The role of positive and negative emotions on multiple components of episodic memory (“what”, “when”, “in which context”) in older compared to young adults: a pre-registered study

Pierrick Laulan [a,b,c,d] & Ulrike Rimmele [a,b,c,d]

[a] Emotion and Memory Laboratory, Faculty of Psychology and Educational Sciences, University of Geneva, Switzerland

[b] Center for Interdisciplinary Study of Gerontology and Vulnerability (CIGEV), University of Geneva, Switzerland

[c] Swiss Center of Affective Sciences, University of Geneva, Switzerland

[d] Neurocenter, University of Geneva

Corresponding Author: Pierrick Laulan, Emotion and Memory Laboratory, Faculty of Psychology and Educational Sciences, University of Geneva, Bd. du Pont-d’Arve 28, CH-1205, Switzerland. E-mail address: Pierrick.Laulan@unige.ch

Abstract

Emotion and age modulate episodic memory. In both young and older adults, emotion has a beneficial effect on item memory, with an advantage for positive *vs*. negative stimuli in older adults. In young adults, emotion has also been shown to enhance memory for intrinsic item features (e.g., temporal memory), but to degrade memory for contextual/extrinsic information. How emotion affects memory for these components in older adults is less clear, as findings are mixed. Small sample sizes are at least partly responsible for these heterogeneous results. Therefore, the aim of this study is to simultaneously investigate how age modulates the effect of positive *vs.* negative emotion on 1) item memory (what?), 2) temporal memory (when?), and 3) associative memory between items and their extrinsic context (in which context?). To this end, we will extend the paradigm developed by Palombo et al. (2021) by including combinations of negative, neutral, and positive images and neutral videos, and compare younger and older adults on image memory, temporal positioning of images in videos, and association between images and videos. In order to guarantee a satisfactory statistical power while potentially reducing the cost of the experimental runs, we will conduct sequential statistical analyses in three time points (time 1: 75 younger *vs.* 75 older adults; time 2: 113 younger *vs*. 113 older adults; time 3: 150 younger *vs.* 150 older adults).

Keywords: aging; emotion; episodic memory; temporal memory; associative memory.

Introduction

The aging process is associated with the progressive decline of several cognitive functions, and episodic memory is particularly affected, especially from age 60 onwards (Nyberg & Pudas, 2019). Episodic memory is the memory of events associated with the spatio-temporal context in which they occurred (Tulving, 2002). The age-related decline in episodic memory results not only in a deficit in item memory (i.e., memory for central information) in older adults (Fraundorf et al., 2019), but also in an even greater deterioration in the binding between an item and its intrinsic features (e.g., temporal order, spatial location) and the binding between an item and its extrinsic context (e.g., a colored frame) (Old & Naveh-Benjamin, 2008). A critical factor that may reduce the age-related decline in episodic memory, at least for item memory, may be emotion. Our study aims to better characterize the influence of positive and negative emotions on memory for items, their intrinsic features and extrinsic context, in both young and older adults.

Effect of emotion on item memory in young and older adults

For item memory, there is ample evidence that individuals of all ages exhibit an emotional memory advantage, i.e., better memory for emotional information than neutral information (Denburg et al., 2003; Williams et al., 2022). This beneficial effect of emotion comes from an increase in attentional and sensory processing of emotional stimuli (e.g., Phelps et al., 2006; Todd et al., 2020), as well as emotion's influence on consolidation processes (McGaugh, 2018). This beneficial effect of emotion can be explained by several mechanisms. When the delay between encoding and retrieval phases is not long enough to enable consolidation processes to develop, emotional memory enhancement depends mainly on three cognitive factors related to the characteristics of emotional *vs.* neutral stimuli (e.g., Talmi & McGarry, 2012): (1) greater semantic relatedness for emotional *vs.* neutral stimuli (e.g., Talmi & Moscovitch, 2004; Talmi et al., 2007), which may facilitate the organization of emotional stimuli around a common theme and thus make their encoding deeper and retrieval easier (e.g., Einstein & Hunt, 1980); (2) greater distinctiveness for emotional *vs.* neutral stimuli (i.e., emotional stimuli possess unique attributes that they do not share with neutral stimuli; Talmi et al., 2007), which may facilitate the retrieval of emotional stimuli after memory search (Tomlinson et al., 2009); (3) greater attentional capture in favor of emotional *vs.* neutral stimuli (e.g., Schmidt & Saari, 2007; Vuilleumier, 2005), resulting in deeper processing of emotional stimuli during encoding and better memory retrieval (Talmi et al., 2008). Of these three factors and mechanisms underlying the effect of emotions on memory, increased attentional capture is likely to enhance memory in recognition and free recall tests, while the greater semantic relatedness and distinctiveness of emotional stimuli could predominantly improve recall accuracy, but not recognition accuracy (Schümann et al., 2018). In addition, the greater attentional capture of emotional *vs*. neutral stimuli may explain the more frequent experience of recollection during the recognition of emotional items (Kensinger & Corkin, 2003), while the greater semantic relatedness of emotional *vs*. neutral stimuli could account for a more liberal response bias for emotional *vs*. neutral stimuli (Dougal & Rotello, 2007; see Bennion et al, 2013). Thus, the better performance observed for emotional *vs*. neutral stimuli in memory tasks may reflect better recall for emotional stimuli but also a response bias in favor of emotional stimuli (Thapar & Rouder, 2009). In young adults, the memory advantage for emotional *vs.* neutral stimuli is greater for negative than for positive stimuli (see Baumeister et al., 2001), although the magnitude of this effect may be overestimated due to a lack of control of arousal between negative *vs.* positive stimuli in many experimental studies, with the arousal of negative stimuli generally higher than that of positive images (see Williams et al., 2022). It has been specified that the greater preference for negativity than for positivity emerges in recognition ($d_{negativity}$ = 0.54 *vs.* $d_{positivity}$ = 0.05) rather than in free recall ($d_{negativity}$ = 0.71 *vs.* $d_{positivity}$ = 0.66) (Murphy & Isaacowitz, 2008). In contrast to younger adults, older adults tend to show a memory advantage for positive *vs.* negative stimuli, a phenomenon called the age-related positivity effect (e.g., Reed & Carstensen, 2012). The age-related positivity effect in item memory stems primarily from a decrease in the preference for negativity in memory in older adults compared to younger adults (Laulan et al, 2020; Murphy & Isaacowitz, 2008), and this effect is thought to depend largely on controlled processes with the function of maintaining or even enhancing the well-being of older adults (Mather & Knight, 2005). Consistent with the premise that the age-related positivity effect in item memory depends on controlled processes, a meta-analysis found that the magnitude of this effect is greater when individuals' processing of information to be remembered is unconstrained (i.e., encoding is incidental; Reed et al., 2014) and several studies have shown that the magnitude of this effect is also larger when the arousal of information to be memorized is low rather than high (Kensinger, 2008; Laulan et al., 2022).

