorder diagnosis, and usage of benzodiazepines, antipsychotics, or more than 20 mg of Oxazepam. Most participants were right handed (*N* = 41, 87.2%), see Table 1. One participant was excluded from analyses because of scanner artifacts resulting in the sample of 47 participants described above.

Participants signed their informed consent to participate in this study. The study was approved by the medical ethics committee of the Leiden University Medical Centre (P12.249) and was performed in accordance with the declaration of Helsinki and the Dutch Medical Research Involving Human Subjects Act (WMO).

2.2 | Procedure

Participants were recruited via local posters and flyers as well as via online advertisements in the context of a study on social impressions. After phone screening for inclusion, two appointments were made. During the first appointment, participants signed informed consent, filled in a demographic form and questionnaires, and wrote down four positive and four neutral autobiographical memories (see below for details). During the second appointment, participants performed the "reliving autobiographical memories" (RAM) task. Participants also performed a social feedback (SF) task in the scanner (see van Schie, Chiu, Rombouts, Heiser, and Elzinga (2018)). There was no significant change in state self-esteem from baseline to after the SF task or before the RAM task, see Figure S2 and thus the RAM task was analyzed in isolation. Median time between appointments was 1 day, with six participants having more than 1 week between appointments due to practical reasons (*Range* = 0–53 days). Time was taken into account in additional confound analyses. Afterwards, outside the scanner, participants filled in questions on their experience with the RAM task and were debriefed and rewarded (30 euro).

2.3 | Reliving autobiographical memories task

In the RAM task participants relived four neutral and four positive autobiographical memories. As the focus of our study is on the ability to relive positive memories instead of the retrieval of memories, retrieval was guided with instructions so that individual variations in the effectiveness of reliving (rather than the retrieval) could be assessed. Given the importance of vividness in prereflective awareness for reliving, participants were instructed to write down a specific moment with as many details as they recalled from a first-person perspective and in the present tense. For positive memories, participants were instructed to recall a memory that made them feel good. For neutral memories, participants were instructed to recall a memory that did not elicit much emotion, either negative or positive. Participants were provided with two examples (one positive, one neutral) to increase the understanding of the writing style (i.e., first-person, present tense, details of that moment). Participants were given a form to write down their memories which restricted length (around 60–80 words to fit on the screen on the MRI scanner), provided a date specification (month/year) and a pleasantness rating scale (range: negative [−10] to positive [−10]). Positive memories were expected to be rated above seven and neutral memories between −2 and 2. When a memory did not fulfill the criteria of pleasantness, first-person perspective, present tense, or details of that moment, participants were reminded of the writing instructions or probed with additional questions, for example, to narrow the memory down or to retrieve another memory. Memories could deviate from these criteria depending on the ability of the participants to retrieve (positive) memories, but strict criteria were kept regarding the emotionality and personal relevance of the memory.

In the scanner, at the start of the RAM task, participants were instructed to use a first-person perspective for reliving. During the task, participants reread their memory on screen (35 s) and were then instructed to relive the memory as good as they could while a fixation cross was shown (30 s), see Figure 1. Each memory was followed by three self-paced questions on how good they felt right now (mood: very bad [1] to very good [4]), how vivid the memory was (vividness: not vivid at all [1] to very vivid [4]) and how well they could focus on the memory (focus: very bad [1] to very good [4]). Time between trials was jittered with a black screen (duration: M = 2000 ms, SD = 258 ms). Within the trial reliving and reading epochs were jittered with a black screen (duration = 1,000 ms, ± 0–100 ms). There were eight trials consisting of four neutral memories followed by four positive memories. Within each valence category, memories were sorted in ascending order of pleasantness. In case of equal pleasantness ratings, memories were ordered by date (most remote first), and then word count (the shortest first). Afterwards, participants reported on their general experience of the RAM task: "How easy/difficult was the RAM task for you?" on a scale of easy (0) to difficult (100) and "Which perspective did you use when reliving the memories" (third-person perspective (0) to first-person perspective (100).

All memories were categorized by specificity, event type and social context by four trained raters (forming four pairs). For specificity, the standard categories of the Autobiographical Memory Task were used (i.e., specific, extended and categoric) (Williams & Broadbent, 1986). Event type was divided in major lifetime event, minor life time event, and activities. Social context was divided in alone, partner, family and friends, colleagues, and stranger, more details available on DataverseNL. All memories were blindly (for valence and participant) and double rated and conflicting labels were resolved through discussion. The interrater agreement was good for the four pairs of raters for specificity [86–94%], event type [81–87%], and social context [80–86%]. The following characteristics were available on the memory itself: valence, pleasantness, remoteness in months, word count, specificity, event type, and social context and on the reliving of the memory: mood, vividness, and focus.

2.4 | Measures and materials

2.4.1 | State self-esteem

State self-esteem was assessed at baseline (before entering the MRI scanner), before and after the SF and before and after the RAM task. Participants orally answered the question "How good do you feel about yourself right now?" on a scale ranging from "very bad—worst I have ever felt about myself" (0) to "very good—best I have ever felt about myself" (100).

