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Patterns of Brain Activity Associated with Nostalgia:

A Social-Cognitive Neuroscience Perspective

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**ABSTRACT**

Nostalgia arises from tender and yearnful reflection on meaningful life events or important persons from one’s past. In the last two decades, the literature has documented a variety of ways in which nostalgia benefits psychological well-being. Only a handful of studies, however, have addressed the neural basis of the emotion. In this prospective review, we postulate a neural model of nostalgia. Self-reflection, autobiographical memory, regulatory capacity, and reward are core components of the emotion. Thus, nostalgia involves brain activities implicated in self-reflection processing (medial prefrontal cortex, posterior cingulate cortex, precuneus), autobiographical memory processing (hippocampus, medial prefrontal cortex, posterior cingulate cortex, precuneus), emotion regulation processing (anterior cingulate cortex, medial prefrontal cortex), and reward processing (striatum, substantia nigra, ventral tegmental area, ventromedial prefrontal cortex). Nostalgia’s potential to modulate activity in these core neural substrates has both theoretical and applied implications.

**Keywords:** nostalgia, self-reflection, emotion regulation, autobiographical memory, reward

# 1. Introduction

Nostalgia has a checkered history. The term was originally coined by a Swiss medical student, Johannes Hofer (1688/1934), who, in his dissertation, labeled nostalgia a medical or neurological disease accompanied by maladaptive psychological and physiological symptoms, such as despondency, anorexia, fever, and pain. The view of nostalgia as a disease persevered in the 18th and 19th centuries. By the turn of the 20th century, the perception of nostalgia as a psychiatric or psychosomatic disorder was well-entrenched. The list of symptoms included anxiety, sadness, pessimism, and insomnia. This perception was softened near the end of that century, when nostalgia came to be regarded a form of depression. Taken together, although its conceptualization changed over time, nostalgia has consistently been seen as dysfunctional. (For historical overviews, see: Batcho, 2013; Sedikides et al., 2004.)

Currently, however, nostalgia is being rehabilitated. It is now considered a predominantly positive, albeit bittersweet, self-conscious emotion that arises from personally relevant, tender, and longful memories of one’s past (Batcho, 2007; Hepper et al., 2012; Wildschut et al., 2006). Nostalgia is elicited by a variety of triggers, such as objects, events, or close others from one’s childhood or youth (Holbrook and Schindler, 1996; Schuman and Scott, 1989), music or songs (Routledge et al., 2011; Sedikides et al., 2021), photographs (Cox et al., 2015; Gilboa et al., 2004), as well as odors and tastes (Reid et al., 2014; Supski, 2013). Further, nostalgia is prevalent (i.e., experienced several times a week), universal (i.e., occurring in many cultures across five continents), and observed across ages (i.e., among older children, teenagers, and adults; Hepper et al., 2014, 2021; Madoglou et al., 2017; Wildschut et al., 2019; Zhou et al., 2008).

Crucially, the emotion has emerged as a psychological resource that confers a variety of intrapersonal and interpersonal benefits (Frankenbach et al., 2021; Sedikides et al., 2008, 2015). In particular, nostalgia boosts self-esteem or self-positivity (Cheung et al., 2013, 2016; Vess et al., 2012), increases meaning in life (Routledge et al., 2011, 2012; Sedikides and Wildschut, 2018), fosters social connectedness and social support (Reid et al., 2014; Sedikides and Wildschut, 2019; Wildschut et al., 2010), encourages help seeking (Juhl et al., 2021), enhances psychological health and well-being (Baldwin et al., 2015; Baldwin and Landau, 2014; Layous et al., 2021; Routledge et al., 2013), and attenuates dysphoric states such as loneliness, boredom, stress, or death anxiety (Routledge et al., 2011; Van Tilburg et al., 2013; Zhou et al., 2008; Zhou, Sedikides et al., 2021). Furthermore, in stark contrast to historical views (Batcho, 2013; Sedikides et al., 2015), nostalgia can be implemented in interventions among older adults to maintain and improve emotional and memory functions (Yamagami et al., 2007), enrich psychological well-being (Bohlmeijer et al., 2007), and ameliorate depression (Chiang et al., 2010).

Over the past decade, the behavioral literature has covered extensively the nature (what it is) and functions (what it does) of nostalgia. Evidence from social cognitive neuroscience has now begun to address the neural substrates of the emotion. Although brain research on nostalgia has progressed rapidly, it is still in its early stage. The field is, to paraphrase Winston Churchill,[[2]](#footnote-2) at the end of the beginning. Therefore, the time is ripe to synthesize the state of the art and identify promising directions for the next stage of neuroscientific research into nostalgia.

We present the first synthesis of brain research into nostalgia. Given its multifaceted nature, it is reasonable to assume that the emotion involves different interacting brain regions. This view is consistent with meta-analyses of neuroimaging studies on basic emotions (e.g., fear, anger, sadness, happiness, disgust, surprise), which show that each basic emotion involves multiple distributed functional networks rather than being specifically related to a single distinct brain region (e.g., fear = amygdala; Kober et al., 2008; Lindquist et al., 2012; Saarimäki et al., 2018). We identified four components of nostalgia based on its definition and relevant theory: self-reflection, autobiographic memory, emotion regulation, and rewards. Accordingly, we first offer several key propositions regarding the neural networks of nostalgia. We then review the neural literature on nostalgia and illustrate its relevance to, and support for, the propositions. Next, we introduce a neural model of nostalgia (Figure 1) that aspires to integrate the empirical findings. We conclude with a discussion of the key issues to be addressed in future neuroimaging research. Overall, this prospective review is intended to attract researchers’ attention to and nurture their interest in the emotion, while offering focused hypotheses in need of empirical scrutiny.

# 2. Core components of nostalgia

## 2.1 Self-reflection

Nostalgia is regarded as a prima facie self-conscious emotion (Van Tilburg et al., 2019). Nostalgia is accompanied by self-reflection (Sedikides et al., 2015), which involves thinking about the self (Lieberman et al., 2019). The central and defining character of nostalgia is the self, as the emotion originates from one’s meaningful experiences. Indeed, the self is featured prominently in nostalgic recollections. Nostalgic narratives, for example, are filled with highly self-relevant events, as well as exchanges between the self and close others, featuring the self as protagonist (Abeyta et al., 2015; Wildschut et al., 2006). The trajectory of these narratives is redemptive (i.e., from humble beginnings to a happy ending), thus depicting the self in favorable light (Luo et al., 2016; Wildschut et al., 2006).

The medial prefrontal cortex (mPFC) is the key brain region involved in self-reflection processing, which requires integrating stimuli in the context of personal thoughts, goals, and traits (Lieberman, 2007; Lieberman et al., 2019; Northoff and Bermpohl, 2004). The posterior cingulate cortex (PCC) is also a key region in self-reflection as well as self-consciousness (Cavanna and Trimble, 2006; Northoff and Bermpohl, 2004; Northoff et al., 2006).For example, both the mPFC and PCC show heightened activation when individuals reflect on information that is highly self-relevant and self-descriptive (Moran et al., 2006; Wagner et al., 2012). We therefore propose the following:

*Proposition 1: Nostalgia involves brain regions associated with self-reflection*.

## 2.2 Autobiographical memory

Autobiographical memory involves processing of the self in mental time travel into the past (Sedikides et al., 2015), which is distinguished from self-reflection (Lieberman et al., 2019). At the trait level, nostalgia serves basic autobiographical memory functions (i.e., greater overall recruitment of memories) as do two other types of autobiographical memory, rumination (brooding and reflection) and counterfactual thinking (downward or upward), but is different from them in terms of its comparatively strong positive associations with self-regard and intimacy maintenance (i.e., acquiring symbolic proximity or strengthening social bonds), and its weak association with bitterness revival (i.e., rekindling resentment from having presumably been wronged; Cheung et al., 2018). When experimentally manipulated, nostalgia (compared to brooding or reflection) leads to (a) greater intimacy maintenance, conversation, teach/inform, death preparation, boredom reduction, and, bitterness revival reduction, as well as (b) elevated positive affect, self-esteem, social connectedness, meaning in life, and self-continuity (Jiang et al., 2021). Taken together, nostalgic recollection can be considered a special case of autobiographical memory (Sedikides et al., 2015; Wildschut and Sedikides, 2020).

According to the neuroscience literature, autobiographical memory processing mainly involves the brain regions of hippocampus (Addis et al., 2004; Cabeza and Nyberg, 2000; Svoboda et al., 2006) as well as mPFC and PCC (Gilboa, 2004; Kim, 2012; Svoboda et al., 2006). We therefore propose the following:

*Proposition 2: Nostalgia involves brain regions associated with autobiographical memory*.

## 2.3 Emotion regulation

Nostalgia is distinct from general autobiographical memory in another important way. Autobiographical memory implicates acts of remembering past events in one’s life, but such events are not necessarily dipped in affect. Nostalgia, however, has a potent affective signature (Sedikides et al., 2015; Van Tilburg et al., 2018). The New Oxford Dictionary of English (1998) defines nostalgia as “a sentimental longing or wistful affection for the past” (p. 1266), and researchers are unanimous in labeling it an emotion (Sedikides et al., 2015; Wildschut and Sedikides, 2020). The emotional potency of autobiographical memories predicts the level or strength of nostalgia (Barrett et al., 2010; Barrett and Janata, 2016).

Nostalgia’s affective signature is ambivalent, as it involves the co-occurrence of positive and negative affect (Barrett et al., 2010), but mostly positive, as it encompasses more positive than negative affect (Sedikides and Wildschut, 2016) and elicits more positive than negative affect (Leunissen et al., 2020). Ambivalent emotions entail neural mechanisms both of simultaneously positive and negative states, and a rapid vacillation between positive and negative states (Vaccaro et al., 2020). As such, nostalgia is not only bittersweet, but also regulates negative states, soothing emotional conflict. This process may be associated with a specific mode of emotion regulation, cognitive reappraisal. When experiencing nostalgia, people generally feel well even when this sentiment is somewhat unwarranted by the valence of the pertinent past event (Cheung et al., 2018; Sedikides et al., 2014). That is, people reframe the nostalgic memory in a rose-colored manner. In addition, nostalgia regulates negative emotionality in itself (Folkman, 2008; Josephson, 1996): When triggered by a discomforting state (e.g., loneliness, meaninglessness), nostalgia counters it through the evocation of upbeat, social, and meaningful memories (Routledge et al., 2011; Maher et al., 2021; Wildshut et al., 2006; Zhou et al., 2008).

Several brain regions, especially the anterior cingulate cortex (ACC) and mPFC, are known to play key roles in emotion regulation, and particularly cognitive reappraisal (Bush et al., 2000; Ochsner and Gross, 2005; Pezawas et al., 2005). We therefore propose the following:

*Proposition 3: Nostalgia involves brain regions associated with emotion regulation processing*.