Effect of emotion on memory for intrinsic features and extrinsic context of items in young adults

In young adults, the results concerning the effects of emotion on memory for intrinsic features of items and their extrinsic context are more heterogeneous than those observed on memory for items (Chiu et al., 2013). Indeed, according to the object-based binding account proposed by Mather (2007), emotion strengthens the binding between emotional items and their constitutive features but impairs the binding between emotional items and distinct contextual details (see also Kensinger, 2009). In this sense, a beneficial effect of emotion has been shown for several types of intrinsic features of items: better memory for color of emotional *vs.* neutral words (D'Argembeau & Van der Linden, 2004; Kensinger & Corkin, 2003; Zhou et al, 2020); better memory for location of emotional *vs.* neutral images on the computer screen (Mather & Nesmith, 2008; Rimmele et al., 2011); better memory for temporal information of emotional *vs.* neutral images (D'Argembeau & Van der Linden, 2005; Rimmele et al., 2012). However, Pereira et al. (2022) reported in their meta-analysis that, overall, these effects are not robust, and that emotion does not significantly influence memory for the intrinsic features of items, either when comparing negative *vs.* neutral items (color: p = .393; location: p = .910; time: p = .204) or positive *vs.* neutral items (color: p = .538; location: p = .730; time: p = .571). One reason for the lack of reliability of these effects is that they can vary significantly depending on how each type of intrinsic feature is implemented in experimental paradigms. For example, in a review of the literature, Petrucci and Palombo (2021) explained that the effect of emotion on temporal memory depends directly on how the latter is operationalized, i.e., either as memory of the moment when an event took place, or "when" memory, or as memory of the duration of an event, or "how long" memory. If we focus on "when" memory, Petrucci and Palombo (2021) concluded that the beneficial effect of emotion on memory for temporal information seems to be robust, though this is based on a small number of studies with some exceptions[1]. Interestingly, it has been suggested that in young adults the effects of emotion on temporal memory may vary as a function of item valence (Yick et al., 2015), and in particular that the beneficial effect of emotion on temporal memory is possibly greater for negative *vs.* positive items (D'Argembeau et al., 2005).

In contrast, other studies have shown that emotion impairs memory for a context that is extrinsic to an item (Mihaylova et al., 2019), and that it also alters memory of the association between an item and its extrinsic context (see Bisby & Burgess, 2017). These deleterious effects of emotion has been revealed for a variety of extrinsic contexts: worse memory for the color of a frame around emotional *vs.* neutral stimuli (Antypa et al., 2019; MacKenzie et al., 2015; Rimmele et al., 2011; Rimmele et al., 2016); worse memory for

[1] The authors state that this is true when stimulus encoding is incidental, with results being more heterogeneous when encoding is intentional (e.g., Koenig & Mecklinger, 2008; Minor & Herzmann, 2019).

backgrounds on which emotional *vs.* neutral stimuli had been presented (Antypa et al., 2022; Bisby & Burgess, 2014; Gutchess et al., 2018; Kensinger et al, 2007); worse memory for neutral objects positioned in the corner of emotional *vs.* neutral scenes (Touryan et al., 2007; Rimmele et al., 2011). In addition, these effects of emotion on the memory for extrinsic item context in young adults have been demonstrated mainly for negative *vs.* neutral items. However, in a recent meta-analysis, Pereira et al. (2022) observed that the effects are comparable for positive *vs.* neutral items although of smaller magnitude (negative *vs.* neutral items, d = 0.21; positive *vs.* neutral items, d = 0.12). It is also important to note that these effects remain subtle and sensitive to the methodology used to test them. Thus, in a series of studies using a cued recall paradigm to disentangle item- and association-memory contributions, Madan and colleagues have reported that: 1) when individuals are asked to learn pairs of neutral or positive words, positive emotions enhance associative memory, but only when both words in a pair are positive (Madan et al., 2019); 2) when scenes consisting of a neutral *vs*. negative object and a neutral background are presented to individuals, negative emotions have a beneficial effect on item memory, deleterious on background memory, and beneficial on associative memory, and this pattern of results could stem from the fact that, contrary to the majority of studies, the associated stimuli were congruent (Madan et al., 2020).

In summary, in young adults, the effect of emotion on memory for intrinsic item features and item extrinsic context are very sensitive to the choices made by researchers when setting up their experimental paradigms (e.g., selection of material and operationalization of concepts such as time and location), and the data in the literature suggest that: 1) memory for intrinsic item features is enhanced for emotional *vs.* neutral items, and in the specific case of temporal memory, the magnitude of this effect would be greater for negative *vs.* positive items; 2) memory for extrinsic item context is disrupted for emotional *vs.* neutral items, with no difference between positive and negative items. Along this line, Palombo et al. (2021)

developed a new paradigm that allows the simultaneous testing of emotion effects on item memory, temporal memory (i.e., memory for a feature intrinsic to an item), and spatial associative memory (i.e., memory for the association between an item and its extrinsic context).With this new paradigm, they found: 1) enhanced item memory for negative *vs.* neutral images which had been inserted in videos and then presented to young adults; 2) later time judgment for the moment of appearance of neutral *vs*. negative images within the videos[2] ; and 3) weaker memory for the association between negative images and videos *vs.* neutral images and videos. Nevertheless, one limitation of this study is that it did not test the effect of positive valence on memory for intrinsic item features and their extrinsic context.

Effect of emotion on memory for intrinsic features and extrinsic context of items in older adults

The influence of emotion on memory for intrinsic item features and their extrinsic context has been sparsely studied in older adults. Kensinger et al. (2005, Experiment 1a) were the first to study the impact of aging on the effect of emotion on memory for extrinsic item context. They conducted a study in which younger and older participants viewed scenes consisting of negative and neutral objects placed on neutral backgrounds. The results revealed that both age groups were more likely to remember fragments of negative *vs.* neutral objects but were less likely to remember background fragments that had been presented with negative *vs.* neutral objects (for similar results, see Kensinger et al., 2007). Waring and Kensinger (2009) conducted a study similar to Kensinger et al. (2005), but in which images superimposed on neutral backgrounds were not only negative and neutral images, but in addition also positive, and emotional images were either low or highly arousing. The results indicated that younger and older adults exhibited improved memory for both low- and high-

[2] Palombo et al. (2021) did not calculate temporal judgment accuracy scores in their pre-registered analyses, so we have no reliable information concerning a potential effect of emotion on this variable.

arousal negative *vs.* neutral images and for high-arousal positive *vs.* neutral images. In contrast, younger and older adults showed reduced memory for neutral backgrounds that had been learned with emotional *vs.* neutral images, and the effect of valence on memory for backgrounds varied between the two age groups: in younger adults, the decrease in memory for backgrounds was greater for negative *vs.* positive images; in older adults, the decrease in memory for backgrounds did not differ depending on whether they had been associated with negative or with positive images. This smaller negativity bias in older versus younger adults suggests an age-related positivity effect in memory for backgrounds, i.e., contexts extrinsic to the items. This effect may stem from the fact that attentional processes are hypothesized to be central in the impairment of memory for extrinsic item context (Reisberg & Heuer, 2004) and that older adults generally pay less attention to negative stimuli than younger adults (e.g., Murphy & Isaacowitz, 2008).