2.4.2 | Trait self-esteem (RSES)

The Rosenberg self-esteem scale (RSES) was used to assess trait self-esteem. The scale consists of 10 items rated on a four-point scale ranging from totally disagree (0) to totally agree (3). The sum of the items was used to represent trait self-esteem. The range in our sample

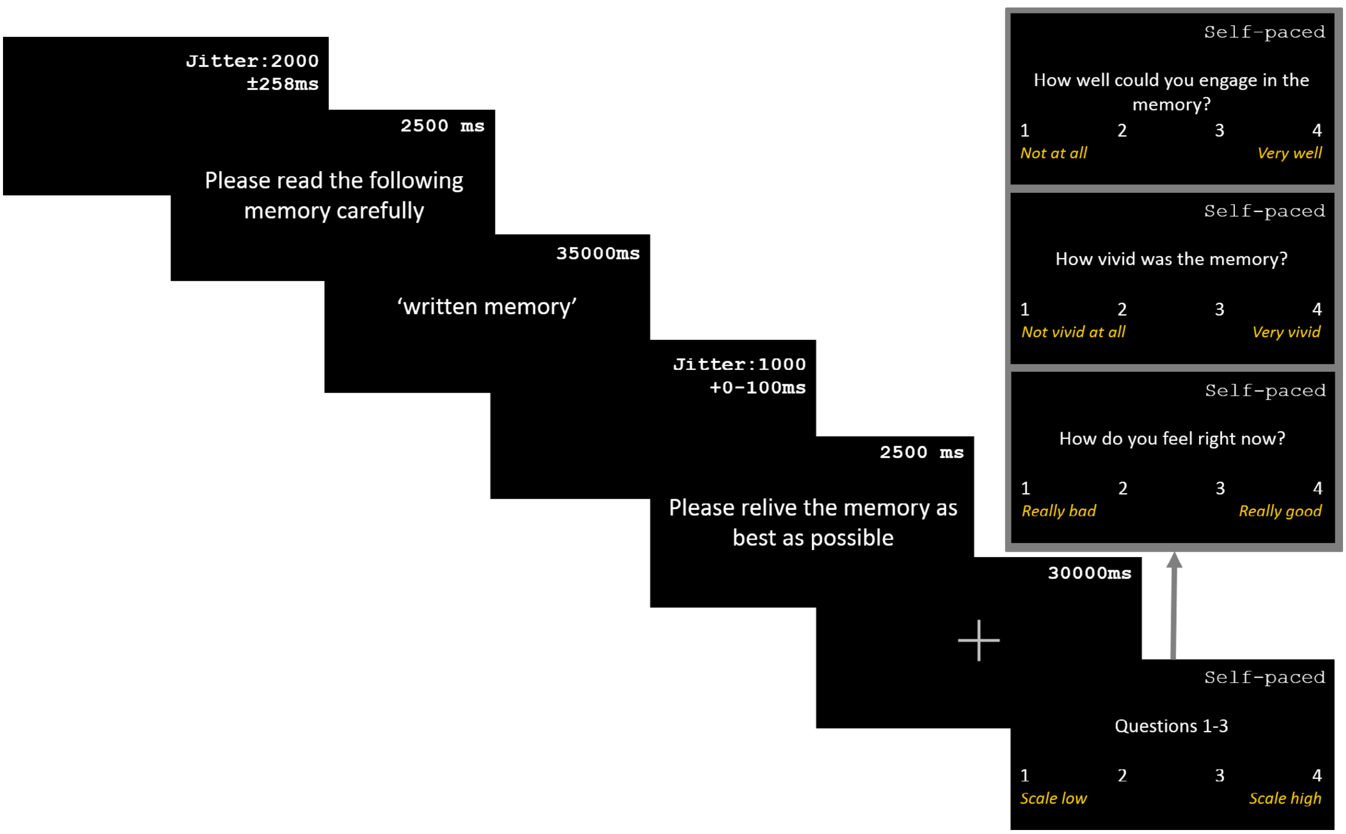

FIGURE 1 Display screens and timings of one trial [Color figure can be viewed at wileyonlinelibrary.com]

(8–29) covered almost all the possible range (0–30). The validity and reliability of the scale has been established (Gray-Little, Williams, & Hancock, 1997; Schmitt & Allik, 2005). The internal consistency in the current sample was good (Cronbach alpha = 0.89).

2.4.3 | Psychopathology

To assess lifetime and current Axis-I disorders based on DSM-IV, the MINI-plus (a semi structured interview [First & Gibbon, 1997]) was used by a trained psychologist (C.v.S.) who held the interview by telephone.

2.4.4 | Handedness

The degree of left- or right-handedness was assessed by a self-report instrument consisting of 10 items asking which hand (left [−1], both [0], or right [1]) is used for a specific action (e.g., brushing your teeth). Sum score ranged from −10 to 10 and |7| is used as a cut-off for left/right handedness (van Strien, 1992).