## 2.4 Reward

As we mentioned, despite its bittersweetness, nostalgia is a predominantly positive emotion (Sedikides and Wildschut, 2016). An integrative data analysis based on 41 experiments showed that nostalgia inductions increase positive rather than negative affect (Leunissen et al., 2020). In addition to positive affect or pleasure, nostalgia is related to motivation and reward seeking. A stream of empirical studies has indicated that nostalgia is approach-oriented, such that it strengthens approach motivation, encourages risk-taking toward reward, and promotes the pursuit of one’s important goals (Sedikides and Wildschut, 2020; Stephan et al., 2014; Zou et al., 2019). Various regions of the reward network, especially ventral striatal dopamine systems, are involved in positive emotion and, moreover, approach motivation (Berridge and Kringelbach, 2015; Burgdorf and Panksepp, 2006; Lindquist et al., 2012).

Key structures in the reward network include the striatum, substantia nigra (SN), ventral tegmental area (VTA), and ventromedial prefrontal cortex (vmPFC, including medial orbitofrontal cortex or mOFC; Haber and Knutson, 2010). The striatum, for example, is a core region of the mesolimbic dopamine system and is critical in reward processing (Delgado, 2007; O’Doherty, 2004). The striatum, and particularly the ventral striatum (VS), is consistently activated by rewarding outcomes. The VS is sensitive to primary rewards such as food, drugs, or sex, and to secondary rewards, such as money and power (Sescousse et al., 2013). Reward-related brain regions are often activated by satisfying stimuli (e.g., picture of a loved one, positive social feedback, music, art; Bartels and Zeki, 2004; Berridge and Kringelbach, 2015). We therefore propose the following:

*Proposition 4: Nostalgia involves brain regions associated with reward processing*.

## 2.5 Overview

Taken together, nostalgia entails self-reflection, autobiographical memory, emotion regulation, and a reward orientation (Sedikides and Wildschut, 2020; Sedikides et al., 2015; Van Tilburg et al., 2018). We thus asked whether nostalgia involves brain regions associated with (1) self-reflection processing, (2) autobiographical memory processing, (3) emotion regulation processing, and (4) reward processing.To answer these questions (*Propositions 1-4*), we reviewed the emerging literature on patterns of brain activity associated with nostalgizing.

We concentrate on specific brain regions that are most strongly implicated in nostalgia, and we do not aim to cover exhaustively and comprehensively all pertinent brain activity. Also, as we have alluded earlier, we frame our review in terms of brain regions rather than specific cortical networks; after all, within a given cortical network (e.g., the default mode network or DMN), different brain regions may exercise distinct roles (Wen et al., 2020). Hence, a focus on brain regions is more informative. Further, a brain region could be linked with more than one of the four core components of nostalgia. For example, mPFC is broadly involved in most of the components. However, it is unclear whether mPFC is activated in conjunction with the specific component under consideration (i.e., mPFC activity might indicate self-reflection or emotion regulation). Put otherwise, although we offered *Propositions 1-4* based on existing nostalgia theory and research, our foci on patterns of brain activity relied to some extent on reverse inference. Lastly, the core components are not independent from each other; for example, self-reflection, autobiographical memory retrieval, and emotion regulation could occur simultaneously. Consequently, we posit that the core components of nostalgia—and relevant processes—are interdependent and coordinated (see also 3.3 Summary).

# 3. Neural substrates of nostalgia

## 3.1 Review of neuroscientific studies investigating the neural basis of nostalgia

To the best of our knowledge, six studies have directly addressed the neural bases of nostalgia. We discuss them below. The results provide initial empirical evidence for our propositions.

In a functional magnetic resonance imaging (fMRI) study (Oba et al., 2015), participants were instructed to view passively nostalgic pictures that described objects or scenes experienced in childhood (e.g., a pencil case from childhood) as well as similar but non-nostalgic (i.e., control) pictures (e.g., a contemporary pencil case). After scanning, participants rated their memory, along with their emotional experience (i.e., personal significance and emotionality), that accompanied each picture during scanning. Nostalgic (compared to control) pictures elicited stronger activity in the hippocampus. Prior work had shown that hippocampal engagement during autobiographical memory retrieval is modulated by qualities such as vividness, emotionality, and personal signiﬁcance (Addis et al., 2004; Gilboa et al., 2004). Consistent with these findings, hippocampal activity was correlated with ratings of the emotional and personal signiﬁcance of nostalgic objects (Oba et al., 2015). Nostalgizing, then, involves autobiographical memory that is more vivid, emotional, and personally significant than non-nostalgic recollection.

In addition, nostalgic (compared to control) pictures enhanced responses in the reward system, including the substantia nigra/ventral tegmental area (SN/VTA) and striatum (Oba et al., 2015). Further, hippocampus-ventral striatum co-activation was positively correlated with participants’ dispositional nostalgia under the influence of experimentally-induced nostalgia. Based on these two sets of findings, Kikuchi and Noriuchi (2017) speculated that memory and reward systems coproduce nostalgia, and each system plays a pivotal role in the experience of the emotion.

Compared with visual triggers, odor-evoked autobiographical memories are more emotionally significant (Herz et al., 2004). In a positron emission tomography (PET) study with venous catheter (injection of H215O), participants were instructed to smell a personalized nostalgic odor as well as a control odor that was irrelevant to nostalgia (Matsunaga et al., 2013).The nostalgic odor induced more autobiographical memories and positive emotions, and, importantly, elicited stronger activation in the vmPFC and precuneus/PCC. Furthermore, across participants, activity in these two regions was positively correlated.

The vmPFC responds to pleasant, emotionally-valenced odorants (Gottfried and Zald, 2005). More generally, vmPFC is involved in reward-related processing, responding preferentially to positive (as opposed to negative) outcomes (Liu et al., 2011; O’Doherty et al., 2001). Therefore, Matsunaga et al.’s (2013) finding of a positive neural correlation between PCC and vmPFC might represent the association of autobiographical memory and reward system. Given that the precuneus/PCC is thought to be a neural correlate of self-relevant processing (Cavanna and Trimble, 2006), the precuneus/PCC activity is consistent with nostalgia’s self-relevance. In addition, Matsunaga et al. showed that nostalgia-induced vmPFC and precuneus/PCC activation was negatively associated with levels of peripheral proinflammatory cytokines measured from blood samples, such as the tumor necrosis factor-α and interferon-γ. Although these across-participant correlations need to be interpreted with caution due to the small sample size (*N* = 10), the researchers suggested that nostalgia might confer benefits on health and well-being via the inhibition of systemic inflammation.

Nostalgia is commonly elicited by music (Janata et al., 2007; Sedikides et al., 2021). Music evokes complex emotions, varying in both valence and arousal (Koelsch, 2014). Behavioral evidence indicates that nostalgia is a low-arousal and positively-valenced emotion (Van Tiburg et al., 2018). Trost and colleagues (2012) tested this idea in an imaging study. They used nine musical epochs to elicit different emotions, with each representing a specific emotion (e.g., nostalgia, joy, sadness), and instructed participants to assess the degree of arousal and valence of each musical epoch. Compared with positive and high-arousal emotions (e.g., joy, wonder), positive but low-arousal emotions (e.g., nostalgia, tenderness) increased brain activity in limbic and medial prefrontal areas.

Irrespective of valence, low-arousal emotions (e.g., nostalgia) also engage a network centered on the hippocampus and vmPFC, including the subgenual ACC. The hippocampus is involved in music-induced emotions (Koelsch, 2014), and is susceptible to chronic stressors (Jacobson and Sapolsky, 1991). Stress and depression conduce to atrophy and loss of neurons in the hippocampus (Warner-Schmidt and Duman, 2006). It is possible, then, that the psychological health benefits of nostalgia (e.g., decreased stress; Routledge et al., 2013) derive in part from the neural change in hippocampus during nostalgizing. We note, however, that Trost et al. (2012) did not differentiate nostalgia from other emotions with similar valence or arousal (e.g., peacefulness, tenderness). Accordingly, the extent to which the above evidence is specific to nostalgia will need to be addressed in follow-up investigations.

Barrett and Janata (2016) examined the neural correlates of music-evoked nostalgia. In an fMRI study, each participant listened to 30 musical excerpts, which were selected from the Billboard Top-100 Pop, Hip Hop, and R&B lists when the participant was between 7 and 19 years old. Immediately after listening to each excerpt, participants reported their level of nostalgia. Although overall results did not reveal significant neural correlates of music-evoked nostalgia, informative individual differences emerged. Among those who were dispositionally lower on nostalgia, activity in the midbrain and left amygdala increased when listening to more nostalgia-evoking music (i.e., when they felt more nostalgic). In contrast, among those who were dispositionally higher on nostalgia, activity in these regions decreased when listening to more nostalgia-evoking music.

The amygdala is one of the most critical brain regions for emotion. It has a germane role in processing social signals of emotion and in the consolidation of emotional memories (Dalgleish, 2004). The amygdala responds to socio-affective stimuli that encourage approach, such that music-evoked joy elicits stronger brain responses in the superficial amygdala (Koelsch et al., 2013). Accordingly, Barrett and Janata’s (2016) finding that individuals higher on dispositional nostalgia manifested decreased amygdala activation during music-evoked nostalgia may suggest that nostalgic listeners may experience less positive affect in response to nostalgic music. Alternatively, as the amygdala also plays an important role in the processing of negative emotion (Kober et al., 2008; Lindquist et al., 2012), their finding may indicate that individuals high (compared to low) on dispositional nostalgia experience less negative emotion when listening to nostalgic music. Stated otherwise, individuals high on dispositional nostalgia may be better at regulating their negative mood elicited by nostalgic music. This possibility is consistent with research demonstrating that high-nostalgia individuals derive greater well-being benefits from a nostalgia induction (Cheung et al., 2016; Layous et al., 2021). Barrett and Janata’s results should be interpreted with caution, however, considering the small sample size (*N* = 12).

More recently, Yang et al. (2021) induced nostalgia through pictures that depicted events or objects in participants’ childhood. Following nostalgia induction, participants judged whether two death-related (vs. neutral) words belonged in the same category. Participants who viewed nostalgic (vs. control) pictures evinced more intense activation in right amygdala in response to death-related (vs. neutral) words, and also manifested greater accuracy in word judgments. Their findings indicate that nostalgia, as an approach-oriented emotion, enhances detection of death-threat.

In addition to experimentally-induced nostalgia, researchers have investigated attendees’ reported nostalgia in Double-A Minor League Baseball games. In a recent electroencephalography (EEG) study, Hungenberg et al. (2020) recorded attendees’ neurological responses as well as their self-reported nostalgia in the games. Attendees’ brainwave frequencies (i.e., theta power in the frontal and temporal lobes, and alpha power in the posterior) that were indicative of self-reflection correlated positively and signiﬁcantly with reported nostalgia. Furthermore, more self-reflection processing predicted, via reported nostalgia, attendees’ desire to attend a future game and recommend a game to a friend.