Nashiro and Mather (2010) extended the work of Waring and Kensinger (2009) by simultaneously testing how age modulates the effects of emotion on memory for the location of an item (i.e., feature intrinsic to an item) and memory for a context extrinsic to an item. To this end, these authors set up a study in which younger and older participants were shown pairs consisting of a negative, neutral, or positive item (in this case, an object) and an abstract shape presented twice in different blocks. Then, participants were tested for item memory, memory for item location, and memory of the association between items and abstract shapes. The results indicated: 1) better memory for emotional *vs.* neutral items in younger and older adults, with an advantage for negative *vs.* positive items in younger but not older adults; 2) better memory for the location of emotional *vs.* neutral items in younger but not older adults, with no difference between negative and positive items; 3) poorer memory for the association between items and abstract shapes for emotional *vs.* neutral items, both in younger and older adults, with no difference between negative and positive items. Thus, this study by Nashiro and Mather (2010) suggests that the beneficial effect of emotion on memory for intrinsic item features (here, the location on a computer screen) is characteristic of younger adults only. The lack of a facilitating effect of emotion on memory for intrinsic item features in older adults may be due to their pronounced difficulty in binding different information together (Old & Naveh-Benjamin, 2008). However, using a similar procedure in which the encoding of item-abstract shape pairs was facilitated by presenting the pairs three times to participants rather than twice, Nashiro and Mather (2011) showed that older adults also have better memory for location for emotional *vs.* neutral images. These data suggest that the beneficial effect of emotion on binding between an item and its intrinsic features can also be observed in older adults under conditions that reduce cognitive load at encoding. Furthermore, the results obtained by Nashiro and Mather (2010) suggest that the deleterious effect of emotion on memory for the association between an item and its extrinsic context (here, an abstract form) emerges in both younger and older adults, with no difference in valence effect between the two groups and thus no age-related positivity effect. These results stand in contrast to the stronger impairment of memory for contexts associated with negative *vs*. positive items obtained in young adults but not in older adults by Waring and Kensinger (2009). The discrepancy in these findings could arise from a difference in the arousal of the emotional stimuli used in the studies by Nashiro and Mather (2010) and Waring and Kensinger (2009). Indeed, Nashiro and Mather (2010) used exclusively high-arousal emotional stimuli while Waring and Kensinger (2009) selected their emotional stimuli so that half had low arousal and half had high arousal. Importantly, it has been repeatedly evidenced that the age-related positivity effect in memory emerges preferentially for low-arousal stimuli (e.g., Kensinger, 2008; Laulan et al., 2022).

Finally, very recently, Ceccato et al. (2022) examined the effect of emotion and age on another crucial component of episodic memory, i.e., time. They exposed young and older adults to an experimental task in which they saw negative, neutral, and positive images in three sessions that occurred 48 hours apart. Then, to test temporal memory, participants were asked to indicate in which session they had seen each of the images. In young adults, the positioning of the images over time was not dependent on the emotionality of the images, whereas in older adults, negative images were erroneously positioned more distantly in time than positive images. Also, in older adults, overall, image positioning in time was less accurate for negative images than for neutral images. Thus, negative emotion appears to have a deleterious impact on temporal memory in older adults but not in younger adults, with negative events reported as having occurred earlier than they actually did. These results are at odds with those obtained by Palumbo et al. (2018) in a study in which younger and older adults viewed a series of negative, neutral, and positive images presented in two different lists. Indeed, Palumbo et al. (2018) found that temporal memory (i.e., the attribution of each image to the list in which it was presented) was better for positive and negative images than for neutral images in both younger and older adults. Given that in the Ceccato et al. (2022) study, learning lists were separated by 48 h, whereas in the Palumbo et al. (2018) study the lists were presented without a break, we can speculate that emotions improve temporal memory in the short term, but that this benefit deteriorates quickly.

In summary, although an age-related positivity effect has been demonstrated regarding memory for extrinsic item context by Waring and Kensinger (2009), it is difficult to draw general conclusions about differences between younger and older adults regarding the effect of emotion on memory for intrinsic item features and their extrinsic context given the paucity of research on this topic. In addition, the results obtained by Ceccato et al. (2022) should be considered cautiously since the authors reported in a sensitivity analysis that with a sample of 75 participants (25 young adults, 25 older adults, 25 very old adults), using a repeated-measures ANOVA (RM-ANOVA) to test for a within-between interaction (i.e., 3 [Valence:

positive *vs*. negative *vs*. neutral] x 2 [Age: young *vs*. older adults]), they were only able to identify effects with a size greater than or equal to $\eta^2 = 0.08$[3]. In order to determine whether the studies by Waring and Kensinger (2009) and Nashiro and Mather (2010) also had insufficient power, we conducted sensitivity analyses on these two studies with the same parameters used by Ceccato et al. (2022), i.e., an alpha of .05 and a desired power of .80. These analyses were performed with MorePower (Version 6.0.4; Campbell & Thompson, 2012). They showed that with a sample of 50 participants (25 young adults and 25 older adults) and using an RM-ANOVA with a within-between interaction (i.e., 2 [Valence: positive *vs.* negative] x 2 [Age: young adults *vs.* older adults]), Waring and Kensiger (2009) were only able to exhibit significant effects with a size greater than or equal to $\eta^2 = 0.15$. Similarly, these analyses revealed that with a sample of 50 participants (25 younger adults and 25 older adults), using an RM-ANOVA to test for a within-between interaction (i.e., 2 [Type of arousal: arousing *vs.* non-arousing] x 2 [Age: young *vs.* older adults]), Nashiro and Mather (2010) were also able to show only significant effects having a size greater than or equal to $\eta^2 = 0.15$. Therefore, we cannot rule out that the absence of some interaction effects in the studies by Waring and Kensinger (2009), Nashiro and Mather (2010), and Ceccato et al. (2022) are in fact false negatives related to a lack of statistical power (for a discussion of the harmful impact of false negatives in psychological research, see Vadillo et al., 2016). New studies with high statistical power are consequently needed to determine whether the effects of emotion observed in the memory for intrinsic item features and extrinsic item context in young adults can be replicated in older adults with larger samples, and whether there are any differences between the two age groups.

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[3] In their article, the authors reported that their experimental design allowed them to detect effects of size $\eta^2 \geq 0.14$. Their power analysis was performed using G*Power (Faul et al., 2009) with the "as in Cohen" effect size specification. This calculation differs from that in MorePower (version 6.0.4; Campbell & Thompson, 2012), which corresponds to the "as in SPSS" option available in G*Power. For greater clarity and consistency in our article, we have recalculated the minimum detectable effect size in the study by Ceccato et al. (2022) using the "as in SPSS" specification in G*Power.

Current study

The aim of this study is to examine simultaneously how age modulates the effect of emotion on 1) memory for items, 2) temporal memory (i.e., memory for a feature intrinsic to an item), and 3) associative memory for contexts extrinsic to the items. For each aspect of memory, we will seek to determine 1) whether there is a facilitating or deleterious effect of emotions, 2) whether this effect is generalizable to younger and older adults, and 3) whether differences emerge between younger and older adults as a function of valence (i.e., positive *vs*. negative). To this end, we will adapt the experimental paradigm developed by Palombo et al. (2021) with young and older adults, as it has the advantage of simultaneously testing item memory, memory for item temporal information, and memory for the association between items and videos in which they are inserted. The use of this paradigm is also relevant because, in young adults, the beneficial effect of emotion on memory for temporal information seems to be robust when it concerns the moment when an event occurred (Petrucci & Palombo, 2021) and temporality is a central facet of episodic memory (Tulving, 2002). The first modification we will introduce to the paradigm of Palombo et al. (2021) is to include positive images (in addition to negative and neutral images) in order to be able to test for the existence of an age-related positivity effect on memory for items as well as on their intrinsic features and their extrinsic context. The second modification to this paradigm will be to increase the delay between encoding and retrieval phases from 10 min in the Palombo et al. (2021) paradigm to 45 min, as the age-related positivity effect in item memory has been shown to increase with time (e.g., Kalenzaga et al., 2016; Laulan et al., 2020). Finally, rather than asking participants to estimate how easy/difficult it will be to remember an association between an image and a video, we will have them assess the degree of congruency between the two types of stimuli. Indeed, it has been shown that the items in a scene that do not correspond to what could reasonably occur in that scene are better remembered than those that correspond to the expectation of what should logically occur in that scene, because their presence is more surprising and therefore captures more attention (Mickley Steinmetz et al., 2018). This change is also crucial because we want the encoding of stimuli to be incidental so that the information is processed in the most natural way possible. Indeed, constraining the processing of information during encoding has been shown to reduce the expression of motivational goals in favor of emotion regulation in older adults and thus decreases the magnitude of the age-related positivity effect in memory (Reed et al., 2014; see also Symeonidou et al., 2022). The study design with the research questions, hypotheses, and the plan for participant recruitment and analysis is presented in Table 1.