2.5 | Data acquisition

Mood and vividness were recorded in E-prime version 2.0 using button boxes operated by left and right index and middle finger. MRI images were acquired using a Phillips 3.0 Tesla scanner equipped with a SENSE-8 channel head coil and situated as the Leiden University Medical Centre (LUMC). A survey scan was used to set scan surface. During the RAM task, T2*-weighted echo planar imaging (EPI) was used with the following parameters: FOV RL: 220 mm, AP: 220 mm, FH: 114.68 mm; Matrix 80×80, Voxel size RL: 2.75 mm AP: 2.75 mm; Slice thickness: 2.75 mm; Interslice skip: .275 mm; 38 transverse slices in descending order; TE: 30 ms, TR: 2200 ms, Flip Angle: 80°. As the RAM task was self-paced, number of volumes (M = 304.43, SD = 7.33) varied. For registration purposes a four-volume high resolution T2 weighted EPI and a structural 3D T1 scan were acquired. The parameters for the T2 scan were: FOV RL: 220 mm, AP: 220 mm, FH: 168 mm; Matrix 112×112, Voxel size RL: 1.96 mm AP: 1.96 mm; Slice thickness 2.0 mm; 84 transverse slices; TE 30 ms, TR 2200 ms, Flip Angle 80°. The parameters for the 3D T1 scan were: FOV RL: 177.33 mm, AP: 224 mm, FH: 168 mm; Matrix 256x256, Voxel size RL: .88 mm AP: .87 mm; Slice thickness 1.20 mm; 140 transverse slices; TE 4.6 ms, TR 9.7 ms, Flip Angle 8°; Duration 4:55 min. Scans were examined by a radiologist and no abnormalities were found.

2.6 | Data preprocessing

Raw e-prime data were pre-processed in excel 2010 to calculate onset and duration times and recode responses. Raw fMRI data were pre-processed using Feat v6.00 in FSL 5.0.7. The first five volumes were discarded. A high pass filter of 120 s was used. Motion was corrected using MCFLIRT with 6° of freedom (dof) and the middle volume as reference volume. No slice time correction was used but temporal derivatives were added in the model. Data were spatially smoothed with FWHM of 5 mm. Raw and pre-processed data were checked for quality, registration, and movement. Most participants (N = 44) showed minimal motion (i.e., smaller than 1 voxel/3 mm). For three participants who showed motion between 1 and 2 voxels (i.e., 3–6 mm), volumes with excessive motion were regressed out by adding confound regressors (one per excessive volume) defined by the FSL motion outlier script (metric = root mean square). The registration process was optimized by using a two-step procedure from low resolution fMRI image to high resolution fMRI image before registration to the anatomical T1-weighted image. The middle volume was registered to the high resolution T2-weighted image using 6 dof. For registration to the anatomical T1-weighted scan, the Boundary-Based Registration algorithm was used. A linear 12 dof transformation was used for registration to the MNI template. In addition, motion parameters (6), and white matter and CSF signal [2] were added, resulting in eight confound regressors plus any additional motion outlier regressors.

2.7 | Data analysis

For both the mood and fMRI data, three models were constructed. First, positive memories were contrasted to neutral memories to assess the general effects of the RAM task on mood and bold response (Valence effect). Second, vividness of each memory (i.e., trial-level) was added to the first model to test the main effect of vividness and the interaction with valence. Third, trait self-esteem (i.e., person-level) was added to the first model to test the main effect of trait self-esteem and interaction with valence. The neutral valence was set as the reference category. Vividness ratings were recoded from values 1, 2, 3, and 4 to contrast values −3, −1, 1, 3 to contrast less and more vivid memories. Trait self-esteem was centered around the sample mean.

2.7.1 | Mood and state self-esteem

For the mood data, R version 3.4.4 was used with the following packages: lme4 for multilevel analysis, psych for descriptive statistics and ggplot2 for creating figures (Bates, Maechler, Bolker, & Walker, 2015; R Core Team, 2013; Wickham, 2009). To model the mood effects during the RAM task, multilevel analysis was used with valence and vividness per memory on the first level and trait self-esteem per participant on the second-level as predictors. To model change in state self-esteem after the RAM task, multilevel analysis was used with state self-esteem at baseline and before RAM on the first level and trait self-esteem per participant on the second-level as predictors.

2.7.2 | fMRI data

On the lower level, for each valence, the onset and duration of the reading and reliving of each memory was specified with equal weighting, resulting in four regressors (i.e., neutral reading, neutral reliving, positive reading, and positive reliving). The following contrasts were of interest: reliving—reading and positive reliving—neutral reliving. In addition, the onset and duration of rating the three questions (mood, vividness, and focus) were specified as regressors (not used in contrasts). For vividness, the reliving (but not reading) of neutral and positive memories was modulated by the vividness rating, adding two regressors to the lower level model. Two contrasts were set up to test the positive and negative relation of vividness with bold responses during both positive and neutral memories. In addition, to examine whether vividness is differentially related to bold responses within the valences, the positive and negative relation of vividness was tested separately for positive and neutral memories (interaction of vividness*valence).

On the group level, the valence effect was tested using a one sample *t*-test (i.e., group mean) on the contrast comparing positive to neutral reliving and vice versa. The effect of vividness was assessed using a one sample *t*-test (i.e., group mean) on the contrast testing the negative and positive relation of vividness overall and per valence. To assess the effect of trait self-esteem, one regression analysis with constant and centered RSES scores was used on the model containing valence only. For inference on the second level contrasts, permutation tests were performed with 10,000 permutations and threshold free cluster enhancement (TFCE) using Randomize v2.9 (Winkler, Ridgway, Webster, Smith, & Nichols, 2014).