## 3.2 Review of other relevant studies

Next, we review studies that, although not addressing nostalgia directly, are highly relevant to it, as they implement manipulations or stimuli that are common in nostalgia research and could elicit nostalgia. Typically, nostalgia is induced by either nostalgic stimuli or cues, such as music, photos, and odors dating to one’s childhood (Oba et al., 2015; Reid et al., 2014), or by recalling personal memories of nostalgic events (Leunissen et al., 2020; Sedikides et al., 2015). First, we will discuss work that involved stimuli deemed nostalgic, and subsequently we will turn to work that involved memories of events deemed nostalgic.

3.2.1 Studies that involved stimuli deemed nostalgic

In an fMRI study, Janata (2009) presented participants with 30 excerpts of popular music from the Apple iTunes Music Store dating to their childhood. Following each excerpt, participants rated the familiarity, affective valence, and autobiographical salience of the music. Strongly autobiographical songs were rated as more vivid, emotional, and strongly associated with a specific memory (i.e., a discrete event). Brain activity in the dorsal mPFC (dmPFC) was positively related to the autobiographical salience of musical excerpts, whereas rostral and ventral mPFC (rmPFC, vmPFC), as well as PCC, responded to familiar, autobiographically salient, and positive affective music pieces. Although based on a small sample (*N =* 13), these results suggest that the mPFC is engaged when people experience emotionally salient memories triggered by familiar songs from their personal past. The mPFC also engaged, along with lateral prefrontal and posterior cortices, to familiar and autobiographically salient songs. Therefore, the autobiographical salience and positive value produced by music-evoked personal memories were manifested mainly in the mPFC and its subregions. The mPFC is typically recruited not only during processing of self-related information (D’Argembeau et al., 2007), but also in autobiographical memory (Gilboa et al., 2004) and in self-conscious emotion (Somerville et al., 2013). Indeed, a meta-analysis indicated that autobiographical memory and self-reflection activated the same region within the mPFC (Martinelli et al., 2013).Thus, the mPFC may serve as a hub that links self-relevant processing with autobiographical memories and emotions, and plays an integrative role in the experience of nostalgia.

Another fMRI study, using songs popular in the past, also demonstrated the engagement of mPFC in specific autobiographical memories (Ford et al., 2011). Participants listened to such songs, and retrieved whatever autobiographical memory came to mind. Certain neural regions of the core autobiographical memory network, including vmPFC, PCC, and medial temporal lobe (MTL—along with the hippocampus), were engaged in all autobiographical memories. Moreover, authors of this fMRI study examined how autobiographical memory specificity modulated activation of the autobiographical memory network by instructing participants to rate the level of specificity (i.e., lifetime period, general event, specific event) of their memory. Relative to retrieval of abstract personal knowledge, event retrieval was accompanied by stronger activation in dorsolateral and dorsomedial prefrontal regions. In addition, participants rated event-specific memories as most vivid, emotional, positive, and subject to reliving. These memories were associated with enhanced activity in the MTL (including the hippocampus) and dmPFC (Ford et al., 2011). Similarly, other studies revealed greater engagement of the mPFC, hippocampus (Maguire and Mummery, 1999), and regions associated with self-reference (anteromedial PFC; Levine et al., 2004) during specific event memory.

Personal photos, as common cues for nostalgia, allow participants to re-experience their memories. Gilboa et al. (2004) induced distant or recent autobiographical memories via photographs of participants ranging from their 5th year of age to the present. Though retrieval of both distant and recent memories activated the hippocampus, there was greater distribution of activation along the hippocampus in distant than recent memories. As opposed to personal semantic information, recalling detailed, vivid, and distant autobiographical experiences determined the involvement of hippocampus and two posterior regions, precuneus and lingual gyrus.

In addition to music and pictures, an fMRI study implemented a personally meaningful odor that linked to one’s childhood time with family (Herz et al., 2004). This kind of odor could elicit more intense emotional responses and greater activation in the amygdala and hippocampal regions during recall than pertinent control odor or visual stimuli. Autobiographical memory triggered by the olfactory stimuli was more emotional than when triggered by alternate sensory stimuli. This effect might be due to the direct neural link between the olfactory system and the amygdala-hippocampal system implicated in emotion and memory processing (LeDoux, 2000).

3.2.2 Studies that involved memories of events deemed nostalgic

Nostalgic memories are predominately positive, specific, vivid, and distant (Van Tilburg et al., 2019). We now discuss neuroimaging studies that examined positive, specific, vivid, and distant autobiographical memories induced through nostalgizing. Evidence indicates that recalling positive autobiographical memories involves reward-related circuitry. In a study by Speer et al. (2014), participants first wrote about their personal memories prompted by life event cues (analogous to the Event Reflection Task typically used to induce nostalgia; Sedikides et al., 2015). Subsequently, participants were given either positive (e.g., visiting Disneyland) or neutral (e.g., packing for a trip) personalized event cues, and asked to savor these memories during scanning. Compared with neutral memories, positive memories enhanced not only self-reported positive mood, but also activity in the striatum and mPFC. Crucially, the increase in positive mood was associated with higher striatum and mPFC activity. Additionally, participants preferred to recall positive past experiences even at the cost of tangible reward (i.e., money) in a gambling task; that is, positive autobiographical memories were valued more than monetary reward. Based on their findings, *Nature* (2014) concluded that “Nostalgia rewards the brain, and people will even give up money for the chance to enjoy some nostalgia” (p. 11). As such, although Speer et al. did not explicitly highlight nostalgia, their findings point to the rewarding basis of nostalgia. Similarly, Lempert et al. (2017) asked participants to write about memories prompted by typical nostalgic life event cues (e.g. family vacation). Positive memory retrieval increased activity in the striatum and temporo parietal junction, and this brain modulation was linked to reduced temporal discounting. Hence, the extent to which memory recall is rewarding inﬂuences future reward-related decision-making.

In a study by Van Schie et al. (2019), participants used a first-person perspective to relive (rather than retrieve) positive autobiographical memories and evaluated the vividness of these memories. Positive compared to neutral memories enhanced mood and activation in the mPFC, ACC, and precentral as well as postcentral gyrus. Higher vividness was related to more pleasurable, distant, and longer memories; it was also relate to greater activation in amygdala, hippocampus, and insula, indicating increased awareness of oneself.[[3]](#footnote-3) In related work, effective vmPFC to hippocampus connectivity was observed when participants relived memories of events that were highly emotionally arousing or elicited stronger positive affect (Nawa and Ando, 2019). Returning to the Van Schie et al. study, participants’ state self-esteem increased after reliving positive autobiographical memories, in line with findings that nostalgia elevates self-esteem (Hepper et al., 2012; Wildshut et al., 2006) and augments self-positivity even when contrasted against an imagined positive future event in one’s life (Vess et al., 2012).

Cooney et al. (2007) investigated the neural correlates of positive autobiographical recall in recovery from negative mood. Retrieving positive autobiographical memories from one’s high school years while in a negative mood state improved one’s mood. Moreover, such retrieval was associated with activation in orbitofrontal cortex and in ACC, highlighting an important role of the vmPFC, and specifically of the subgenual cingulate, in regulating negative mood. These findings suggest that recall of positive memories could counteract affective negativity and regulate mood, consistent with the emotion regulatory capacity of nostalgia (Wildschut and Sedikides, 2022).

## 3.3 Summary

Nostalgia is an emotional experience that arises from memories featuring the self in social contexts (Sedikides et al., 2008, 2015). Nostalgia is a complex emotion, involving multiple psychological processes. Existing studies, although limited in number, have shown that nostalgia involves brain structures known to be engaged in self-reflection (mPFC, PCC, precuneus), autobiographical memory (hippocampus, mPFC, PCC, precuneus), emotion regulation (ACC, mPFC), and reward processing (SN, VTA, STA, vmPFC). We summarize in Table 1 the research findings, including both fMRI studies directly examining neural basis of nostalgia and studies relevant to the neural basis of nostalgia. Further, we propose in Figure 1 a “nostalgic brain” model based exclusively on studies that directly addressed the neural basis of nostalgia. Lastly, we highlight in Box 1 core brain regions activated more strongly in nostalgia than control conditions (studies represented in Figure 1), and we incorporate core components of the emotion in describing its neural substrates.

We emphasize that the evidence for the abovementioned propositions is suggestive at best. Granted, experimental inductions of nostalgia yielded activation in the brain regions we discussed (Figure 1). However, as we mentioned, our interpretations relied on reverse inference, an issue that needs to be addressed by future research (see also Section 4.1). We have listed brain regions most consistently associated with the four components of nostalgia (i.e., self-reflection, autobiographical memory, emotion regulation, reward processing) based on the social neuroscience literature. However, each component is associated with other brainregions as well; for example, amygdala and insula are also implicated in reward processing(Sescousse et al., 2013),whereastemporal cortex and cerebellum are also implicated in autobiographical memory (Svoboda et al., 2006). For example, key brain regions involved in nostalgia (specifically self-reflection), such as mPFC and PCC, are also core regions of the DMN (Philippi and Koenigs, 2014), raising the possibility that DMN is implicated in nostalgizing. Yet, to the extent that a given brain region is associated with one of the four components, it should also be involved in nostalgia. Thus, when testing the propositions, it is more informative to demonstrate that nostalgia and a given component share a neural basis rather than simply showing that nostalgia activates the listed brain regions (see Section 4.1).

Further, we observe that the components (and relevant processes) are interdependent and coordinated. *First*, autobiographical memories have high emotional potency and, vice versa, emotional experiences attain a privileged status in memory (Bluck and Li, 2001; LaBar and Cabeza, 2006; Schaefer and Philippot, 2005; Talarico et al., 2004). This emotion-memory interaction may make the nostalgic experience more lasting and significant. *Second*, autobiographical memory, emotion-imbued autobiographical memories, and self-reflection overlap (Lieberman et al., 2019). In both positive and negative autobiographical memory processing, the precuneus shows connections with the mPFC, a key region of the self-processing network (Xu et al., 2018). Also, the mPFC and PCC play a role in integrating self-relevance into autobiographical memory (Cabeza and St Jacques, 2007; Northoff and Bermpohl, 2004), whereas the mPFC and ACC play a role in integrating emotion into self-reflection processing (Moran et al., 2006).

