DOCUMENT SUMMARY This document is a comprehensive review of the neuroscience of nostalgia, authored by Ziyan Yang and colleagues in 2022. It synthesizes existing research to propose a neural model of nostalgia, identifying four core components: self-reflection, autobiographical memory, emotion regulation, and reward processing. The paper reviews fMRI and other neuroimaging studies to identify the key brain regions associated with these components, such as the mPFC, hippocampus, ACC, and striatum, and discusses how their interaction produces the nostalgic experience.

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FORMATTED CONTENT

Patterns of brain activity associated with nostalgia: a social-cognitive neuroscience perspective

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 and precuneus), **autobiographical memory** processing (hippocampus, medial prefrontal cortex, posterior cingulate cortex and precuneus), **emotion regulation** processing (anterior cingulate cortex and medial prefrontal cortex) and **reward processing** (striatum, substantia nigra, ventral tegmental area and ventromedial prefrontal cortex). **Nostalgia's** potential to modulate activity in these core neural substrates has both theoretical and applied implications.

Key words: nostalgia; self-reflection; emotion regulation; autobiographical memory; reward

Introduction

Nostalgia has a checkered history. The term was originally coined by a Swiss medical student, Johannes Hofer (Hofer, 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 as a form of depression. Taken together, although its conceptualization changed over time, **nostalgia** has consistently been seen as dysfunctional (for historical overviews, see Sedikides et al., 2004; Batcho, 2013).

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 (Wildschut et al., 2006; Batcho, 2007; Hepper et al., 2012).

Nostalgia is elicited by a variety of triggers, such as objects, events or close others from one's childhood or youth (Schuman and Scott, 1989; Holbrook and Schindler, 1996), music or songs (Routledge et al., 2011; Sedikides et al., 2021) and photographs (Gilboa et al., 2004; Cox et al., 2015), as well as odors and tastes (Supski, 2013; Reid et al., 2014). Furthermore, **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; Zhou et al., 2008; Hepper et al., 2014, 2021; Madoglou et al., 2017; Wildschut et al., 2019).

Crucially, the emotion has emerged as a psychological resource that confers a variety of intrapersonal and interpersonal benefits (Sedikides et al., 2008, 2015; Frankenbach et al., 2021). In particular, **nostalgia** boosts self-esteem or self-positivity (Vess et al., 2012; Cheung et al., 2013, 2016), increases meaning in life (Routledge et al., 2011, 2012; Sedikides and Wildschut, 2018), fosters social connectedness and social support (Wildschut et al., 2010; Reid et al., 2014; Sedikides and Wildschut, 2019), encourages help seeking (Juhl et al., 2021), enhances psychological health and well-being (Routledge et al., 2013; Baldwin and Landau, 2014; Baldwin et al., 2015; Layous et al., 2021) and attenuates dysphoric states such as loneliness, boredom, stress or death anxiety (Zhou et al., 2008, 2021a; Routledge et al., 2011; Van Tilburg et al., 2013). 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, 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 and 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.

The nostalgic brain model

The nostalgic brain model: brain regions activated in nostalgia vs 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**.

Core components of nostalgia

Self-reflection

Nostalgia is regarded as a prima facie self-conscious emotion (Van Tilburg et al., 2019) and is accompanied by **self-reflection** (Sedikides et al., 2015). 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 a protagonist (Wildschut et al., 2006; Abeyta et al., 2015). The trajectory of these narratives is redemptive (i.e. from humble beginnings to a happy ending), thus depicting the self in favorable light (Wildschut et al., 2006; Luo et al., 2016).

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 (Northoff and Bermpohl, 2004; Lieberman, 2007; Lieberman et al., 2019). The **posterior cingulate cortex (PCC)** is also a key region in **self-reflection** as well as self-consciousness (Northoff and Bermpohl, 2004; Cavanna and Trimble, 2006; Northoff et al., 2006). For example, both the **mPFC** and **PCC** show heightened activation when individuals reflect on the 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**.

Autobiographical memory

Autobiographical memory involves the 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 (i) greater intimacy maintenance, conversation, teach/inform, death preparation, boredom reduction and bitterness revival reduction and (ii) 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** (Cabeza and Nyberg, 2000; Addis et al., 2004; Svoboda et al., 2006), as well as **mPFC** and **PCC** (Gilboa, 2004; Svoboda et al., 2006; Kim, 2012). We therefore propose the following:

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

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 (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., 2021). 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**.

Several brain regions, especially the **anterior cingulate cortex (ACC)** and **mPFC**, are known to play key roles in **emotion regulation**, 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.

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., 2021). 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 (Stephan et al., 2014; Zou et al., 2019; Sedikides and Wildschut, 2020).

Various regions of the **reward network**, especially ventral **striatal dopamine systems**, are involved in positive emotion and, moreover, approach motivation (Burgdorf and Panksepp, 2006; Lindquist et al., 2012; Berridge and Kringelbach, 2015). 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** (O'Doherty, 2004; Delgado, 2007). We therefore propose the following:

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

Neural substrates of nostalgia

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.

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.