3 | RESULTS

3.1 | Characteristics of autobiographical memories

Participants rated positive memories (N = 188, M = 8.69, SD = 1.87) more pleasurable than neutral memories (N = 188, M = 0.60, SD = 1.77), (Valence: χ^2 [1] = 913.42, p < .001, positive valence: b = 8.10, SE = 0.12, t = 65.01). Moreover, the majority of memories were categorized as specific and positive and neutral memories did not differ in this regard (neutral: N = 176 (94%), positive: N = 168 (89%). Valence related to memory specificity in the sense that positive memories were more often categorized as extended than neutral memories (neutral: N = 3 (1.6%), positive: N = 18 (9.6%), Valence: χ^2 [2] = 15.36, p < .001), see Table 2. Most participants relived the memories from a first-person perspective (M = 84.87, SD = 17.90, *Range* = 30–100[1]), and rated the RAM task as fairly easy (M = 32.77 [SD = 24.47], *Range* = 0–80). Trait self-esteem (RSES) was neither related to the self-reported difficulty of the RAM task ($r[45]$ = –0.18, p = 0.227) nor to the perspective taken during the RAM task ($r[37]$ = 0.13, p = 0.427). These findings confirm that participants were to a large extent able to follow the instructions for generating specific memories of positive and neutral events from a first-person perspective, regardless of level of trait self-esteem.

TABLE 2 Characteristics of neutral and positive memories

	Neutral (N = 188)		Positive (N = 188)		
	M/N(std. res)	*SD/%*	*M/N(std. res)*	*SD/%*	Valence test
Pleasurableness (emotional intensity [–10–10])	0.60	1.77	8.69	1.87	χ^2 (1) = 913.42, p < .001
Vividness (1–4)	3.03	0.80	3.51	0.80	χ^2 (1) = 54.03, p < .001
Focus (1–4)	3.14	0.82	3.51	0.78	χ^2 (1) = 34.00, p < .001
Word count	56.74	15.31	64.10	16.37	χ^2 (1) = 33.88, p < .001
Remoteness (in months)[a]	1.27	41.26	52.56	89.51	χ^2 (1) = 72.25, p < .001
Specificity					χ^2 (2) = 15.36, p < .001
Specific	176 (1.5)	93.6%	168 (–1.5)	89.4%	
Categoric	9 (2.1)	4.8%	2 (–2.1)	1.1%	
Extended	3 (–3.4)	1.6%	18 (3.4)	9.6%	
Event					χ^2 (4) = 107.35, p < .001
Major life event	0 (–5.1)	0.0%	24 (5.1)	12.8%	
Minor life event	6 (–8.0)	3.2%	67 (8.0)	35.6%	
Activities	176 (10.0)	93.6%	87 (–10.0)	46.3%	
Pets	4 (–1.4)	2.1%	9 (1.4)	4.8%	
Other	2 (0.6)	1.1%	1 (–0.6)	0.5%	
Context					χ^2 (5) = 98.68, p < .001
Alone	101 (8.1)	53.7%	27 (–8.1)	14.4%	
Romantic partner	5 (–2.8)	2.7%	18 (2.8)	9.6%	
Family/friends	26 (–7.0)	13.8%	88 (7.0)	46.8%	
Colleagues/acquaintances/(fellow)pupils/team members	26 (–0.30)	13.8%	28 (0.30)	14.9%	
Stranger	24 (3.0)	12.8%	8 (–3.0)	4.3%	
Other(s) present but relation unknown to raters	6 (–2.7)	3.2%	19 (2.7)	10.1%	

[a]Remoteness was missing for four participants.

Positive memories were relived more vividly (Valence: χ^2 [1] = 54.03, p < .001, positive: M = 3.51, SD = 0.80, neutral: M = 3.03, SD = 0.80) and with more focus (Valence: χ^2 [1] = 34.00, p < .001, positive: M = 3.51, SD = 0.78, neutral: M = 3.14, SD = 0.82). Positive memories compared to neutral memories were written with more words (Valence: χ^2 [1] = 33.88, p < .001, positive: M = 64.10, SD = 16.37, neutral: M = 56.74, SD = 15.31) and were more remote in time (Valence: χ^2 (1) = 72.25, p < .001, positive: N = 171, M = 52.56 months, SD = 89.51, neutral: N = 172, M = 1.27 months, SD = 41.26). The positive memories more often concerned major and minor life events (Valence: χ^2[4] = 107.35, p < .001) and involved close others (Valence: χ^2 [5] = 98.68, p < .001), see Table 2. Neutral memories often referred to routine activities, and were experienced alone or with a stranger.

Higher vividness was related to more pleasurable, remote, and longer memories, but was not related to specificity, see Table S1. In contrast, lower trait self-esteem (RSES) was not related to vividness, pleasantness, remoteness, or word count, but was associated with less specific (neutral and positive) memories, see Table S1.

3.2 | RAM task: General effects

As expected, participants' mood was better after reliving positive memories (M = 3.65, SD = 0.52) than neutral memories (M = 3.19, SD = 0.57), (Valence: χ^2[1] = 99.30, p < .001) see Tables S2 and S3. Also, state self-esteem increased after the RAM task (M = 72.66, SD = 8.71) compared to before the RAM task (M = 66.17, SD = 6.20), controlled for baseline state self-esteem (M = 64.36, SD = 8.75) (χ^2 [2] = 21.33, p < .001), see Figure S2.