*Third*, memory and reward systems interact closely in the nostalgic experience. High-value (e.g., nostalgic) stimuli engage reward-related regions such as the VTA and VS, promoting memory formation and better subsequent recall (Scimeca and Badre, 2012), potentially owing to the interactions with memory-related regions such as the hippocampus (Adcock et al., 2006; Wittmann et al., 2005). Dopamine release supports hippocampal plasticity and memory formation, and increased dopamine release may make memories more self-relevant and salient, strengthening them over time and rendering them more accessible in the future (Shohamy and Adcock, 2010). Indeed, the simultaneous involvement of autobiographic memory and reward system during nostalgia was manifested by hippocampus-ventral striatum (Oba et al., 2015) and PCC-vmPFC (Matsunaga et al., 2013) co-activation. Jointly, these findings highlight the function of memory and reward networks: The association between autobiographical memory and its reward property would be reinforced by dopamine transmission when experiencing nostalgia, such that the nostalgic memory would be re-encoded and re-stored in the network. The reinforced memory and reward association would further improve the reward value of the future nostalgic experiences (Oba et al., 2015). Given that nostalgia is thought to “bestow an endearing luster on past selves” (Davis, 1979, p. 41), it may add more lustrous elements to autobiographical events that may not have seemed all that positive at the time.

Brain activity involved in nostalgizing could be modulated by the triggered memories’ emotional significance, distance, and vividness. For example, greater activation in amygdala, hippocampus, and insula (van Schie et al., 2019), as well as effective vmPFC to hippocampus connectivity (Nawa and Ando, 2019), were detected when details about a personal event were recalled. Indeed, nostalgia could be considered a more specific, vivid, and emotionally salient form of distant autobiographical memories (Van Tilburg et al., 2019). Thus, when examining nostalgia-specific brain activities and cognitive processes, the control condition (e.g., equally vivid and emotional salient non-nostalgic autobiographical memories) is vital in helping researchers pinpoint a unique neural signature of nostalgia.

# 4. Future directions in neuroimaging research on nostalgia

## 4.1. Multivariate approach to testing the propositions

Our four propositions pertain to which brain regions are activated when an individual nostalgizes and why (e.g., mPFC because it is involved in autobiographical memory). Thus, to test each proposition, one ought to document not only that nostalgizing activates the corresponding brain region, but also that the activation is due to a specific component (e.g., autobiographical memory). Consider the case of ACC, known to be one of the most functionally heterogeneous brain regions (Poldrack, 2011; Wager et al., 2016). Even if a study found activation in ACC when participants were presentedwith nostalgia-evoking stimuli, one could not infer that this activation was due to emotion regulation (i.e., Proposition 3) as opposed to another component. Therefore, to test our propositions, one would need to compare directly brain regions activated by nostalgia with brain regions activated by a component of interest (e.g., emotion regulation).

Furthermore, in doing so, it does not suffice to show that there are activation overlaps, because such overlaps do not necessarily mean that they involve a common component (i.e., the same brain region could be activated for different reasons). Recently, a multivariate pattern analysis (MVPA) approach has been proven useful in discriminating between conditions that involve a common component (Levorsen et al., 2020; Wake and Izuma, 2017; Woo et al., 2014). For example, suppose that each of two conditions—for example, nostalgia and emotion regulation—significantly activated the same 100 voxels within the ACC. If activation patterns across the 100 voxels were similar between conditions (i.e., significantly positive voxel-by-voxel correlation), these patterns would constitute strong evidence of a common component (e.g., nostalgia involves emotion regulation).

Furthermore, a multivariate approach is suitable for testing the idea that multiple brain regions (Figure 1) collectively contribute to the subjective experience of nostalgia. As an example, a recent MVPA study has demonstrated that activation patterns across distributed brain regions (i.e., prefrontal, midcingulate, insular cortices, thalamus, and amygdala) can predict subjective fear ratings (Zhou, Zhao et al., 2021). This finding constitutes another critical piece of evidence against the idea that each emotion is specifically related to a single distinct brain region. Similarly, the attempt to predict the subjective experience of nostalgia using a whole-brain multivariate pattern is promising. The endeavor to unveil the neural signatures of nostalgia via a multivariate approach will add to the understanding of neural mechanisms of emotions in general—for example, how activation patterns in brain regions linked to different functions converge to produce a specific felt emotion.

## 4.2 Differentiating nostalgia from positive affect

Nostalgia is bittersweet, but more sweet than bitter (Leunissen et al., 2020; Van Tilburg et al., 2019). However, although the affective signature of nostalgia is predominantly positive, it should be distinguished from general positive affect (Sedikides et al., 2015; Stephan et al., 2012). Nostalgic engagement involves co-activation of positive and negative affect, a pattern that produces an emotional dynamic felt as ambivalence. The ambivalence of nostalgia may, at least in part, be responsible for its psychological benefits (Sedikides and Wildschut, 2016). There is evidence that individuals who experience mixed emotions show improved well-being (Adler and Hershfield, 2012).

To differentiate nostalgia from positive affect, psychologists have compared the effects of recalling nostalgic versus positive memories (e.g., a lucky event). These studies have documented unique effects of nostalgia (compared to positive memory per se) on ingroup evaluation and motivation to approach ingroup members (Wildschut et al., 2014), social connectedness, self-esteem, and ensuing inspiration (Stephan et al., 2015), openness to experience and ensuing creativity (Van Tilburg et al., 2015), social connectedness and ensuing self-continuity (Sedikides et al., 2016), and perceived social support (Zou et al., 2019). Other research that compared listening to nostalgic versus cheerful songs demonstrated unique effects of music-evoked nostalgia on self-esteem and ensuing optimism (Cheung et al., 2013). These diverse findings illustrate the distinctiveness of nostalgia, above and beyond general positive recollection and concomitant positive affect.

Future neuroimaging research could emulate these procedures by comparing the neural activation associated with nostalgic stimuli (e.g., autobiographical recall, music, scent) to patterns of activation associated with equally positive, but non-nostalgic, stimuli. This would address a limitation of existing studies, which generally did not systematically control for stimulus valence. For example, in Oba et al. (2015), the nostalgic (vs. control) stimuli elicited greater self-reported happiness.

## 4.3 Regulatory function of nostalgia

According to the regulatory model (Sedikides et al., 2015; Wildschut and Sedikides, 2022), nostalgia counteracts or down-regulates diverse psychological threats. One account for the regulatory (e.g., threat-buffering) capacity of nostalgia is the engagement of top-down processes, including cognitive emotion regulation. These processes involve the PFC and ACC (Cisler and Koster, 2010; Ochsner and Gross, 2005; Ochsner et al., 2004). Given that activation in these regions is also associated with nostalgia, PFC and ACC may represent the neural substrate of nostalgia’s regulatory function (Barret and Janata, 2016; Janata, 2009; Trost et al., 2012). Stated otherwise, when encountering a psychological threat, nostalgia may modulate activity in the emotion regulation network. This regulatory mechanism has been documented in an fMRI study on self-esteem and mortality salience (Yanagisawa et al., 2016). Individuals with high self-esteem showed increased amygdala-ventrolateral prefrontal cortex (vLPFC) connectivity in response to death-related stimuli, and this stronger functional connectivity predicted a reduction in defensive reactions following exposure to these stimuli. Notably, nostalgia inductions boost self-esteem (Hepper et al., 2012; Wildschut et al., 2006), which may shed light on the mechanisms underlying the self-regulatory potential of nostalgia.

Another regulatory mechanism may be indirect and derive from nostalgia’s rewarding potential. Rewarding stimuli decrease physiological stress reactivity (Creswell et al., 2013), and this may explain the beneficial influence of nostalgia (a predominantly positive emotion) in the context of threat. Given that the VS shows resting-state functional connectivity with the vmPFC (Di Martino et al., 2008), it is possible that striatum activity is accompanied by heightened vmPFC activity, which regulates psychological and behavioral responses to threat information (Dutcher et al., 2016; Falk et al., 2015). When individuals experience nostalgia, their reward-related neural activity intensifies, which may modulate their neural responses to threat allowing them to be more resilient and less defensive. Overall, nostalgia might modulate neural responses to threats, thereby buffering their impact (Juhl et al., 2010; Routledge et al., 2011) and reducing defensive responding (Routledge et al., 2013; Sedikides and Wildschut, 2018). Future neuroscience research would do well to focus on providing further evidence for this proposed regulatory function of nostalgia.

## 4.4 Individual differences

4.4.1 Nostalgia proneness

Neural responses to nostalgia-evoking music are modulated by individual differences in nostalgia proneness. Barrett and Janata (2016) found that high (vs. low) dispositional nostalgia attenuated the relation between music-evoked nostalgia and brain activity in regions implicated in affect and reward processing (i.e., left amygdala and a midbrain region including the SN and VTA). As mentioned before, for individuals who were more chronically nostalgic, activity in these regions decreased when they experienced music-evoked nostalgia, whereas, for those less chronically nostalgic, activity in these areas increased when exposed to music-evoked nostalgia. The findings highlighted the importance of incorporating individual differences in future research on neural responses to complex and idiosyncratic emotional experiences.

Genetic influences are also relevant. A twin study demonstrated that dispositional nostalgia is partly shaped by heredity (Luo et al., 2016). More recently, Luo et al. (2017) uncovered a biological basis for nostalgia’s heritability. These researchers focused on a polymorphism in the promoter of the serotonin transporter gene (5-HTTLPR) as a possible biological basis. Participants with the 5-HTTLPR short allele were higher on dispositional nostalgia than those without this allele. Given that the serotonin system is linked with sensitivity to negative experiences, the findings suggest that individuals with the 5-HTTLPR short allele may recruit nostalgia to cope with the psychological consequences of aversive events. This interpretation is consistent with evidence from an EEG study, indicating that relative right-frontal EEG asymmetry, a neural correlate of withdrawal from aversive stimulation (Davidson, 1998), is positively associated with dispositional nostalgia (Tullett et al., 2015). Future research should consider the role of serotonin in modulating the neurological networks implicated in nostalgia (Hensler, 2006).

4.4.2 Attachment avoidance

Nostalgia functions as a social resource, decreasing attachment-related anxiety and avoidance (Wildschut et al., 2006). Individual differences in attachment-related avoidance moderate the sociality function of nostalgia. Nostalgic reflection fosters social connectedness, interpersonal competence (Wildschut et al., 2010), and relationship satisfaction (Juhl et al., 2012) among low-avoidance, but not among high-avoidance, individuals. Moreover, attachment-related avoidance is implicated in the extent to which people recruit nostalgia to cope with social distress, such as loneliness and social exclusion. Specifically, low-avoidance (compared to high-avoidance) individuals are more likely to respond to social distress with increased nostalgia (Abakoumkin et al., 2017; Wildschut et al., 2010). Notably, attachment-related avoidance has been linked to hippocampal reduction (Quirin et al., 2009), suggesting that the hippocampus is involved in the formation and maintenance of social attachment (Koelsch, 2014). This suggestion aligns with results of neuroimaging studies that document changes in hippocampal activity during nostalgic reflection (Trost et al., 2012; Oba et al., 2015). Signal changes in hippocampus in response to nostalgic stimuli might be contingent upon individual differences in attachment style. Future research could examine whether person low (than high) on attachment avoidance evince greater changes in hippocampal and reward-network activity when nostalgizing.