Hypotheses

In view of the low level of evidence in the literature regarding the combined effects of age and emotion on the memory for intrinsic item features and extrinsic item context, we are cautious in formulating our hypotheses about temporal memory and associative memory for context extrinsic to the items. This caution is all the more justified given that we chose to use low-arousal stimuli in our study, in contrast to the majority of studies mentioned in our introduction that favored high-arousal stimuli (e.g., Ceccato et al., 2023; Nashiro & Mather, 2010, 2011). Furthermore, when an age-related positivity effect is mentioned in the hypotheses presented below, several patterns of results are possible. According to Langeslag and van Strien (2009), the age-related positivity effect can be characterized mainly by three distinct patterns: 1) no bias is observed in young adults (i.e., no difference between positive and negative stimuli) and a positivity bias is observed in older adults (i.e., an advantage of positive stimuli compared to negative stimuli) ; 2) a negativity bias is observed in younger adults (i.e., an advantage of negative stimuli compared to positive stimuli) and no bias is observed in older adults; 3) a negativity bias is observed in younger adults and a positivity bias is observed in older adults. However, based on the definition by Reed et al. (2012), it is conceivable to observe an age-related positivity effect when there is a positivity bias in both younger and older adults but with a larger magnitude in older adults or when there is a negativity bias in both younger and older adults with a smaller magnitude in older adults (see Kalenzaga et al., 2016; Laulan et al., 2022). As such, in order to consider all possible patterns of results, we will assume that there is an age-related positivity effect when there is either a greater advantage of positive stimuli over negative stimuli or a reduced advantage of negative stimuli over positive stimuli when comparing older adults to younger adults.

Hypothesis 1: Effect of age and emotion on item memory

(a) Positive and negative images are better remembered than neutral images in young adults. Positive and negative images are better remembered than neutral images in older adults (e.g., Denburg et al., 2003).

(b) There is an age-related positivity effect, such that positive images are better remembered than negative images in older adults *vs.* younger adults (e.g., Reed et al., 2014).

Hypothesis 2: Effect of age and emotion on temporal memory

(a) Positive and negative images are positioned more accurately in time than neutral images in young adults (e.g., D'Argembeau & Van der Linden, 2005). Positive and negative images are positioned more accurately in time than neutral images in older adults (Nashiro & Mather, 2010; Palumbo et al., 2018).

(b) There is an age-related positivity effect, such that positive images are positioned more accurately in time than negative images in older adults *vs.* younger adults.

Hypothesis 3: Effect of age and emotion on memory for the association between an item and its extrinsic context

(a) Young adults remember less well in which videos the positive and negative images had been presented compared to in which videos the neutral images had been presented, i.e., the associations between positive and negative images and videos are less well remembered than associations between neutral images and videos in young adults (MacKenzie et al., 2015). Older adults remember less well in which videos the positive and negative images had been presented compared to in which videos the neutral images had been presented, i.e., the associations between positive and negative images and videos are less well remembered than associations between neutral images and videos in older adults (Nashiro & Mather, 2010).

(b) There is an age-related positivity effect, such that associations between positive images and videos are less well remembered than associations between negative images and videos in older adults *vs.* younger adults (Waring & Kensinger, 2009).

Method

Power analysis and sample size estimation

We are interested in testing the existence of a main effect of valence independently in younger and older adults (hypotheses 1a, 2a, and 3a) and of a valence x age interaction effect (hypotheses 1b, 2b, and 3b) in (1) an item memory task, (2) a temporal judgment task, and (3) an associative memory task. Given the complexity of accessing a population of physically and psychologically healthy older adults, a problem that has been particularly evident in our recent research, especially for studies requiring a time commitment of more than 2 hours, we adopted a pragmatic approach to justifying our experimental sample size (see Lakens, 2022). This approach is guided by a recognition of the limitations inherent in our research context and a desire to maximize the scientific value of our study despite these challenges. To complete our data collection over a period of 1 to 1.5 years, it was decided to target a maximum of 150 younger and 150 older adults in our study. A first sensitivity analysis conducted with MorePower (version 6.0.4; Campbell & Thompson, 2012) revealed that, based on our target experimental sample of 150 young adults and 150 older adults, using a repeated-measures ANOVA (RM-ANOVA), we are able to detect a within-subjects effect of valence in each age group (i.e., 3 [Valence: positive *vs*. neutral *vs*. negative] in young adults and in older adults; see hypotheses 1a, 2a and 3a) of size $\eta^2 = 0.06$, with an alpha of .05 and a power of 0.964[4,5]. A second sensitivity analysis conducted under the same conditions and with the same parameters as the first revealed that we are able to detect a within-between interaction effect between valence and age (i.e., 3 [Valence: positive *vs*. neutral *vs*. negative] x 2 [Age: young *vs*. older adults]; see hypotheses 1b, 2b and 3b) of size $\eta^2 = 0.03$, with an alpha of .05 and a power of 0.964.

Given the considerable uncertainty about the size of the effects of interest in our study, we chose to follow the sequential procedure proposed by Lakens (2014, 2022). By performing sequential analyses, it is possible to reduce the experimental sample size and thus minimize the cost of the experiment (i.e., time, money) thanks to the opportunity of rejecting the null hypothesis or stopping the study for futility at an interim look while controlling both Type 1 and Type 2 error rates. Efficacy and futility boundaries for interim analyses were calculated with an online Shiny application using functions from the R *rpact* package (Wassmer & Pahlke, 2020). Analyses indicated that with a two-tailed test with an alpha of .05, a power of 0.964 and three analyses using O'Brien and Fleming-type alpha and beta spending functions, the efficacy boundary for the first analysis (time = 0.50) is .003; the efficacy and futility boundaries for the second analysis (time = 0.75) are respectively .018 and .298; the efficacy boundary for the third analysis (time = 1.00) is .044[6]. Thus, if the hypothesis tests all return a $p < .003$ after the first interim analyses (i.e., after 150 participants, including 75 young adults

[4] Given that we aim to test 6 independent hypotheses divided into 3 blocks (respectively hypotheses 1a and 1b, 2a and 2b, 3a and 3b) with a power of 0.80, we have chosen a targeted power of 0.964 for each of the hypotheses, i.e. the sixth root of 0.80.
[5] We decided to base our power analysis on an RM-ANOVA because, to our knowledge, there are no software packages that allow us to directly implement a power analysis for generalized estimating equations (GEE; see Kal et al., 2022). Also, with GEE, a smaller number of participants is required in order to obtain satisfactory power compared to an RM-ANOVA (Ma et al., 2012), so our power analysis is conservative.
[6] A simulation study showed that the cumulative error probabilities for ANOVAs are similar to the probabilities of t-tests, especially when the number of looks of the data is small (i.e., ⩽3; Lang, 2017), so it is valid to use the computational methods of the R package *rpact* (Wassmer & Pahlke, 2020) in our situation.

and 75 older adults), data collection will be interrupted; if the hypothesis tests all return a $p <$ .018 or a $p >$ .298 after the second interim analyses (i.e., after 226 participants, including 113 young adults and 113 older adults), data collection will be interrupted.