The contrast reliving compared to reading memories autobiographical memories, activated a broad autobiographical neural network, including mPFC, hippocampus, insula, amygdala, ACC, precuneus, PCC, OFC, and cerebellum (Svoboda et al., 2006), see Figure 2a[2]. No activation was found in the occipital lobe, which is most likely due to the fact that the reading condition also activated the occipital lobe (Benedek et al., 2016) and hence no additional activation is elicited when reliving the memory.

Permutation tests did not reveal significant differences for reliving positive compared to neutral memories. Exploratory, a cluster threshold (z = 3.1, p < .05) on the same contrast revealed increased activation in the mPFC, (pregenual and subgenual) ACC and pre- and postcentral gyrus for positive memories, see Figure 2b and Table S6. Permutation tests revealed significant differences for neutral compared to positive memories with increased activation in the precuneus and PCC/MCC,[3] see Figure 2b and Table S6.

3.3 | Vividness

The more vivid the memory was relived, the better the reported mood (Vividness: χ^2 (1) = 15.01, p < .001, vividness: b = 0.14, SE = 0.04, t = 3.92). The interaction effect between valence and vividness indicated that mood enhancement was mainly due to vividness of positive memories, whereas vividness of neutral memories did not alter mood (Vividness*Valence: χ^2 (1) = 9.54, p = .002, vividness*valence (positive > neutral): b = 0.20, SE = 0.06, t = 3.13), see Figure S3, Tables S2 and S3.

The more vivid a memory was relived the more activation was found in bilateral hippocampus and amygdala, and right insula, see Figure 3a and Table S7. Decreased activation, in response to increased vividness, was found in the occipital cortex, precuneus, and PCC, see Figure 3a. Vividness was also tested separately for positive

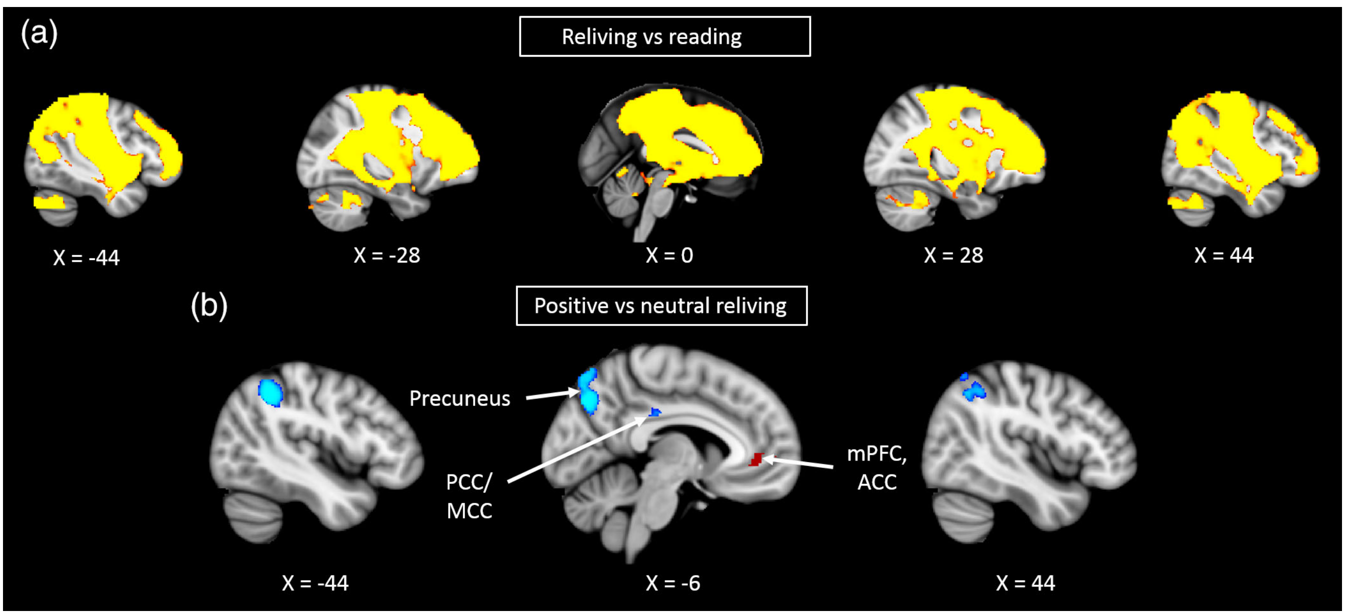

FIGURE 2 One sample t-test on contrast (a) reliving versus reading (*permutation test with TFCE)* and (b) positive versus neutral reliving (red) (*cluster threshold, z = 3.1, p < .05)* and neutral versus positive reliving (blue) (*permutation test with TFCE)*