4.4.3 Resilience

Resilience is defined as the ability to experience positive emotions (Bonanno, 2005) and to use personal and social resources for bouncing back effectively from adversity (Tugade and Fredrickson, 2004). Resilience can moderate the relation between loneliness and nostalgia, such that highly resilient individuals are more likely or able to recruit nostalgia when feeling lonely (Zhou et al., 2008). When recollecting positive memories, resilience was associated with greater striatal activity (Speer et al., 2014). That is, resilient individuals, who have a greater tendency to experience positive emotions (i.e., improvement of positive mood), are also those who exhibit more reward-related activity in the striatum when engaging in positive autobiographical memories. In addition, the memory and reward network (i.e., the hippocampal-VTA loop) involved in nostalgia may be related to resilience (Oba et al., 2015). To be precise, when nostalgia is experienced, the connection between the nostalgic memory and its reward value would be reinforced by dopamine transmission, with the memory re-encoded and re-stored in the network. Consequently, the reinforced association is likely to produce more rewards when nostalgia is re-experienced, thereby strengthening resilience (Oba et al., 2015). Future neuropsychological studies could assess more closely the association between resilience and nostalgia’s role in threat or adversity regulation.

## 4.5 Multi-sensory nostalgia

Neuroscientists have used auditory (Barrett and Janata, 2016; Ford et al., 2011; Janata, 2009; Trost et al., 2012), visual (including semantic and image; Oba et al., 2015; Speer et al., 2014), and olfactory (Matsunaga et al., 2013) stimuli to induce nostalgia. However, these differing nostalgia inductions may produce distinct effects. For example, odor-evoked autobiographical memories are more emotionally potent than memories evoked by other stimuli (Herz et al., 2004), yielding stronger activity in MTL regions and precuneus (Arshamian et al., 2013). Also, music- and odor-induced nostalgia may elicit stronger activity in regions implicated in emotion and visual vividness (e.g., precuneus; Barrett and Janata, 2016; Matsunaga et al., 2013; Trost et al, 2012). In the case of musical memory, an amnesia-patient study suggested that memory for music depends on brain networks that are distinct from those involved in episodic and semantic memory (Finke et al., 2012). These findings underscore the importance of addressing the mechanisms that underlie different nostalgia inductions. Furthermore, it is useful to investigate the neural bases of nostalgia through different inductions within the same group of participants. This would allow researchers to test whether the brain regions proposed above are actually *core* structures (thus, activated regardless of induction methods) and to identify other brain regions that are contingent on specific induction methods.

# 5. Conclusion

In recent years, social cognitive neuroscience has begun to offer valuable insights into the neural bases of nostalgia, as well as human emotion and memory in general. Based on psychological understanding, we postulated that nostalgia involves several neural regions, specifically those involved in self-reflection, autobiographical memory, emotion regulation, and reward processing. The results of recent neuroscientific studies are at least partially consistent with these propositions,although some evidence is indirect (i.e., based on reverse inference).

Nostalgia’s influence on neural activity within multiple brain structures suggests the potential for applications of nostalgia-based therapy and treatment to emotional and memory dysfunctions. The social cognitive neuroscience approach can provide evidence and novel explanations for the psychological benefits of nostalgia. Involvement of the reward network may further elucidate nostalgia’s benefits, and could be mediated by nostalgia’s capacity to fulfil personal and social needs. Future research could explicate the functional mechanisms underlying nostalgiathrough a multivariate approach as well as elucidate the connectivity among the core regions associated with this emotion. Future research could also compare nostalgia with positive emotion or memory, examine multi-sensory nostalgia by various triggers, and explore individual differences that may modulate brain responses during nostalgic engagement.

Emotion is one of the most elusive topics in both psychology and neuroscience, and advances in neuroscience testify to how complex the neural representation of emotion is (Adolphs, 2017; Barrett, 2017; Lindquist et al., 2012; Saarimäki et al., 2018). Yet, we hope that our review provides a good starting point for unraveling the neural basis of nostalgia.

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**References**

Abakoumkin, G., Wildschut, T., Sedikides, C., Bakarou, M. (2017). Nostalgia in response to group-based exclusion: The role of attachment-related avoidance. *European Journal of Social Psychology*, 47, 373-381.

Abeyta, A., Routledge, C., Roylance, C., Wildschut, R. T., & Sedikides, C. (2015). Attachment-related avoidance and the social and agentic content of nostalgic memories. *Journal of Social and Personal Relationships*, 32, 406-413.

Adcock, R. A., Thangavel, A., Whitfield-Gabrieli, S., Knutson, B., Gabrieli, J. D. (2006). Reward-motivated learning: Mesolimbic activation precedes memory formation. *Neuron*, 50, 507-517.

Addis, D. R., Moscovitch, M., Crawley, A.P., McAndrews, M. P. (2004). Recollective qualities modulate hippocampal activation during autobiographical memory retrieval. *Hippocampus*, 14, 752-762.

Adler, J. M., Hershfield, H. E. (2012). Mixed emotional experience is associated with and precedes improvements in psychological well-being. *PloS One*, 7, e35633.

Adolphs, R. (2017). How should neuroscience study emotions? By distinguishing emotion states, concepts, and experiences. *Social Cognitive and Affective Neuroscience*, 12, 24-31.

Arshamian, A., Iannilli, E., Gerber, J. C., Willander, J., Persson, J., Seo, H. S., ... Larsson, M. (2013). The functional neuroanatomy of odor evoked autobiographical memories cued by odors and words. *Neuropsychologia*, 51, 123-131.

Baldwin, M., Biernat, M., Landau, M. J. (2015). Remembering the real me: Nostalgia offers a window to the intrinsic self. *Journal of Personality and Social Psychology*, 108, 128-147.

Baldwin, M., Landau, M. J. (2014). Exploring nostalgia’s influence on psychological growth. *Self and Identity*, 13, 162-177.

Barrett, F. S., Grimm, K. J., Robins, R. W., Wildschut, T., Sedikides, C., Janata, P. (2010). Music-evoked nostalgia: affect, memory, and personality. *Emotion*, 10, 390-403.

Barrett, F. S., Janata, P. (2016). Neural responses to nostalgia-evoking music modeled by elements of dynamic musical structure and individual differences in affective traits. *Neuropsychologia*, 91, 234-246.

Barrett, L. F. (2017). The theory of constructed emotion: an active inference account of interoception and categorization. *Social Cognitive and Affective Neuroscience*, 12, 1-23.

Bartels, A., Zeki, S. (2004). The neural correlates of maternal and romantic love. *Neuroimage*, 21, 1155-1166.

Batcho, K. I. (2007). Nostalgia and the emotional tone and content of song lyrics. *The American Journal of Psychology*, 120, 361-381.

Batcho, K.I. (2013). Nostalgia: The bittersweet history of a psychological concept. *History of Psychology*, 16, 165-176.

Berridge, K. C., Kringelbach, M .L. (2015). Pleasure systems in the brain. *Neuron*, 86, 646-664.

Bluck, S., Li, K. Z. (2001). Predicting memory completeness and accuracy: Emotion and exposure in repeated autobiographical recall. *Applied Cognitive Psychology*, 15, 145-158.

Bohlmeijer, E., Roemer, M., Cuijpers, P., Smit, F. (2007). The effects of reminiscence on psychological well-being in older adults: A meta-analysis. *Aging and Mental Health*, 11, 291-300.

Bonanno, G. A. (2005). Resilience in the face of potential trauma. *Current Directions in Psychological Science*, 14, 135-138.

Burgdorf, J., Panksepp, J. (2006). The neurobiology of positive emotions. *Neuroscience and Biobehavioral Reviews*, 30, 173-187.

Bush, G., Luu, P., Posner, M. I. (2000). Cognitive and emotional influences in anterior cingulate cortex. *Trends in Cognitive Sciences*, 4, 215-222.

Cabeza, R., Nyberg, L. (2000). Imaging cognition II: An empirical review of 275 PET and fMRI studies. *Journal of Cognitive Neuroscience*, 12, 1-47.

Cabeza, R., St Jacques, P. (2007). Functional neuroimaging of autobiographical memory. *Trends in Cognitive Sciences*, 11, 219-227.

Cavanna, A. E., Trimble, M. R. (2006). The precuneus: a review of its functional anatomy and behavioural correlates. *Brain*, 129, 564-583.

Cheung, W. Y., Sedikides, C., Wildschut, T. (2016). Induced nostalgia increases optimism (via social connectedness and self-esteem) among individuals high, but not low, in trait nostalgia. *Personality and Individual Differences,* 90, 283-288.

Cheung, W.-Y., Wildschut, T., Sedikides, C. (2018). Autobiographical memory functions of nostalgia in comparison to rumination: Similarity and uniqueness. *Memory*, 26, 229-237.

Cheung, W. Y., Wildschut, T., Sedikides, C., Hepper, E. G., Arndt, J., Vingerhoets, A. J. J. M. (2013). Back to the future: Nostalgia increases optimism. *Personality and Social Psychology Bulletin*, 39, 1484-1496.

Chiang, K. J., Chu, H., Chang, H. J., Chung, M. H., Chen, C. H., Chiou, H. Y., Chou, K. R. (2010). The effects of reminiscence therapy on psychological well-being, depression, and loneliness among the institutionalized aged. *International Journal of Geriatric Psychiatry*, 25, 380-388.

Cisler, J. M., Koster, E. H. (2010). Mechanisms of attentional biases towards threat in anxiety disorders: An integrative review. *Clinical Psychology Review*, 30, 203-216.

Cooney, R. E., Joormann, J., Atlas, L.Y., Eugène, F., & Gotlib, I. H. (2007). Remembering the good times: neural correlates of affect regulation. *Neuroreport*, 18, 1771-1774.

Cox, C. R., Kersten, M., Routledge, C., Brown, E. M., & Van Enkevort, E. A. (2015). When past meets present: The relationship between website‐induced nostalgia and well‐being. *Journal of Applied Social Psychology*, 45, 282–299.

Creswell, J. D., Pacilio, L. E., Denson, T. F., Satyshur, M. (2013). The effect of a primary sexual reward manipulation on cortisol responses to psychosocial stress in men. *Psychosomatic Medicine*, 75, 397-403.

D’Argembeau, A., Ruby, P., Collette, F., Degueldre, C., Balteau, E., Luxen, A., ... Salmon, E. (2007). Distinct regions of the medial prefrontal cortex are associated with self-referential processing and perspective taking. *Journal of Cognitive Neuroscience*, 19, 935-944.

Dalgleish, T., 2004. The emotional brain. *Nature Reviews Neuroscience*, 5, 583-589.

Davidson, R. J. (1998). Affective style and affective disorders: Perspectives from affective neuroscience. *Cognition and Emotion*, 12, 307–330.

Davis, F. (1979). *Yearning for yesterday: A sociology of nostalgia*. New York: The Free Press.

Delgado, M. . (2007). Reward-related responses in the human striatum. *Annals of the New York Academy of Sciences*, 1104, 70-88.

