Emotional Memory in Younger and Older Adults

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Content

Chapter 1

Introduction

It is generally acknowledged that physical health and cognitive processing, with memory in particular, decline as people age. It has been suggested that also emotional processing, as well as the interaction between emotion and cognition, change with advancing age, though not in a detrimental fashion. The current aging of the population makes research on emotional and cognitive processing and their interaction in older adults highly relevant. The interaction between emotion and cognition, and age differences therein, is the topic of this thesis.

Contrary to the widespread idea that emotions are harmful to rational thought, the emotionality of stimuli often actually improves cognitive processing. Compared to equivalent neutral stimuli, emotional stimuli are better perceived (Zeelenberg, Wagenmakers, & Rotteveel, 2006), are allocated more attention (Compton, 2003), and are more likely to be remembered (Kensinger, 2004). The other way around, cognition also affects emotional processing, such as in the case of emotion regulation (Ochsner & Gross, 2005). It has been argued that when people grow older they start to prioritize positive stimuli in attention and memory and become better at regulating their emotions (Mather & Carstensen, 2005).

In this chapter, the scientific background of the interaction between emotion and cognition will be outlined. First, issues concerning experimental research on emotions will be discussed. Subsequently, different forms of the interaction between emotion and cognition (i.e. emotional attention, emotional memory, and emotion regulation) will be described. Because in most of the studies reported on in this thesis event-related potentials are used as a research technique, this technique is shortly introduced here. Theories and previous findings about how the interplay between emotion and cognition would change across the life span will be discussed. This introductory chapter will conclude with the research questions and hypotheses that will be addressed in this thesis.

Emotion

Emotion has long been neglected by the scientific community. Descartes, for example, stated 'cogito, ergo sum', behaviorists considered emotions to be unobservable and therefore unsuitable as a research topic, while early cognitive psychologists took the emotionless computer as a metaphor for the human mind (LeDoux, 1998). Fortunately, emotion now finally receives the scientific attention that it deserves.

To the best of my knowledge, there is no single definition of emotion that is widely accepted and used. The description of the lemma 'emotion' in the *Penguin Dictionary of Psychology* starts of by noting that "(…) this term has proven utterly refractory to definitional effort; probably no other term in psychology shares it combination of nondefinability and frequency of use” (Reber & Reber, 2001, p. 236). Nevertheless, there is some agreement on a number of characteristics of emotion. First, emotions are induced by some object in the environment (Beck, 2004) or a cognitive action. For example, the sight of a snake may elicit fear, the smell of spoiled food may elicit disgust, getting a compliment may elicit joy, and retrieving a memory of your late grandmother may evoke sadness. Second, emotions can be classified along the two independent dimensions of valence and arousal. The valence of an emotion describes whether the emotion is unpleasant or pleasant, whereas arousal reflects the intensity of an emotion. Negative and positive emotions occupy opposite sides of the valence dimension, with neutral states in-between. Both negative and positive emotions are typically highly arousing, whereas neutral states tend to be low in arousal (Bradley & Lang, 1994). Third, emotions cause action tendencies (Frijda, 1986). The action tendency could be to approach or to avoid the eliciting object (Beck, 2004), depending on whether it has rewarding or punishing properties, respectively (Rolls, 2005). Fourth, the elicited action tendency ultimately promotes the survival and/or reproduction of the individual (or organism) in which the emotion occurs (LeDoux, 1998).[1]

Because emotion is such a complex phenomenon, the key of doing scientific research on emotion is to consider its different aspects separately. This is comparable to research on memory, for instance, in which short- and long-term memory, or encoding and retrieval processes are studied individually. Figure 1 gives an overview of the different aspects of emotion. First, research on emotion could focus on one or more of the discrete emotion such as happiness, disgust, anger, etc. Second, one could use the valence, arousal, or motivational tendency dimensions to classify the emotions under study. The effects of valence and arousal on some dependent variable, for instance, may be separated by using both high and low arousing stimuli of negative and positive valences (e.g. Van Strien, Langeslag, Strekalova, Gootjes, & Franken, 2009). Third, emotions can be expressed in multiple ways, such as through facial expressions or verbal utterances, each of which can be studied separately. Finally, in research on emotion a distinction has to be made between the different processing modes of emotion, including the perception, experience, and expression of an emotion.