Participants

This study was approved by the ethics committee of the University of Geneva. All participants will give written informed consent and will be paid 30 CHF (approximately $31) for participation. Participants will be recruited through advertisements posted on the Internet (websites affiliated with the University of Geneva, social networks), through flyers placed in research centers (e.g., Campus Biotech) or in places often frequented by seniors (e.g., university for seniors, clubs for seniors) and through word of mouth. In order to be included in our study, participants will have to meet the following criteria: be between 18 and 30 years old or between 60 and 80 years old; be native French speakers or fluent in French; have normal or corrected-to-normal vision; have no history of major neurological (e.g., stroke, head injury) or psychiatric disorders (e.g., depression, bipolar disorder). In addition, older participants will be tested for cognitive functioning using the French Telephone Interview for Cognitive Status Modified (F-TICS-m, Lacoste & Trivalle, 2009) to ensure that they do not have dementia. Thus, only participants with a score of 28 or higher will be included in our study since it was demonstrated in a validation study using an English version of the F-TICS-m (Welsh et al., 1993) that a score of 27 is the optimal threshold to distinguish between individuals with dementia and those with mild cognitive impairment (MCI) (Knopman et al., 2010). In order to verify that our results obtained with an F-TICS threshold of 27 do not stem from the cognitive fragility of some older participants, we will also conduct our statistical analyses by removing participants with a score of 31 or less on the F-TICS-m as it has also been shown that a score of 31 is the optimal cut-off to distinguish individuals with MCI from individuals with normal cognition (Knopman et al., 2010). We will also ensure that young adults and older adults are matched by gender. Finally, participants will complete questionnaires regarding individual characteristics related to emotion and affect for purely descriptive purposes and to allow comparison of our experimental sample to the general population. More precisely, the participants will be characterized according to:

- emotional reactivity assessed with the Emotional Reactivity Scale (ERS; original version: Nock et al., 2008; French version: Lannoy et al., 2014);
- positive and negative affects assessed with the Positive and Negative Affect Schedule (PANAS; original version: Watson et al., 1988; French version: Caci & Baylé, 2007);
- trait and state anxiety measured with the State-Trait Anxiety Inventory Form Y (STAI-Y; original version: Spielberger et al., 1983; French version: Bruchon-Schweitzer & Paulhan, 1993);
- stress measured with the Perceived Stress Scale (PSS 4; original version: Cohen et al., 1983; French version: Lesage et al., 2012);
- suppression and reappraisal of emotion measured with the Emotion Regulation Questionnaire (ERQ; original version: Gross & John, 2003; French version: Christophe et al., 2009).

Materials

Videos. The 60 videos in our study will be the same as those used by Palombo et al. (2021) except for five videos that are no longer available on YouTube. These videos were replaced with videos considered equivalent by three independent raters (e. g., a video that contained scenes from a basketball game was replaced with a video on the same theme). The videos were downloaded from YouTube and cut with HitfFilm software (FXhome, 2022) in order to last 18 s with the constraint to exclude all situations which could lead to misunderstandings or surprise effects, such as the presence of writings in a foreign language or of scenes too far from our contemporary world. In summary, all the videos in our study represent scenes from everyday life (e.g., a walk on the beach or in a shopping center) selected so that they are not too repetitive or exciting for the participants (see Palombo et al., 2021).

Images. The main characteristics (means and standard deviations) of the experimental materials are presented in Table 2. The experimental materials consisted of 120 images (40 negative, 40 neutral and 40 positive) selected from the 180 images used by Leclerc and Kensinger (2011) in a study on the effect of age on item emotional memory. All these images were from the International Affective Picture System (IAPS, Lang et al., 2005) and their valence and arousal were rated on scales from 1 to 9 by 50 young and 50 older adults. The 120 images of our study were divided into two equivalent sets of 60 images, thus the controls described below are valid for both sets of images and the p-values indicated may belong to Set 1 or Set 2 depending on the lower values obtained. The set of images that will be used during encoding *vs.* the one that will be used as distractors during item recognition will be counterbalanced across participants.

Based on image ratings collected by Leclerc & Kensinger (2011), we ensured that negative images in our study have a valence between 1 and 3.5, both in younger and older adults (in Sets 1 and 2 combined, younger adults: [1.80, 3.47]; older adults: [1.45, 3.46]); neutral images have a valence between 4 and 6, both in younger and older adults (in Sets 1 and 2 combined, younger adults: [4.04, 5.69]; older adults: [4.18, 5.95]); positive images have a valence between 6.5 and 9, both in younger and older adults (in Sets 1 and 2 combined, younger adults: [6.51, 8.34]; older adults: [6.55, 8.42]). Therefore, valence differed significantly between negative, neutral, and positive images in both younger and older adults (all $ps < .001$). Furthermore, the images in our study were selected so that the arousal of negative and positive images did not differ significantly in either young or older adults (all $ps > .337$). Also, when selecting images, we sought to keep the arousal of negative and positive images as low as possible to maximize the probability of observing an age-related positivity effect in item memory (Kensinger, 2008; Laulan et al., 2022) and in item-context memory (Waring & Kensinger, 2009)[7]. Thus, the highest arousal for a negative image is 7.71 whether in younger or older adults (in Sets1 and 2 combined, younger adults: [3.67, 6.46]; older adults [3.81, 7.71]) and that the highest arousal for a positive image is 7.70 whether in younger or older adults (in Sets 1 and 2 combined, younger adults: [3.67, 6.46]; older adults [3.80, 7.70]). However, due to the U-shaped relationship between valence and arousal frequently obtained in normative studies (e.g., Lang et al., 1998), arousal for negative and positive images was higher than for neutral images in both younger and older adults (in Sets 1 and 2 combined, younger adults: [2.30, 4.38]; older adults: [2.05, 4.86]) (all *ps* < .001). Finally, valence and arousal were matched across the two age groups of our study for each category of images (i.e., negative, neutral, and positive images) (all *ps* > .088). The distribution of valence and arousal scores for Set 1 and Set 2 images as a function of age is shown in Figure 1.

To reduce potential confounding effects, negative, neutral, and positive images were matched on the same low-level visual properties controlled in the study by Palombo et al. (2021): 1) luminance (all *ps* > 0.410); 2) contrast (all *ps* > 0.606); entropy (all *ps* > .300); L* dimension of CIELAB color space (color brightness) (all *ps* > 0.446); a* dimension of CIELAB color space (color channel from red to green) (all *ps* > 0.99); b* dimension of CIELAB color space (color channel from blue to yellow) (all *ps* > 0.573). To extract the physical properties of the images in our study, we used a Python-based script developed by Marchewka et al. (2014). In addition, three research assistants coded the content of images from the study by Leclerc and Kensinger (2011) following the instructions described in the article by Marchewka et al. (2014). Thus, each image was categorized as animal, object, landscape, people or face, and only images for which all three coders provided identical

[7] However, this choice may reduce the possibility of observing an effect of emotions on item-context memory in young adults, since it has been shown in individuals of this age group that high-arousal items are remembered more often with spatial and temporal context than low-arousal items (Schmidt et al., 2011).

responses were selected as potential candidates for inclusion in our study. Among the images selected for our study, we ensured that image content did not differ between negative, neutral and negative images in both Set 1 and Set 2[8] (all *ps* > .731).