Di Martino, A., Scheres, A., Margulies, D. S., Kelly, A. M. C., Uddin, L. Q., Shehzad, Z., ... Milham, M. P. (2008). Functional connectivity of human striatum: A resting state FMRI study. *Cerebral Cortex*, 18, 2735-2747.

Dutcher, J. M., Creswell, J. D., Pacilio, L. E., Harris, P. R., Klein, W. M., Levine, J. M., ... Eisenberg, N. I. (2016). Self-affirmation activates the ventral striatum: a possible reward-related mechanism for self-affirmation. *Psychological Science*, 27, 455-466.

Falk, E. B., O’Donnell, M. B., Cascio, C. N., Tinney, F., Kang, Y., Lieberman, M. D., ... Strecher, V. J. (2015). Self-affirmation alters the brain’s response to health messages and subsequent behavior change. *Proceedings of the National Academy of Sciences*, 112, 1977-1982.

Finke, C., Esfahani, N. E., Ploner, C. J. (2012). Preservation of musical memory in an amnesic professional cellist. *Current Biology*, 22, R591-R592.

Folkman, S. (2008). The case for positive emotions in the stress process. *Anxiety, Stress, and Coping*, 21, 3-14.

Ford, J. H., Addis, D. R., Giovanello, K. S. (2011). Differential neural activity during search of specific and general autobiographical memories elicited by musical cues. *Neuropsychologia*, 49, 2514-2526.

Frankenbach, J., Wildschut, T., Juhl, J., & Sedikides, C. (2021). Does neuroticism disrupt the psychological benefits of nostalgia? A meta-analytic test. *European Journal of Personality*, 35, 249-266

Gilboa, A. (2004). Autobiographical and episodic memory—one and the same? Evidence from prefrontal activation in neuroimaging studies. *Neuropsychologia*, 42, 1336-1349.

Gilboa, A., Winocur, G., Grady, C. L., Hevenor, S. J., Moscovitch, M. (2004). Remembering our past: functional neuroanatomy of recollection of recent and very remote personal events. *Cerebral Cortex*, 14, 1214-1225.

Gottfried, J. A., Zald, D. H. (2005). On the scent of human olfactory orbitofrontal cortex: meta-analysis and comparison to non-human primates. *Brain Research Reviews*, 50, 287-304.

Haber, S. N., Knutson, B. (2010). The reward circuit: linking primate anatomy and human imaging. *Neuropsychopharmacology*, 35, 4-26.

Hensler, J. G. (2006). Serotonergic modulation of the limbic system. *Neuroscience & Biobehavioral Reviews*, 30, 203-214.

Hepper, E. G., Ritchie, T. D., Sedikides, C., Wildschut, T. (2012). Odyssey’s end: Lay conceptions of nostalgia reflect its original Homeric meaning. *Emotion*, 12, 102-119.

Hepper, E. G., Wildschut, T., Sedikides, C., Ritchie, T. D., Yung, Y.-F., Hansen, N., ... Zhou, X. (2014). Pancultural nostalgia: Prototypical conceptions across cultures. *Emotion*, 14, 733-747.

Hepper, E. G., Wildschut, T., Sedikides, C., Robertson, S., Routledge, C. D. (2020). The time capsule: Nostalgia shields wellbeing from limited time horizons. *Emotion*, 21, 644-664.

Herz, R. S., Eliassen, J., Beland, S., Souza, T. (2004). Neuroimaging evidence for the emotional potency of odor-evoked memory. *Neuropsychologia*, 42, 371-378.

Hofer, J. (1934). Medical dissertation on nostalgia (C. K. Anspach, Trans.). B*ulletin of the History of Medicine*, 2, 376-391. (Original work published 1688.)

Holbrook, M. B., Schindler, R. (1996). Market segmentation based on age and attitude toward the past: Concepts, methods, and findings concerning nostalgic influences on customer tastes. *Journal of Business Research*, 37, 27-39.

Hungenberg, E., Slavich, M., Bailey, A., Sawyer, T. (2020). Examining minor league baseball spectator nostalgia: A neuroscience perspective.*Sport Management Review*, 23, 824-837.

Jacobson, L., Sapolsky, R. (1991). The role of the hippocampus in feedback regulation of the hypothalamic-pituitary-adrenocortical axis. *Endocrine Reviews*, 12, 118-134.

Janata, P., 2009. The neural architecture of music-evoked autobiographical memories. *Cerebral Cortex*, 19, 2579-2594.

Janata, P., Tomic, S. T., Rakowski, S. K. (2007) Characterisation of music-evoked autobiographical memories. *Memory*, 15, 845-860.

Jiang, T., Cheung, W.-Y., Wildschut, T., & Sedikides, C. (2021). Nostalgia, reflection, brooding: Psychological benefits and autobiographical memory functions. *Consciousness and Cognition*, 90, 103107.

Josephson, B. R. (1996). Mood regulation and memory: Repairing sad moods with happy memories. *Cognition and Emotion*, 10, 437-444.

Juhl, J., Routledge, C., Arndt, J., Sedikides, C., Wildschut, T. (2010). Fighting the future with the past: Nostalgia buffers existential threat. *Journal of Research in Personality,* 44, 309-314.

Juhl, J., Sand, E., Routledge, C. (2012). The effects of nostalgia and avoidant attachment on relationship satisfaction and romantic motives. *Journal of Social and Personal Relationships*, 29, 661-670.

Juhl, J., Wildschut, T., Sedikides, C., Xiong, X., & Zhou, X. (2021). Nostalgia promotes help seeking by fostering social connectedness. Emotion, 21, 631-643.

Kikuchi, Y., Noriuchi, M. (2017). The nostalgic brain: Its neural basis and positive emotional role in resilience. In S. Fukuda (Ed.), *Emotional engineering* (Vol. 5). New York, NY: Springer.

Kim, H. (2012). A dual-subsystem model of the brain's default network: self-referential processing, memory retrieval processes, and autobiographical memory retrieval. *Neuroimage*, 61, 966-977.

Kober, H., Barrett, L.F., Joseph, J., Bliss-Moreau, E., Lindquist, K., Wager, T. D. (2008). Functional grouping and cortical-subcortical interactions in emotion: a meta-analysis of neuroimaging studies. *Neuroimage*, 42, 998-1031.

Koelsch, S. (2014). Brain correlates of music-evoked emotions. *Nature Reviews Neuroscience*, 15, 170-180.

Koelsch, S., Skouras, S., Fritz, T., Herrera, P., Bonhage, C., Küssner, M. B., Jacobs, A. M. (2013). The roles of superficial amygdala and auditory cortex in music-evoked fear and joy. *Neuroimage*, 81, 49-60.

LaBar, K. S., Cabeza, R. (2006). Cognitive neuroscience of emotional memory. *Nature Reviews Neuroscience*, 7, 54-64.

Layous, K., Kurtz, J. L., Wildschut, T., & Sedikides, C. (2021). The effect of a multi-week nostalgia intervention on well-being: Mechanisms and moderation. *Emotion*. Advance online publication. <https://doi.org/>10.1037/emo0000817

LeDoux, J. E. (2000). Emotion circuits in the brain. *Annual Review of Neuroscience*, 23, 155-184.

Lempert, K. M., Speer, M. E., Delgado, M. R., & Phelps, E. A. (2017). Positive autobiographical memory retrieval reduces temporal discounting. *Social Cognitive and Affective Neuroscience*, 12, 1584-1593.

Leunissen, J., Wildschut, T., Sedikides, C., Routledge, C. (2020). The hedonic character of nostalgia: An integrative data analysis. *Emotion Review*, 13, 139-156.

Levine, B., Turner, G. R., Tisserand, D., Hevenor, S. J., Graham, S. J., McIntosh, A. R. (2004). The functional neuroanatomy of episodic and semantic autobiographical remembering: a prospective functional MRI study. *Journal of Cognitive Neuroscience*, 16, 1633-1646.

Levorsen, M., Ito, A., Suzuki, S., & Izuma, K. (2021). Testing the reinforcement learning hypothesis of social conformity. *Human Brain Mapping*, *42*, 1328-1342.

Lieberman, M. D. (2007). Social cognitive neuroscience: a review of core processes. *Annual Review of Psychology*, 58, 259-289.

Lieberman, M. D., Straccia, M. A., Meyer, M. L., Du, M., Tan, K. M. (2019). Social, self, (situational), and affective processes in medial prefrontal cortex (MPFC): Causal, multivariate, and reverse inference evidence. *Neuroscience & Biobehavioral Reviews*, 99, 311-328.

Lindquist, K. A., Wager, T. D., Kober, H., Bliss-Moreau, E., Barrett, L. F. (2012). The brain basis of emotion: a meta-analytic review. *Behavioral and Brain Sciences*, 35, 121-143.

Liu, X., Hairston, J., Schrier, M., Fan, J. (2011). Common and distinct networks underlying reward valence and processing stages: a meta-analysis of functional neuroimaging studies. *Neuroscience & Biobehavioral Reviews*, 35, 1219-1236.

Luo, Y. L. L., Liu, Y., Cai, H., Wildschut, T., Sedikides, C. (2016). Nostalgia and self-enhancement: Phenotypic and genetic approaches. *Social Psychological and Personality Science*, 7, 857-866.

Luo, Y. L., Way, B., Welker, K., DeWall, C. N., Bushman, B. J., Wildschut, T., Sedikides, C. (2017). 5-HTTLPR Polymorphism is associated with nostalgia proneness: The role of neuroticism. *Social Neuroscience*, 14, 183-190.

Madoglou, A., Gkinopoulos, T., Xanthopoulos, P., Kalamaras, D. (2017). Representations of autobiographical nostalgic memories: Generational effect, gender, nostalgia proneness and communication of nostalgic experiences. *Journal of Integrated Social Sciences*, 7, 60-88.

Maguire, E. A., Mummery, C. J. (1999). Differential modulation of a common memory retrieval network revealed by positron emission tomography. *Hippocampus*, 9, 54-61.

Maher, P. J., Igou, E. R., & van Tilburg, W. A. P. (2021). Nostalgia relieves the disillusioned mind. *Journal of Experimental Social Psychology*, 92, 104061.

Martinelli, P., Sperduti, M., Piolino, P. (2013). Neural substrates of the self-memory system: New insights from a meta-analysis. *Human Brain Mapping*, 34, 1515-1529.

Matsunaga, M., Bai, Y., Yamakawa, K., Toyama, A., Kashiwagi, M., Fukuda, K., ... Yamada, J. (2013). Brain-immune interaction accompanying odor-evoked autobiographic memory. *PloS One*, 8, e72523.

Moran, J. M., Macrae, C. N., Heatherton, T. F., Wyland, C. L., Kelley, W. M. (2006). Neuroanatomical evidence for distinct cognitive and affective components of self. *Journal of Cognitive Neuroscience*, 18, 1586-1594.