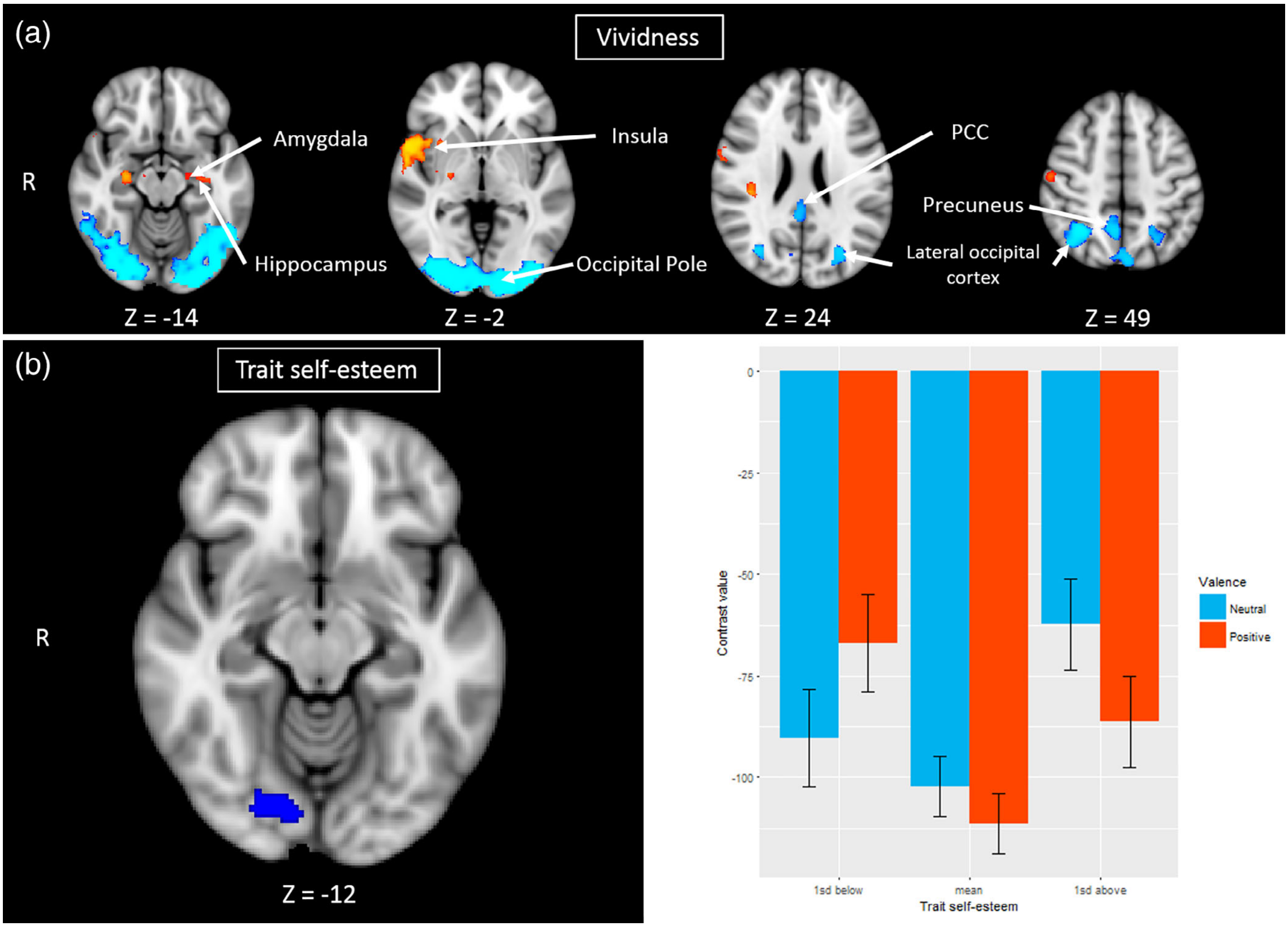

FIGURE 3 Neural activation of (a) vividness of the memory that is either positively (orange) or negatively (blue) related (*permutation test with TFCE*) and (b) trait self-esteem that is negatively (blue) related to the difference in reliving positive versus neutral memories (*cluster threshold, z = 3.1, p < .05*. The error bars in the bar plot represent 95% confidence intervals. Note: Brain is depicted in radiological convention, that is, left = right

and neutral memories indicating that the activation for vividness seems mostly driven by positive memories, see Figure S4 and Table S7. No suprathreshold activation related to vividness during the reliving of neutral memories.

3.4 | Trait self-esteem

Trait self-esteem did not relate to mood ($\chi^2[1] = 0.01$, $p = .913$), see Table S3, but related to state self-esteem after the RAM task compared to before the RAM task (controlled for baseline) ($\chi^2[2] = 6.74$, $p = .034$), see Table S5. Especially individuals with lower trait self-esteem increased in state self-esteem ($b = 0.81$, $SE = 0.31$, $t = 2.58$), see Table S4. Activation of the right lateral occipital lobe for positive compared to neutral memories depended on the level of trait self-esteem, using a cluster threshold ($z = 3.1$, $p < .05$), see Table S7. Participants with lower trait self-esteem showed more activation for positive compared to neutral memories, whereas participants with higher trait self-esteem showed the reverse pattern of more activation for neutral than positive memories, see Figure 3b.