One way of tapping into a particular aspect of emotion when doing experimental research is using a certain class of stimuli, such as words, pictures, film clips, or faces. Prototypical examples of negative, positive, and neutral stimuli of each of these stimuli classes are the words ‘rape’, ‘holiday’, and ‘square’; photographs of mutilated people, cute animals, and household objects; movie scenes from thrillers, comedies, and nature documentaries; and photographs of angry, happy, and neutral faces. Whereas it may be difficult to select pictures

[1] ‘Feeling’ has been defined as the conscious representation of an emotion (LeDoux, 1998).

or words that convey only one of the discrete emotions, facial expressions are rather specific in this respect. But photographs of emotional faces may not elicit the experience of an emotion. They may instead be used to study the integrity of emotion perception. Emotional words, on the other hand, may cause an emotional experience in the observer, though usually not very intense. Emotional pictures and film clips are more effective in eliciting emotional experiences (Keil, 2006), but their physical characteristics (e.g. brightness, complexity, membership of semantic category) are less well controllable across conditions compared to words and faces. In conclusion, to study emotion, one should focus on one or more of the specific aspects of emotion. This may for example be achieved by selecting suitable stimuli, with each class of stimuli having its advantages and disadvantages.

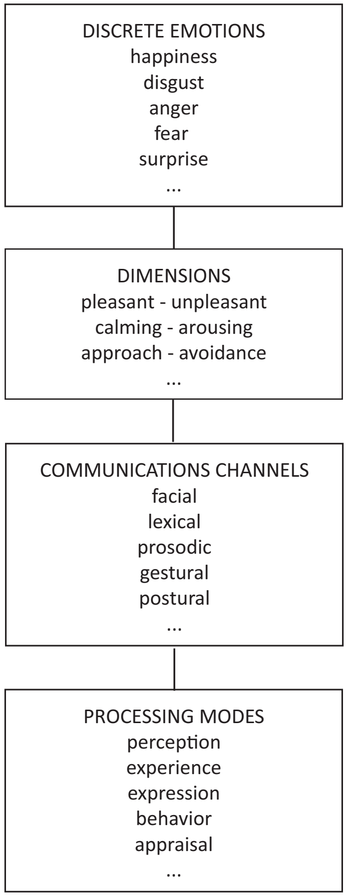

Figure 1. Overview of the different aspects of emotion (adapted from Borod (1993)).

Emotion and cognition

Emotion and cognition influence each other reciprocally in various ways. Because emotional stimuli contain information that is highly relevant for survival and reproduction, it is essential that these stimuli are preferentially processed (LeDoux, 1998). Therefore, the influence of emotion on cognition generally entails that cognitive processing of emotional stimuli, for example in attention and memory, is enhanced (e.g. Dolcos & Cabeza, 2002; Lipp & Waters, 2007; Ochsner, 2000; Stormark, Nordby, & Hugdahl, 1995). The influence of cognition on emotion, on the other hand, entails that we are not a plaything of our emotions, but that we can regulate them using cognitive processes such as attention and reappraisal (e.g. D. C. Jackson, Malmstadt, Larson, & Davidson, 2000; Kim & Hamann, 2007).

Emotional attention

One way of classifying attention is by determining the origin of the attention allocation, yielding a range from bottom-up to top-down attention (Connor, Egeth, & Yantis, 2004). Bottom-up attention implies that attention is allocated because of stimulus characteristics. Stimuli that are loud, bright or moving, for example, readily attract selective attention. Top-down attention occurs when attention is actively directed to a stimulus that is not particularly salient by itself, for example when students try to follow a boring lecture because they want to pass their exam. Increased attention for personally relevant stimuli (Wingenfeld et al., 2006) can be considered to involve interplay of bottom-up and top-down processes, as characteristics of both the stimulus as well as the observer play a role.