Nawa, N. E., & Ando, H. (2019). Effective connectivity within the ventromedial prefrontal cortex-hippocampus-amygdala network during the elaboration of emotional autobiographical memories. *NeuroImage*, 189, 316-328.

Nature (2014). Nostalgia rewards the brain. *Nature*, 515, 11.

Northoff, G., Bermpohl, F. (2004). Cortical midline structures and the self. *Trends in Cognitive Sciences*, 8, 102-107.

Northoff, G., Heinzel, A., De Greck, M., Bermpohl, F., Dobrowolny, H., Panksepp, J. (2006). Self-referential processing in our brain—a meta-analysis of imaging studies on the self. *Neuroimage*, 31, 440-457.

O’Doherty, J. P. (2004). Reward representations and reward-related learning in the human brain: insights from neuroimaging. *Current Opinion in Neurobiology*, 14, 769-776.

O’Doherty, J., Kringelbach, M. L., Rolls, E. T., Hornak, J., Andrews, C. (2001). Abstract reward and punishment representations in the human orbitofrontal cortex. *Nature Neuroscience*, 4, 95-102.

Oba, K., Noriuchi, M., Atomi, T., Moriguchi, Y., Kikuchi, Y. (2015). Memory and reward systems coproduce ‘nostalgic’ experiences in the brain. *Social Cognitive and Affective Neuroscience*, 11, 1069-1077.

Ochsner, K. N., Gross, J. J. (2005). The cognitive control of emotion. *Trends in Cognitive Sciences*, 9, 242-249.

Ochsner, K. N., Ray, R. D., Cooper, J. C., Robertson, E. R., Chopra, S., Gabrieli, J. D., Gross, J. J. (2004). For better or for worse: neural systems supporting the cognitive down-and up-regulation of negative emotion. *Neuroimage*, 23, 483-499.

Pezawas, L., Meyer-Lindenberg, A., Drabant, E. M., Verchinski, B. A., Munoz, K. E., Kolachana, B. S., ... Weinberger, D. R. (2005). 5-HTTLPR polymorphism impacts human cingulate-amygdala interactions: A genetic susceptibility mechanism for depression. *Nature Neuroscience*, 8, 828-834.

Philippi, C. L., & Koenigs, M. (2014). The neuropsychology of self-reflection in psychiatric illness. *Journal of Psychiatric Research*, 54, 55-63.

Piefke, M., Weiss, P. H., Zilles, K., Markowitsch, H. J., & Fink, G. R. (2003). Differential remoteness and emotional tone modulate the neural correlates of autobiographical memory. *Brain*, 126, 650-668.

Poldrack, R. A. (2011). Inferring mental states from neuroimaging data: from reverse inference to large-scale decoding. *Neuron*, 72, 692-697.

Quirin, M., Gillath, O., Pruessner, J. C., Eggert, L. D. (2009). Adult attachment insecurity and hippocampal cell density. *Social Cognitive and Affective Neuroscience*, 5, 9-47.

Reid, C. A., Green, J. D., Wildschut, T., Sedikides, C. (2014). Scent-evoked nostalgia. *Memory*, 23, 157-166.

Routledge, C., Arndt, J., Wildschut, T., Sedikides, C., Hart, C. M., Juhl, J., … Schlotz, W. (2011). The past makes the present meaningful: nostalgia as an existential resource. *Journal of Personality and Social Psychology*, 101, 638-652.

Routledge, C., Wildschut, T., Sedikides, C., Juhl, J. (2013). Nostalgia as a resource for psychological health and well-being. *Social and Personality Psychology Compass*, 7, 808-818.

Routledge, C., Wildschut, T., Sedikides, C., Juhl, J., Arndt, J. (2012). The power of the past: Nostalgia as a meaning-making resource. *Memory*, 20, 452-460.

Saarimäki, H., Ejtehadian, L.F., Glerean, E., Jääskeläinen, I. P., Vuilleumier, P., Sams, M., Nummenmaa, L. (2018). Distributed affective space represents multiple emotion categories across the human brain. *Social Cognitive and Affective Neuroscience*, 13, 471-482.

Schaefer, A., Philippot, P. (2005). Selective effects of emotion on the phenomenal characteristics of autobiographical memories. *Memory*, 13, 148-160.

Schuman, H., Scott, J. (1989). Generations and collective memories. *American Sociological Review*, 54, 359-381.

Scimeca, J. M., Badre, D. (2012). Striatal contributions to declarative memory retrieval. *Neuron*, 75, 380-392.

Sedikides, C., Leunissen, J. M., & Wildschut, T. (2021). The psychological benefits of music-evoked nostalgia. *Psychology of Music*. Advance online publication. https://doi.org/10.1177/03057356211064641

Sedikides, C., Wildschut, T. (2016). Nostalgia: A bittersweet emotion that confers psychological health benefits. In: A.M. Wood, J. Johnson (eds.), *Wiley handbook of positive clinical psychology*. Hoboken: Wiley, p. 25-136.

Sedikides, C., Wildschut, T. (2018). Finding meaning in nostalgia. *Review of General Psychology*, 22, 48-61.

Sedikides C., & Wildschut, T. (2019). The sociality of personal and collective nostalgia. *European Review of Social Psychology*, 30, 123-173.

Sedikides, C., Wildschut, T. (2020). The motivational potency of nostalgia: The future is called yesterday. *Advances in Motivation Science*, 7, 75-111.

Sedikides, C., Wildschut, T., Arndt, J., Routledge, C. (2008). Nostalgia past, present, and future. *Current Directions in Psychological Science*, 17, 304-307.

Sedikides, C., Wildschut, T., Baden, D. (2004). Nostalgia: Conceptual issues and existential functions. *Handbook of experimental existential psychology* (pp. 200-214). New York, NY: Guilford Press.

Sedikides, C., Wildschut, T., Cheung, W.-Y., Routledge, C., Hepper, E. G., Arndt, J., Vail, K., Zhou, X., Brackstone, K., Vingerhoets, A. J. J. M. (2016). Nostalgia fosters self-continuity: Uncovering the mechanism (social connectedness) and consequence (eudaimonic wellbeing). *Emotion*, 16, 524-539.

Sedikides, C., Wildschut, T., Routledge, C., Arndt, J., Hepper, E. G., Zhou, X. (2015). To nostalgize: Mixing memory with affect and desire. *Advances in Experimental Social Psychology*, 51, 189-273.

Sescousse, G., Caldú, X., Segura, B., Dreher, J. C. (2013). Processing of primary and secondary rewards: A quantitative meta-analysis and review of human functional neuroimaging studies. *Neuroscience & Biobehavioral Reviews*, 37, 681-696.

Shohamy, D., Adcock, R. A. (2010). Dopamine and adaptive memory. *Trends in Cognitive Sciences*, 14, 464-472.

Somerville, L. H., Jones, R. M., Ruberry, E. J., Dyke, J. P., Glover, G., Casey, B. J. (2013). The medial prefrontal cortex and the emergence of self-conscious emotion in adolescence. *Psychological Science*, 24, 1554-1562.

Speer, M. E., Bhanji, J. P., Delgado, M. R. (2014). Savoring the past: Positive memories evoke value representations in the striatum. *Neuron*, 84, 847-856.

Stephan, E., Sedikides, C., Wildschut, T. (2012). Mental travel into the past: Differentiating recollections of nostalgic, ordinary, and positive events. *European Journal of Social Psychology,* 42, 290-298.

Stephan, E., Sedikides, C., Wildschut, T., Cheung, W.-Y., Routledge, C., Arndt, J. (2015). Nostalgia-evoked inspiration: Mediating mechanisms and motivational implications. *Personality and Social Psychology Bulletin*, 41, 1395-1410.

Stephan, E., Wildschut, T., Sedikides, C., Zhou, X., He, W., Routledge, C., Cheung, W.-Y., & Vingerhoets, A. J. J. M. (2014). The mnemonic mover: Nostalgia regulates avoidance and approach motivation. *Emotion*, 14, 545-561.

Supski, S. (2013). Aunty Sylvie’s sponge: Foodmaking, cookbooks and nostalgia. *Cultural Studies Review*, 19, 28-49.

Svoboda, E., McKinnon, M. C., Levine, B. (2006). The functional neuroanatomy of autobiographical memory: a meta-analysis. *Neuropsychologia*, 44, 2189-2208.

Talarico, J. M., LaBar, K. S., Rubin, D. C. (2004). Emotional intensity predicts autobiographical memory experience. *Memory & Cognition*, 32, 1118-1132.

The New Oxford Dictionary of English. (1998). (J. Pearsall, Ed.). Oxford, UK: Oxford University Press.

Trost, W., Ethofer, T., Zentner, M., Vuilleumier, P. (2012). Mapping aesthetic musical emotions in the brain. *Cerebral Cortex*, 22, 2769-2783.

Tugade, M. M., Fredrickson, B. L. (2004). Resilient individuals use positive emotions to bounce back from negative emotional experiences. *Journal of Personality and Social Psychology*, 86, 320-333.

Tullett, A. M., Wildschut, T., Sedikides, C., Inzlicht, M. (2015). Right-frontal cortical asymmetry predicts increased proneness to nostalgia. *Psychophysiology*, 52, 990-996.

Vaccaro, A. G., Kaplan, J. T., Damasio, A. (2020). Bittersweet: The neuroscience of ambivalent affect. *Perspective on Psychological Science*, 15, 1187-1199.

Van Schie, C. C., Chiu, C.D., Rombouts, S. A., Heiser, W. J., & Elzinga, B. M. (2019). When I relive a positive me: Vivid autobiographical memories facilitate autonoetic brain activation and enhance mood. *Human Brain Mapping*, 40, 4859-4871.

Van Tilburg, W. A. P., Bruder, M., Wildschut, T., Sedikides, C., Göritz, A. S. (2019). An appraisal profile of nostalgia. *Emotion*, 19, 21-36.

Van Tilburg, W. A. P., Igou, E.R., Sedikides, C. (2013). In search of meaningfulness: Nostalgia as an antidote to boredom. *Emotion*, 13, 450-461.

Van Tilburg, W. A., Sedikides, C., Wildschut, T. (2015). The mnemonic muse: Nostalgia fosters creativity through openness to experience. *Journal of Experimental Social Psychology*, 59, 1-7.

Van Tilburg, W. A., Wildschut, T., Sedikides, C. (2018). Nostalgia’s place among self-relevant emotions. *Cognition and Emotion*, 32, 742-759.

Vess, M., Arndt, J., Routledge, C., Sedikides, C., Wildschut, T. (2012). Nostalgia as a resource for the self. *Self and Identity*, 11, 273-284.

Wake, S. J., Izuma, K. (2017). A common neural code for social and monetary rewards in the human striatum. *Social Cognitive and Affective Neuroscience*, 12, 1558-1564.