Video-image combinations. We will create six different lists of stimuli for the encoding phase from image Sets 1 and 2 so that: 1) at encoding, half of the participants will see the images from Set 1 and the other half of the participants will see the images from Set 2; 2) for each image set, each video will be associated for one third of the participants with a negative image, for another third of the participants with a neutral image, and for a final third of the participants with a positive image. In addition, the assignment of images to videos will be random and equal numbers of younger and older participants will see each of the six lists of stimuli. The images will be inserted into the videos (i.e., without superimposition in order not to mask sequences of the videos) using the HitfFilm software (FXhome, 2022). Each image will be shown for 2 s at a random time, but with the constraint that it will not appear before 2 s of video or after 16 s of video. We will verify that the average image placement times do not differ significantly between conditions (i.e., negative, neutral, and positive images).

Procedure

The experimental procedure will be adapted from that used by Palombo et al. (2021) to test the effect of emotion on item recognition, temporal judgment, and associative recognition between items and their context. Thus, it will consist of five phases whose order

[8] The content of the images in our study for each set and for each category was as follows:
- Set 1: negative images = 2 with animals, 6 with objects, 2 with landscapes, 7 with people, 3 with faces; neutral images = 1 with animals, 7 with objects, 2 with landscapes, 7 with people, 3 with faces; positive images = 3 with animals, 5 with objects, 3 with landscapes, 6 with people, 3 with faces.
- Set 2: negative images = 2 with animals, 5 with objects, 3 with landscapes, 8 with people, 2 with faces; neutral images = 1 with animals, 7 with objects, 3 with landscapes, 5 with people, 4 with faces; positive images = 3 with animals, 5 with objects, 3 with landscapes, 6 with people, 3 with faces.

will be invariant for all participants (see below). The task will be implemented in PsychoPy (Peirce et al., 2019).

Phase 1: Encoding

Before the encoding phase begins, participants will be explained that they will be viewing a series of videos containing an image and that for each video-image combination they will be asked to rate the degree of congruence between the two types of stimuli. Thus, participants will not be informed that their memory will be tested during the experiment. The rating of congruency between the videos and the images will be done with the following question that will be asked immediately after the presentation of each video: "In your opinion, how compatible is the image with the video in which it was presented?". To answer this question, participants will use a 9-point analog scale ranging from "0 = not at all" to "8 = totally" which will be presented for 5 s and followed by a 2 s fixation cross. The order of presentation of the stimuli will be random. To ensure that the instructions are fully understood, all participants will perform three practice trials before starting the experimental task.

Phase 2: Item recognition

After a 45-minute break during which participants can walk around and do some coloring (see Palombo et al., 2021), the images presented during the encoding phase will be shown again to the participants, as well as new images serving as distractors. The order of the images will be pseudo-randomized so that a maximum of two images of the same valence will be presented in succession. Each image will be displayed for 8 s *vs.* 4 s in the study by Palombo et al. (2021), given the inclusion of older adults in our study, and participants will have to determine if they have seen the image before by answering "Old" or "New" using two keys on the keyboard of the computer ("Old": Q; "New": P). A 2 s fixation cross will follow each judgment made by the participants.

Phase 3: Temporal judgment

In Phase 3, the images presented during the encoding phase will be shown to the participants in a pseudo-random order and, under each image, a timescale ranging from 0 to 20 s will be displayed. Markers will be placed on the scale to divide it into four equal parts (i.e., 5 s intervals will be indicated to participants). Participants will have 8 s to click on the location on the scale corresponding to the time at which they consider that they saw the image within the video. A 2 s fixation cross will appear after each participant response.

Phase 4: Associative recognition

Then, participants will see the images presented during the encoding phase in a pseudo-randomized order and the images will be surrounded by five screenshots from the videos that were also presented during the encoding phase. Among these screenshots, four will be distractors and one will be a target (i.e., it will come from the video in which the image was actually presented) and the placement of the distractors and the target around the image will be random. Thus, each screenshot will be presented on five different trials. For one-third of the trials (i.e., 20 trials), two screenshots will be from videos associated with negative images, two screenshots will be from videos associated with positive images, and one screenshot will be from a video associated with a neutral image; for another third of the trials, two screenshots will be from videos associated with negative images, two screenshots will be from videos associated with neutral images, and one screenshot will be from a video associated with a positive image; for another third of the trials, two screenshots will be from videos associated with positive images, two screenshots will be from videos associated with neutral images, and one screenshot will be from a video associated with a negative image. Also, the proportion of screenshots taken before and after the moment when an image was presented within a video will be matched between the different experimental conditions (i.e., video associated with a positive, negative, or neutral image). Participants will have 8 s to select the screenshot of the video that they believe was associated with the image during the encoding phase. A 2 s fixation cross will be displayed after each participant response.

Phase 5: Assessment of participants' characteristics and debriefing

The ERS (original version: Nock et al., 2008; French version: Lannoy et al., 2014), the PANAS (original version: Watson et al., 1988; French version: Caci & Baylé, 2007), the STAI-Y (original version: Spielberger et al, 1983; French version: Bruchon-Schweitzer & Paulhan, 1993), the PSS 4 (original version: Cohen et al., 1983; French version: Lesage et al., 2012), and the ERQ (original version: Gross & John, 2003; French version: Christophe et al., 2009) will be administered to the participants. Finally, we will ask the participants if they understood the objective of the experiment and in particular if they suspected that their memory would be evaluated (this will allow us to check that the encoding of the video-image combinations was indeed performed incidentally). Then, we will debrief the participants to explain the interest of the study.

Data analyses plan

Criteria for participant data exclusion

We have defined three criteria according to which a participant's data may be excluded from the final analyses. First, a participant's data will be excluded if he/she/they explains during the debriefing that he/she/they did not perform all the experimental phases correctly for reasons beyond her/his/them control (e.g., he/she/they was considerably interrupted or disturbed by a person or alarm while performing a phase of the experiment) and/or within her/his/them control (e.g., he/she/they was not concentrating because he/she/they regularly looked at her/his/them phone or because he/she/they was tired). This information will be completed and nuanced by the observations noted by the experimenters during the experimental runs. Second, a participant's data will be excluded if he/she/they fails to provide a response for 25% or more of the trials in at least one of the four experimental phases (see Palombo et al., 2021). Third, for the three dependent variables in our study (i.e., responses to the item recognition task, accuracy in the temporal judgment task, and responses to the associative recognition task), we will calculate the median and Median Absolute Deviation (MAD) for each age group. If any participants have scores that fall beyond 3 MAD of the median for a given dependent variable, her/his/them data will be excluded from the analyses. We decided to use MADs rather than standard deviations to identify potential outliers because standard deviations are measures that are sensitive to extreme values and therefore do not robustly detect them (Leys et al., 2013; see Monéger et al., 2022).

Methods of analysis of the dependent variables

Responses in the item recognition task, in the temporal judgment task, and in the associative recognition task will be analyzed using generalized estimating equations (GEEs; Liang & Zeger, 1993). GEEs are preferred for the analysis of these variables to more conventional methods such as RM-ANOVA because they support correlational analyses of repeated measurements without requiring the residuals to follow a normal distribution and they have more statistical power (Ma et al., 2012). In addition, unlike generalized linear mixed-effect models (GLMMs), GEEs target population-level effects rather than subject-specific effects, which is more in line with the objectives of our study.