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. Nostalgic (compared to control) pictures elicited stronger activity in the **hippocampus**. In addition, nostalgic (compared to control) pictures enhanced responses in the reward system, including the **SN/VTA** and **striatum**.

In a positron emission tomography study (Matsunaga et al., 2013), participants were instructed to smell a personalized nostalgic odor. The nostalgic odor induced more **autobiographical memories** and positive emotions and, importantly, elicited stronger activation in the **vmPFC** and **precuneus/PCC**.

Trost et al. (2012) tested this idea in an imaging study using musical epochs to elicit different emotions. Irrespective of valence, low-arousal emotions (e.g., **nostalgia**) also engage a network centered on the **hippocampus** and **vmPFC**, including the subgenual **ACC**.

Barrett and Janata (2016) examined the neural correlates of music-evoked **nostalgia** in an **fMRI** study. Among those who were dispositionally higher on **nostalgia**, activity in the midbrain and left amygdala decreased when listening to more nostalgia-evoking music. This may indicate that individuals high on dispositional **nostalgia** may be better at regulating their negative mood elicited by nostalgic music.

More recently, Yang et al. (2021) induced **nostalgia** through pictures that depicted events or objects in participants' childhood. Participants who viewed nostalgic (vs control) pictures evinced more intense activation in right amygdala in response to death-related (vs neutral) words.

In a recent electroencephalography (**EEG**) study, Hungenberg et al. (2020) recorded attendees' neurological responses at Minor League Baseball games. Attendees' brainwave frequencies that were indicative of **self-reflection** correlated positively and significantly with reported **nostalgia**.

Review of other relevant studies

Next, we review studies that, although not addressing **nostalgia** directly, are highly relevant to it.

Studies that involved stimuli deemed nostalgic: In an **fMRI** study, Janata (2009) presented participants with music from their childhood. Brain activity in the dorsal **mPFC** was positively related to the autobiographical salience of musical excerpts. The **mPFC** may serve as a hub that links **self-reflection** 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).

Studies that involved memories of events deemed nostalgic:

> Nostalgic memories are predominately positive, specific, vivid and distant (Van Tilburg et al., 2019).

Evidence indicates that recalling positive **autobiographical memories** involves reward-related circuitry. In a study by Speer et al. (2014), positive memories enhanced not only self-reported positive mood but also activity in the **striatum** and **mPFC**. 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).

Summary

Nostalgia is an emotional experience that arises from memories featuring the self in social contexts. It 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** and **precuneus**), **autobiographical memory** (**hippocampus**, **mPFC**, **PCC** and **precuneus**), **emotion regulation** (**ACC** and **mPFC**) and **reward processing** (**SN**, **VTA**, **STA** and **vmPFC**).

Table 1. Summary of functional magnetic resonance imaging (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 and Ando, 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	✓	✓			✓		

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Note: Table reconstructed from source document. Studies 1-4 directly addressed the neural basis of nostalgia. Studies 5-14 used stimuli or manipulations common in nostalgia research.

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.

- **mPFC**: it is 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 **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**.
- **ACC**: it is involved in monitoring and in functions associated with the cognitive control of emotion. The **ACC** also acts as an affective component of the self.
- **PCC**: it is involved in **self-reflection** and in **autobiographical memory**.
- **Precuneus**: it is involved in a wide spectrum of highly integrated tasks, including visuospatial imagery, episodic memory retrieval and **self-reflection**. **Precuneus** has been proposed as neural correlate of self-consciousness.
- **Hippocampus**: it 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 VS is sensitive to primary rewards such as food, drugs or sex and to secondary rewards such as money and power.
- **SN/VTA**: it plays a central role in **reward processing**, such as reward anticipation, and has been associated with the experience of positive affect during music listening.

Future directions in neuroimaging research on nostalgia

Differentiating nostalgia from positive affect

Although the affective signature of **nostalgia** is predominantly positive, it should be distinguished from general positive affect. Nostalgic engagement involves co-activation of positive and negative affect, a pattern that produces an emotional dynamic felt as ambivalence. Future neuroimaging research could emulate these procedures by comparing the neural activation associated with nostalgic stimuli to patterns of activation associated with equally positive, but non-nostalgic, stimuli.

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 capacity of **nostalgia** is the engagement of top-down processes, including cognitive **emotion regulation**. These processes involve the **PFC** and **ACC**. 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.

Individual differences

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. Future research should consider the role of serotonin in modulating the neurological networks implicated in **nostalgia**. Individual differences in attachment-related avoidance and resilience also moderate the effects and recruitment of **nostalgia**.

Multisensory nostalgia

Neuroscientists have used auditory, visual, and olfactory 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. Future research should investigate the neural bases of **nostalgia** through different inductions within the same group of participants to identify core structures versus induction-specific regions.

Conclusion

In recent years, social cognitive neuroscience has begun to offer valuable insights into the neural bases of **nostalgia**. 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.

> **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**. Future research could explicate the functional mechanisms underlying **nostalgia** through a multivariate approach as well as elucidate the connectivity among the core regions associated with this emotion.