3.5 | Confounds

The number of days between memory retrieval and memory reliving as well as psychotropic medication status (on/off) were taken into account in additional confound analyses. Results concerning mood or state self-esteem were not altered. Taking medication was associated with having a lower mood overall. No effects were found of these confounds on the neural activation related to reliving versus reading, neutral versus positive reliving, negative relation of vividness and trait self-esteem. Adding number of days between retrieval and reliving and medication status led to subthreshold activation of the mPFC during positive versus neutral reliving. Adding number of days led to subthreshold activation of the amygdala and hippocampus positively related to vividness. Number of days itself did not relate to neural activation. In addition, adding remoteness in months (reduced sample size $N = 43$) did not alter mood results and was itself not related to mood. Adding remoteness as parametric modulator made the negative relation of trait self-esteem with the lateral occipital gyrus and the positive relation of vividness with the amygdala, hippocampus, and insula nonsignificant. The negative relation of vividness became less widespread. Remoteness itself was positively related to lingual gyrus and cuneus activation.

4 | DISCUSSION

This study investigated the underlying neural processes of reliving positive autobiographical memories and its effect on improving mood state and state self-esteem. In general, reliving memories activated a large autobiographical neural network compared to reading the memories confirming that reliving the memory engaged the relevant brain regions. Moreover, intervention studies using reading or reliving may consider that these techniques could have differential emotional effects (Hornsveld et al., 2011; Jacob et al., 2011; Joormann et al., 2007; Joormann & Siemer, 2004). Positive compared to neutral memories enhanced mood and activation in the mPFC, ACC, and pre- and postcentral gyrus. Though the effect of positive (vs. neutral) memories on activation was small, it is corroborated by previous research (Speer et al., 2014). The mPFC is a key area for self-referential processing, and it could be thought that positive memories engage the self more strongly than neutral memories do irrespective of how specific or vivid the memory is (Gilboa, 2004; Levine, 2004; Martinelli, Sperduti, & Piolino, 2013). In line with this, positive memories more often entailed major life events and therefore were more self-relevant. The activation found in motor and somatosensory areas may indicate actual or imagined movement of oneself (Hetu et al., 2013; Kosslyn, Ganis, & Thompson, 2001) which seemed to be more strongly induced by positive than neutral memories. Neutral compared to positive memories related to stronger activation of the precuneus and a region which anatomically has been labeled as the PCC but has also been referred to as MCC in other studies (Gilmore, Nelson, & McDermott, 2015; Vogt & Paxinos, 2014). The location of this activation is more rostral than the area of PCC activation, which was associated with lower vividness. The precuneus and PCC/MCC are involved in the parietal control network (Dixon, Fox, & Christoff, 2014; Kim, 2018). In particular, the PCC/MCC region is relevant for regulating the balance between internally and externally directed attention (Kim, 2018). It could be proposed that neutral memories may take more effort to hold in mind, which may result in more switching between externally and internally directed attention. This would be in line with our finding that participants report lower focus during neutral memories compared to positive memories.

Vividness appeared to be a key factor for the reliving of autobiographical memories. First of all, vivid memories were associated with enhanced mood. Importantly, at the neural level more vivid memories related to increased activation of the bilateral hippocampi, linked to the quality of remembering an event (Addis et al., 2004; Burgess, Maguire, & O'Keefe, 2002; Viard et al., 2007), bilateral activation in the amygdala, linked to the emotionality of the memory (Cabeza & St Jacques, 2007; Hermans et al., 2014) and the right anterior and posterior insula (Deen, Pitskel, & Pelphrey, 2011). The insula has been linked to self-awareness (Pais-Vieira et al., 2016) with the anterior insula being more often related to awareness of the saliency and emotionality of the subjective experience and the posterior insula more often related to awareness of sensations of the body (Craig, 2009, 2011; Simmons et al., 2013). Together, this activation pattern indicates an awareness of the (emotional) self in another time. Specifically, this activation pattern is indicative of autonoetic consciousness, where one is in the moment of re-experiencing an event in a pre-reflective manner (Prebble et al., 2013). Our findings further indicate that vividness affected neural and affective responses more during positive memories than neutral memories indicating that positive memories may facilitate pre-reflective awareness and hence the re-experience of positive emotions associated with the event, thereby improving mood.

Interestingly, we found that relatively low vividness was related to *increased* activation in the occipital lobe. This may seem surprising as visual imagery supports reliving (Daselaar et al., 2008; Rubin, 2005). However, our finding is corroborated by previous studies that found deactivation in the occipital lobe related to the vividness of visual imagery (Fulford et al., 2017; Tailby, Rayner, Wilson, & Jackson, 2017). Increased activation of the occipital lobe during less vivid memories may indicate difficulty with suppressing external sensory information (Benedek et al., 2016). Additionally, lower vividness was related to increased PCC and precuneus activation which have been associated with successful retrieval of autobiographical memories as opposed to nonself memories (e.g., a movie) (Summerfield, Hassabis, & Maguire, 2009) or more abstract levels of self-processing (Martinelli et al., 2013). However, the PCC and precuneus may not be specific to re-experiencing self-related memories per se but may be related to the cognitive processes that facilitate viewing the self from a third-person perspective (viewing the self as me-self) (Grol et al., 2017; Legrand & Ruby, 2009; Prebble et al., 2013).