Specification of the model for the analysis of each of the dependent variables

In all analyses, the correlation structure assumed in the residuals will be modeled with an exchangeable correlation matrix that presumes that all observations of a participant are identically correlated (e.g., Pekàr & Brabec, 2018). Furthermore, for the analysis of responses in the item recognition task, we will use a binomial distribution and a probit link function (e.g., DeCarlo, 1998; Hourihan et al., 2013); for the analysis of responses in the temporal judgment task, we will calculate accuracy scores for each trial based on the absolute value of the difference between each participant's response along the time line and the actual moment when the image was placed in the video (e.g., Schönenkorb et al., 2023) and we will use a Gaussian distribution and an identity link function; for the analysis of responses in the associative recognition task, we will use a binomial distribution and a logit link function (Ballinger, 2004). The data acquired in the item memory, temporal judgment and associative recognition tasks will be analyzed three times consecutively to provide precise answers to our six hypotheses. Thus, in the first stage, and for each dependent variable, we will introduce valence (positive *vs*. negative *vs*. neutral images) and age (younger *vs*. older adults) and the interaction between valence and age as factors; in the second stage, we will replicate the analyses, focusing only on younger adults; in the third stage, we will replicate the analyses, focusing only on older adults. For the analysis of responses in the item recognition task, we will position ourselves within the framework of signal detection theory (Green & Swets, 1966) in order to obtain a measure of response bias (i.e., the overall tendency to respond "yes" rather than "no") and a measure of discriminability (i.e., the likelihood of responding "yes" when the image has been seen rather than when it has not)[9]. For this, we will add the type of target (previously seen images *vs.* distractors) as a factor.

A priori contrasts applied to independent variables

Deviation coding will be applied to age and type of target (age, young adults = -1, older adults = 1; type of target: previously seen images = 1, distractors = -1). In addition, two a priori orthogonal contrasts will be applied to valence. This statistical method is recommended for testing accurate predictions when an independent variable has more than

[9] With a probit link function, the response bias obtained in the analyses will be the additive inverse of the C measure classically used in the literature while the discriminability measure will correspond to the d' index (Hourihan et al., 2013). In order to be able to compare our results to those of studies similar to ours and in particular to those from the study by Palombo et al. (2021), we will report the response bias transformed into C when we describe our results. Also, to avoid undefined values of C and d' when pass or false alarm rates are equal to 1 or 0, we will use the log-linear rule proposed by Hautus (1995) by adding 0.5 to passes or false alarms, and 1 to the total of trials seen or not seen.

two modalities without increasing Type 1 errors (Schad et al., 2020). A quadratic contrast applied to valence will allow us to compare performance for both positive and negative images to performance for neutral images (positive images = 1; negative images = 1; neutral images = -2). Moreover, a linear contrast applied to valence will allow us to compare performance for positive images to performance for negative images (positive images = 1; negative images = -1; neutral images = 0). Thus, thanks to the quadratic contrast applied to valence we will be able to test for the existence of an emotional bias in young and older adults in item memory and item-context memory (i.e, proposition (a) of each of our three hypotheses); the analysis of the interaction effect between the linear contrast applied to valence and age will allow us to test the existence of an age-related positivity effect in item memory and item-context memory (i.e., proposition (b) of each of our three hypotheses).

Additional analyses

When we find a significant interaction effect between the linear contrast applied to valence and age, we will examine the direction of this effect by testing the effect of age on positivity preference scores and on negativity preference scores (see Murphy & Isaacowitz, 2008) by applying two new contrasts to valence (contrast for positivity preference: positive images = 1; negative images = 0; neutral images = -1; contrast for negativity preference: positive images = 0; negative images = 1; neutral images = -1). Since these two new contrasts applied to valence are non-orthogonal, an adjustment for multiple comparisons will be made via a Bonferroni correction to reduce the risk of Type 1 errors.

Statistical analysis software

Data will be analyzed using IBM SPSS Statistics version 28 for Windows (SPSS Inc, Chicago, IL, USA) and the R statistical software version 4.2.2 (R Core Team, 2022), using the *geepack* package (version 1.3.9, Højsgaard et al., 2022) for GEEs.

Data and code availability

The authors are committed to sharing all data, experimental scripts, and materials used in this study upon Stage 2 acceptance.

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Table 1

Design table

Question	**Hypothesis**	**Sampling plan**	**Analyses plan**	**Rationale for deciding the sensitivity of the test for confirming or disconfirming the hypothesis**	**Interpretation given different outcomes**	**Theory that could be shown wrong by the outcomes**
Q1: How do age and emotion influence item memory?	H1-a: Memory for emotional images (i.e., both negative and positive items) is better than memory for neutral images in young adults. Memory for emotional images is better than memory for neutral images in older adults (e.g., Denburg et al., 2003).	We will conduct sequential analyses (Lakens, 2014), so participant recruitment will be conducted in a maximum of three stages, and may be interrupted in stage 1 if all our effects of interest are significant, or in stage 2 if all the effects are significant, or if they are beyond the futility boundary: stage 1, 75 younger adults and 75 older adults; stage 2, 113 younger adults and 113 older adults; 150 younger adults and 150 older adults. Inclusion criteria: native French speaker or fluent in French; normal or corrected-to-normal vision; no	Responses in the item recognition task will be analyzed using generalized estimating equations with the following parameters: exchangeable correlation matrix; binomial distribution; probit link function (e.g., Hourihan et al., 2013). Factor: 3 [Valence: positive *vs.* neutral *vs.* negative] The analysis will be performed in young adults and then in older adults. For the H1-a hypothesis, a quadratic contrast applied to valence will allow us to compare performance for positive and negative items to performance for neutral items (positive images = 1; negative images = 1; neutral images = -2).	Given the complexity of accessing a population of physically and psychologically healthy older adults, particularly for time-consuming studies, we adopted a pragmatic approach to justifying our sample size, aiming to achieve a satisfactory balance between the feasibility of our study and its scientific significance (see Lakens, 2022). Thus, we determined a target sample of 150 younger and 150 older participants. Sensitivity analyses indicated that with an alpha of .05 and	Hypothesis H1-a will be confirmed if we observe a significant effect of the quadratic contrast applied to valence in any of the three stages of sequential analyses performed on responses in the item memory task in both young and older adults.	The results concerning hypothesis H1-a will support or not the fact that the advantage for emotional stimuli in item memory is present in both younger and older adults. The results concerning hypothesis H1-b will support or not the existence of an age-related positivity effect in item memory, i.e., better memory for positive vs. negative stimuli in older adults compared to younger adults (see Reed et al., 2014). The results concerning hypotheses H2-a and H3-a will support or not:
	H1-b: There is an age-related positivity effect in item memory, i.e.,		Factors: 3 [Valence: positive *vs.* neutral *vs.*		Hypothesis H1-b will be confirmed if we observe a	