Wager, T. D., Atlas, L. Y., Botvinick, M. M., Chang, L. J., Coghill, R. C., Davis, K. D., ... Yarkoni, T. (2016). Pain in the ACC? *Proceedings of the National Academy of Sciences*, 113, E2474-E2475.

Wagner, D. D., Haxby, J. V., Heatherton, T. F. (2012). The representation of self and person knowledge in the medial prefrontal cortex. *Wiley Interdisciplinary Reviews: Cognitive Science*, 3, 451-470.

Warner-Schmidt, J. L., Duman, R. S. (2006). Hippocampal neurogenesis: opposing effects of stress and antidepressant treatment. *Hippocampus*, 16, 239-249.

[Wen](https://pubmed.ncbi.nlm.nih.gov/?term=Wen+T&cauthor_id=32572493), T., [Mitchell](https://pubmed.ncbi.nlm.nih.gov/?term=Mitchell+DJ&cauthor_id=32572493), D. J., & [Duncan](https://pubmed.ncbi.nlm.nih.gov/?term=Duncan+J&cauthor_id=32572493), J. (2020). The functional convergence and heterogeneity of social, episodic, and self-referential thought in the default mode network. *Cerebral Cortex*, 30, 5915-5929.

Wildschut, T., Bruder, M., Robertson, S., Van Tilburg, W. A. P., Sedikides, C. (2014). Collective nostalgia: A group-level emotion that confers unique benefits on the group. *Journal of Personality and Social Psychology*, 107, 844-863.

Wildschut, T., Sedikides, C. (2020). The psychology of nostalgia: Delineating the emotion’s nature and functions. In M. H. Jacobson (Ed.), *Nostalgia now: Cross-disciplinary perspectives on the past in the present* (pp. 47-65). London: Routledge Press.

Wildschut, T., Sedikides, C. (2022). Psychology and nostalgia: Towards a functional approach. In M. H. Jacobsen (Ed.), *Intimations of nostalgia: Multidisciplinary explorations of an enduring emotion* (pp. 110-128). Bristol: Bristol University Press.

Wildschut, T., Sedikides, C., Alowidy, D. (2019). *Hanin*: Nostalgia among Syrian refugees. *European Journal of Social Psychology, 49*(7), 1368-1384.

Wildschut, T., Sedikides, C., Arndt, J., Routledge, C. (2006). Nostalgia: content, triggers, functions. *Journal of Personality and Social Psychology*, 91, 975-993.

Wildschut, T., Sedikides, C., Routledge, C., Arndt, J., Cordaro, F. (2010). Nostalgia as a repository of social connectedness: the role of attachment-related avoidance. *Journal of Personality and Social Psychology*, 98, 573-586.

Wittmann, B.C., Schott, B.H., Guderian, S., Frey, J.U., Heinze, H.J., Düzel, E. (2005). Reward-related FMRI activation of dopaminergic midbrain is associated with enhanced hippocampus-dependent long-term memory formation. *Neuron*, 45, 459-467.

Woo, C. W., Koban, L., Kross, E., Lindquist, M. A., Banich, M. T., Ruzic, L., ... Wager, T. D. (2014). Separate neural representations for physical pain and social rejection. *Nature Communications*, 5, 1-12.

Xu, R., Yang, J., Feng, C., Wu, H., Huang, R., Yang, Q., ... Luo, Y. J. (2018). Time is nothing: emotional consistency of autobiographical memory and its neural basis. *Brain Imaging and Behavior*, 12, 1053-1066.

Yamagami, T., Oosawa, M., Ito, S., Yamaguchi, H. (2007). Effect of activity reminiscence therapy as brain-activating rehabilitation for elderly people with and without dementia. *Psychogeriatrics*, 7, 69-75.

Yanagisawa, K., Abe, N., Kashima, E. S., Nomura, M. (2016). Self-esteem modulates amygdala-ventrolateral prefrontal cortex connectivity in response to mortality threats. *Journal of Experimental Psychology: General*, 145, 273-283.

Yang, Z., Sedikides, C., Izuma, K., Wildschut, T., Kashima, E., Luo, Y. L., Chen, J., & Cai, H. (2021). Nostalgia enhances detection of death threat: Neural and behavioral evidence. *Scientific Reports*, 11, 1-8.

Zhou, X., Sedikides, C., Mo. T., Li, W., Hong, E., & Wildschut, T. (2021). The restorative power of nostalgia: Thwarting loneliness by raising happiness during the COVID-19 pandemic. *Social Psychological and Personality Science*. Advance online publication. https://doi.org/10.17605/OSF.IO/U5RJB

Zhou, X., Sedikides, C., Wildschut, T., Gao, D.-G. (2008). Counteracting loneliness: On the restorative function of nostalgia. *Psychological Science*, 19, 1023-1029.

[Zhou](https://pubmed.ncbi.nlm.nih.gov/?term=Zhou+F&cauthor_id=34789745), F., [Zhao](https://pubmed.ncbi.nlm.nih.gov/?term=Zhao+W&cauthor_id=34789745), W., [Qi](https://pubmed.ncbi.nlm.nih.gov/?term=Qi+Z&cauthor_id=34789745), Z. [Geng](https://pubmed.ncbi.nlm.nih.gov/?term=Geng+Y&cauthor_id=34789745), Y., [Yao](https://pubmed.ncbi.nlm.nih.gov/?term=Yao+S&cauthor_id=34789745), S., [Kendrick](https://pubmed.ncbi.nlm.nih.gov/?term=Kendrick+KM&cauthor_id=34789745), K. M., [Wager](https://pubmed.ncbi.nlm.nih.gov/?term=Wager+TD&cauthor_id=34789745), T. D., & [Becker](https://pubmed.ncbi.nlm.nih.gov/?term=Becker+B&cauthor_id=34789745), B. (2021). A distributed fMRI-based signature for the subjective experience of fear. *Nature Communications*, 12, 6643.

Zou, X., Lee, M., Wildschut, T., Sedikides, C. (2019). Nostalgia increases financial risk taking. *Personality and Social Psychology Bulletin*, 45, 907-919.

**Table 1**. Summary of fMRI Studies and Findings Directly or Indirectly Relevant to Nostalgia

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Studies | Sample Size | Trigger | | mPFC | ACC | PCC | Precuneus | | HPC | Striatum | | SN/VTA |
| 1. Barrett and Janata, 2016 | 12 | | Music |  |  |  | |  |  |  | √ | |
| 2. Matsunaga et al., 2013 | 10 | | Odor | √ |  | √ | | √ |  |  |  | |
| 3. Oba et al., 2015 | 15 | | Picture |  |  |  | |  | √ | √ | √ | |
| 4. Trost et al., 2012 | 16 | | Music | √ | √ |  | | √ | √ | √ |  | |
| 5. Cooney et al., 2007 | 14 | | Event | √ | √ |  | |  |  |  |  | |
| 6. Ford et al., 2011 | 16 | | Music | √ |  | √ | |  | √ |  |  | |
| 7. Gilboa et al., 2004 | 9 | | Photo |  |  | √ | | √ | √ |  |  | |
| 8. Herz et al., 2004 | 5 | | Odor |  |  |  | |  | √ |  |  | |
| 9. Janata, 2009 | 13 | | Music | √ |  | √ | |  |  |  |  | |
| 10. Lempert et al., 2017 | 35 | | Event | √ |  | √ | |  |  | √ |  | |
| 11. Nawa et al., 2019 | 36 | | Event | √ |  |  | |  | √ |  |  | |
| 12. Piefke et al., 2003 | 20 | | Event | √ |  |  | |  | √ |  |  | |
| 13. Speer et al., 2014 | 28 | | Event | √ | √ |  | |  |  | √ |  | |
| 14. Van Schie et al., 2019 | 47 | | Event | √ | √ |  | |  | √ |  |  | |

*Note 1*: HPC = hippocampus; mPFC = medial prefrontal cortex; ACC = anterior cingulate cortex; PCC = posterior cingulate cortex; SN = substantia nigra; VTA = ventral tegmental area.

*Note 2*: Studies 1-4 directly addressed the neural basis of nostalgia. Studies 5-14 used stimuli or manipulations common in nostalgia research that were likely to elicit nostalgia. We did not include the Yang et al. (2021) study, because it examined the neural modulation of nostalgia on death threat rather than the neural basis of nostalgia. Also, we did not include the Hungenberg et al. (2020) study, because it used EEG rather than fMRI.

**Box 1**. Neural Substrates of Nostalgia

Nostalgia is considered a combination of self-reflection processing, autobiographical memory, emotion regulation, and reward processing. The mPFC serves as a hub, integrating these four components.

We summarize below the functional significance of brain structures highlighted in the nostalgic brain model.

* Medial prefrontal cortex (mPFC): involved in tasks of high self-relevance and tasks that require self-reflection. The mPFC also functions in autobiographical memory, self-conscious emotion, and emotion regulation. Its subregions, such as ventral mPFC (vmPFC), are also relevant to the model. The vmPFC is involved in assigning personal signiﬁcance to self-related contents, playing an important role in reward processing.
* Anterior cingulate cortex (ACC): involved in monitoring and in functions associated with the cognitive control of emotion. The ACC also acts as an affective component of the self.
* Posterior cingulate cortex (PCC): involved in self-reflection and in autobiographical memory.
* Precuneus: involved in a wide spectrum of highly integrated tasks, including visuo-spatial imagery, episodic memory retrieval, and self-reflection. Precuneus has been proposed as neural correlate of self-consciousness.
* Hippocampus (HPC): plays a key role in memory function, particularly in the retrieval of autobiographical memory.
* Striatum: a core region of the mesolimbic dopamine system, and a critical component of reward systems. The ventral striatum is sensitive to primary rewards such as food, drugs, or sex, and to secondary rewards, such as money and power.
* Substantia nigra/ventral tegmental area (SN/VTA): plays a central role in reward processing, such as reward anticipation, and has been associated with the experience of positive affect during music listening.

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**Figure 1**. The nostalgic brain model: brain regions activated in nostalgia versus control conditions. mPFC = medial prefrontal cortex; vmPFC = ventromedial prefrontal cortex; ACC = anterior cingulate cortex; PCC = posterior cingulate cortex; HPC =, hippocampus; SN = substantia nigra; VTA = ventral tegmental area. Nostalgia involves neural substrates known to be engaged in self-reflection, autobiographical memory, emotion regulation, and reward processing.

1. \* Corresponding author: Huajian Cai, Institute of Psychology, Chinese Academy of Sciences, 16 Lincui Road, Beijing 100101, P. R. China. E-mail: [caihj@psych.ac.cn](mailto:caihj@psych.ac.cn) [↑](#footnote-ref-1)
2. The paraphrase is based on a Winston Churchill 1942 speech referring to the Second Battle of El Alamein. [↑](#footnote-ref-2)
3. Piefke et al. (2003) reported hippocampal engagement for recent (five years pre-interview), but not distant (up to participants’ 10th year of age), autobiographical memories. [↑](#footnote-ref-3)