Vividness seems to distinguish two neural patterns with insula, hippocampus, and amygdala on the one hand and occipital cortex, PCC, and precuneus on the other hand. These areas may be relevant for a different manner of reliving autobiographical memories, with higher vividness, insula, hippocampus, and amygdala indicating the re-experience of the memory in the present moment and lower vividness, precuneus, PCC, and occipital lobe indicating a more distant reliving. The latter manner of reliving may have less potential to boost mood, as we observed lower mood with lower vividness. Even though, this manner of reliving could be beneficial when deliberately reflecting on the self (Dritschel, Beltsos, & McClintock, 2014), to improve mood a vivid re-experience seems essential.

Trait self-esteem was relevant to activation in right lateral occipital cortex. In people with lower self-esteem the occipital cortex was more involved (i.e., less deactivation) during positive compared to neutral reliving. This could indicate that when reliving positive memories people with lower trait self-esteem have more difficulty with keeping the memory in mind (Conway et al., 2001; Fulford et al., 2017; Libby & Eibach, 2002). Remarkably, this was not reflected in lower mood or state self-esteem. In fact, when controlled for baseline state self-esteem, lower trait self-esteem related to increased state self-esteem after the RAM task. A previous study indicated that when in a sad mood, people with lower self-esteem can not benefit from reliving positive memories (Smith & Petty, 1995). However, the participants in our study felt relatively well at the start of the RAM task. Moreover, reliving memories was guided by specific instructions (e.g., relive the memory from a first-person perspective). These circumstances may have helped people with low self-esteem to benefit from reliving positive memories. Interestingly, participants with lower self-esteem did not report lower vividness of the memories despite lower specificity. Trait self-esteem and vividness seemed to tap into different aspects of memory reliving given that these two constructs were not related to each other and had opposing (i.e., significant vs. nonsignificant) relations to other memory characteristics. However, further research could investigate whether specificity and/or vividness have differential consequences of reliving, for example, the integration of positive information into the self-system in individuals with low self-esteem (Conway & Pleydell-Pearce, 2000; Martinelli et al., 2013).

Before concluding, we would like to mention the strengths and a few limitations of the current study. The RAM paradigm used in this study uses personally relevant autobiographical memories and provides detailed information on the content of the memories, in particular vividness. This makes the paradigm ecologically valid and the results translatable to clinical practice. A limitation to this approach is that there was less control over the remoteness of memories. It has been argued that remoteness is not relevant for reliving (Martinelli et al., 2013). However, it has also been shown that more remote memories were experienced as more distant and less vivid (Rice & Rubin, 2009). In this study, remoteness was positively related to brain areas which vividness was negatively related to, that is, more remote or less vivid memories related to increased activation of the occipital lobe. This may be surprising given that more vivid memories were more remote. However, vividness and remoteness were not strongly related and may each have their separate effects on memory reliving (e.g., direct vs. more effortful) (Sheldon & Levine, 2013) or degree of switching between perspectives) (Rice & Rubin, 2009). Another strength is including a large range in trait self-esteem and studying vividness per memory to observe fine grained relation of vividness with mood and bold responses. However, individual differences trait vividness may exist (Kosslyn et al., 2001; Palombo et al., 2018; Sheldon et al., 2017) and in future studies it might be interesting to consider this factor. Since we included only females in our sample, the results may however not generalize to men (Young, Bellgowan, Bodurka, & Drevets, 2013). Finally, the effects of the mPFC, amygdala, and hippocampus were smaller compared to other clusters. Therefore, these clusters may be particularly prone to loss of power in confound analyses and warrant further replication.

Our study shows that vividness is an important aspect of memory reliving and consequent mood enhancement. When using positive autobiographical memories in clinical memory-based interventions for enhancing mood and self-evaluation, vividness of memories is encouraged to facilitate autonoetic consciousness. People with lower trait self-esteem can benefit from positive memory reliving when reliving is guided and the memory is vivid. However, further research should investigate whether decreased specificity and more distant reliving has consequences for integration of positive self-relevant information and how specific neural (sub)regions may contribute and interact to establish autonoetic consciousness.

AUTHOR CONTRIBUTIONS

All authors contributed to the study design. Testing and data collection were performed by C.C. van Schie and C.-D. Chiu. C.C. van Schie performed the data analysis and interpretation under the supervision B.M. Elzinga and S.A.R.B. Rombouts. C.C. van Schie drafted the manuscript and C.-D. Chiu, B.M. Elzinga, S.A.R.B. Rombouts, and W.J. Heiser provided critical revisions. All authors approved the final version of the manuscript for submission.

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DATA ACCESSIBILITY STATEMENT

The de-identified data, analysis scripts and materials for this study are available on DataverseNL and the MRI data are available on neurovault (https://identifiers.org/neurovault.collection:5589). For any questions or additional material, please contact the corresponding author.

ENDNOTES

[1] N = 39. This question was not answered by the first eight participants.

[2] As all significant voxels belonged to the same cluster no helpful table of peak correlations could be made. However, the statistical maps are available on the online archive neurovault.

[3] The PCC/MCC region found for neutral compared to positive memories and the PCC region found for lower vividness were mapped together to view degree of overlap/segregation, see Figure S5. Neutral compared to positive memories activate a PCC/MCC region that is more rostral than the PCC activation found for lower vividness.

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Additional supporting information may be found online in the Supporting Information section at the end of this article.

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