	there is either a greater advantage of positive *vs.* negative images or a reduced advantage of negative *vs.* positive images when comparing older adults to younger adults (Reed et al., 2014).	history of major neurological (e.g., stroke, head injury) or psychiatric (e.g., depression, bipolar disorder) disorders. In addition, older participants will be tested for cognitive functioning using the F-TICS-m (Lacoste & Trivalle, 2009) to ensure that they do not have dementia (score $\geq$ 28). Participants with scores that are more than 3 MAD from the median for a given dependent variable will be excluded from the analyses (analyses will be performed independently for each age group).	negative] x2 [Age: young *vs.* older adults] For the H1-b hypothesis, a linear contrast applied to valence will allow us to compare performance for positive images to performance for negative images (positive images = 1; negative images = -1; neutral images = 0).	a power of 0.964, our target sample would allow us to detect effects of size $\eta^2 = 0.06$ for hypotheses H1-a, H2-a, and H3-a, and effects of size $\eta^2 = 0.03$ for hypotheses H1-b, H2-b, and H3-b.	significant interaction effect between the linear contrast applied to valence and age in any of the three stages of sequential analyses performed on responses in the item memory task.	- the object-based binding account proposed by Mather (2007) regarding young adults; - the generalization of the object-based binding account proposed by Mather (2007) to older adults. The results regarding hypotheses H2-b and H3-b will support or not the generalization of the age-related positivity effect robustly shown in item memory (e.g., Reed et al., 2014) to memory of intrinsic item features and extrinsic context, in this case the temporal memory for the items and their context of appearance.
Q2: How do age and emotion influence temporal memory (i.e., memory for a feature intrinsic to an item)?	H2-a: Emotional images (i.e., negative and positive images) are positioned more accurately in time than neutral images in young adults (e.g., D'Argembeau & Van der Linden, 2005). Emotional images are positioned more accurately in time than neutral images in older adults (e.g., Palumbo et al., 2018).		Responses in the temporal memory task will be analyzed using GEEs with the following parameters: exchangeable correlation matrix; gaussian distribution; identity link function. Factor: 3 [Valence: positive *vs.* neutral *vs.* negative] The analysis will be performed in young adults and then in older adults. For the H2-a hypothesis, a quadratic contrast applied to valence will allow us to compare performance for positive and negative items to performance for neutral items (positive images = 1; negative images = 1; neutral images = -2).	Since we will be conducting sequential analyses, we planned to adjust the alpha significance level at each stage of the analyses so that there would be no inflation of the risk of Type 1 errors. We determined that with a two-tailed test with an alpha of 0.05, a power of 0.964, and three looks using an O'Brien and Fleming-type spending function, the adjusted alpha levels for the first analysis (time = 0.50), the second analysis (time = 0.75), and the third analysis (time =	Hypothesis H2-a will be confirmed if we observe a significant effect of the quadratic contrast applied to valence in any of the three stages of sequential analyses performed on responses in the temporal memory task in both young and older adults.	
	H2-b: There is an age-related positivity effect		Factors: 3 [Valence: positive *vs.* neutral *vs.*		Hypothesis H2-b will be confirmed	

	in temporal memory, i.e., there is either greater temporal accuracy for positive *vs.* negative images or reduced temporal accuracy for negative *vs.* positive images when comparing older adults to younger adults.		negative] x2 [Age: young *vs.* older adults] For the H2-b hypothesis, a linear contrast applied to valence will allow us to compare performance for positive images to performance for negative images (positive images = 1; negative images = -1; neutral images = 0).	1.00) are 0.003, 0.018, and 0.044.	if we observe a significant interaction effect between the linear contrast applied to valence and age in any of the three stages of sequential analyses performed on responses in the temporal memory task.	
Q3: How do age and emotion influence memory for the association between an item and its extrinsic context?	H3-a: The associations between emotional images (i.e., negative and positive images) and videos are less well remembered than associations between neutral images and videos in young adults (MacKenzie et al., 2015). The associations between emotional images (i.e., negative and positive images) and videos are less well remembered than associations between neutral images and videos in older adults (Nashiro & Mather, 2010).		Responses in the associative recognition task will be analyzed using GEEs with the following parameters: exchangeable correlation matrix; binomial distribution; logit link function (e.g., Ballinger, 2004). Factor: 3 [Valence: positive *vs.* neutral *vs.* negative] The analysis will be performed in young adults and then in older adults. For the H3-a hypothesis, a quadratic contrast applied to valence will allow us to compare performance for positive and negative items to performance for neutral items (positive images = 1; negative images = 1; neutral images = -2).		Hypothesis H3-a will be confirmed if we observe a significant effect of the quadratic contrast applied to valence in any of the three stages of sequential analyses performed on responses in the associative memory task in both young and older adults.	Explanations for all results will be presented in the discussion and elements of interpretation will be given if we find unexpected effects.

	H3-b: There is an age-related positivity effect in associative memory between an item and its extrinsic context, i.e., there is either a greater memory impairment of the association between videos and positive images *vs.* the association between videos and negative images or a reduced memory impairment of the association between videos and negative images *vs.* the association between videos and positive images when comparing older adults to younger adults. (Waring & Kensinger, 2009).		Factors: 3 [Valence: positive *vs.* neutral *vs.* negative] x2 [Age: young *vs.* older adults] For the H3-b hypothesis, a linear contrast applied to valence will allow us to compare performance for positive images to performance for negative images (positive images = 1; negative images = -1; neutral images = 0).		Hypothesis H3-b will be confirmed if we observe a significant interaction effect between the linear contrast applied to valence and age in any of the three stages of sequential analyses performed on responses in the associative memory task.	

Table 2

Main Characteristics of the Experimental Materials (Means and SD)

		Set1			Set 2	
Property	Negative Images (n = 20)	Neutral Images (n = 20)	Positive Images (n = 20)	Negative Images (n = 20)	Neutral Images (n = 20)	Positive Images (n = 20)
Valence						
Young adults	2.70 (0.52)	5.06 (0.29)	7.28 (0.54)	2.48 (0.39)	4.99 (0.43)	7.42 (0.52)
Older adults	2.67 (0.61)	5.14 (0.44)	7.19 (0.47)	2.45 (0.34)	5.01 (0.49)	7.27 (0.51)
Arousal						
Young adults	5.30 (0.64)	3.37 (0.51)	5.08 (0.82)	5.09 (0.71)	3.49 (0.50)	4.98 (0.88)
Older adults	5.13 (0.94)	3.29 (0.80)	4.99 (0.85)	5.00 (0.99)	3.37 (0.65)	4.91 (0.97)
Luminance	83.11 (28.79)	91.76 (38.93)	99.11 (42.59)	99.98 (37.24)	82.96 (31.50)	93.85 (37.89)
Contrast	70.17 (14.42)	68.02 (10.73)	67.98 (15.59)	70.02 (15.77)	73.95 (17.11)	67.36 (15.55)
Entropy	6.51 (1.15)	6.61 (1.27)	6.71 (1.27)	6.96 (1.04)	6.36 (1.14)	6.68 (1.22)
L*a*b-L	34.53 (11.93)	38.19 (15.78)	41.34 (16.95)	41.40 (15.08)	34.62 (13.35)	39.52 (15.41)
L*a*b-A	4.14 (5.14)	3.37 (7.43)	3.94 (6.75)	6.29 (7.78)	6.61 (6.47)	6.93 (10.53)
L*a*b-B	9.99 (8.70)	14.52 (12.27)	11.91 (11.16)	9.54 (8.69)	13.67 (12.12)	13.27 (14.55)

Figure 1

Density plot showing the distribution of valence and arousal scores for all images in our study (i.e., both Set 1 and Set 2) as a function of age (i.e., younger vs. older adults)