More attention is allocated to emotional stimuli than to comparable neutral stimuli. Assuming that emotionality is a stimulus characteristic, this type of attention is a form of bottom-up attention (Compton, 2003). However, this emotional attention can not be conceived as a pure bottom-up process, as some semantic processing may be required to assess the emotional salience of stimuli such as words or complex pictures. Correspondingly, certain stimuli will elicit emotional attention in certain individuals only. Whereas a picture of a mutilated person or the word 'rape' elicits emotional attention in the large majority of people, spider-related stimuli capture more attention than neutral stimuli especially in spider phobics (Lipp & Waters, 2007; Van Strien, Franken, & Huijding, 2009).

Another way of classifying attention is by its time course. Attention can be allocated towards a stimulus at the early stage of its processing and/or during later processing stages (Schupp, Flaish, Stockburger, & Junghöfer, 2006). In an attentional blink paradigm, emotional stimuli amongst a rapid serial visual stream of distractor words are typically better perceived than comparable neutral words (e.g. Keil, Ihssen, & Heim, 2006), showing that emotional salience enhances attention during early processing (Schupp et al., 2006). Moreover, emotional stimuli also retain attention better during later processing than neutral stimuli (Schupp et al., 2006). It has been shown that this increased sustained attention for emotional compared to neutral stimuli may last as long as six seconds after stimulus onset (Cuthbert, Schupp, Bradley, Birbaumer, & Lang, 2000). The emotional attention during late processing stages has been called motivated attention (Schupp et al., 2004; Schupp et al., 2006).

Emotional memory

The human memory system comprises both long-term memory (LTM) and working or short-term memory (STM). Both of these memory types involve the encoding, retention and retrieval of information. STM is a system that stores and manipulates a limited amount of information temporarily. It consists of different subsystems. The visuo-spatial sketch pad and the phonological loop, for example, store visual and auditive information respectively. The central executive is involved in manipulating the stored information and functions as a source of attentional control. The episodic buffer stores information in a multi-modal code and is thought to be the interface between STM and LTM (Repovs & Baddeley, 2006). In LTM, in principle an unlimited amount of information can be stored indefinitely. Episodic memory is a form of declarative memory that can be probed by free recall, cued recall, or recognition tests that refer to a prior event (Gabrieli, 1998). The majority of the studies on the influence of emotion on human memory have focused on episodic LTM.

Long-term memory

The most well-known effect of emotion on memory is the so-called emotion enhancement effect, which entails that memory is improved for emotional compared to equivalent neutral information (Kensinger, 2004). The fact that emotional stimuli are better perceived and attended than neutral stimuli (Compton, 2003) increases the likelihood that emotional information is remembered. It may also increase the quality of the memory representation of emotional information. The emotionality of stimuli further boosts several memory-specific processes, such as encoding, (re)consolidation, and retrieval (Hamann, 2001; LaBar & Cabeza, 2006; Liu, Graham, & Zorawski, 2008; Phelps, 2004), which again increases the likelihood that a memory representation is formed and/or enhances the quality of this representation.

In recognition tests, two different retrieval processes are supposed to underlie recognition performance, namely familiarity and recollection. Familiarity is the mere sense of having seen a stimulus previously without being able to recall any details of the circumstances (e.g. you see someone who is familiar to you, but you can not recall who it is or how you know that person), whereas recollection refers to the explicit memory of the circumstances in which a stimulus was previously encountered (Yonelinas, 2001, 2002). The emotional salience of stimuli typically does not influence familiarity but does boost recollection (Dewhurst & Parry, 2000; Kensinger & Corkin, 2003b; Ochsner, 2000), which leads to more vivid memories of emotional than neutral information.

There is some debate on whether the effect of stimulus emotionality on memory is a valence or an arousal effect. Because emotional information (whether negative or positive) is typically more arousing than neutral information, the often observed memory benefit for emotional compared to neutral information suggests that the emotion enhancement effect is an arousal effect. It has, however, been observed that also low-arousing negative and positive stimuli are remembered better than equally low-arousing neutral information (Kensinger & Corkin, 2003b; Ochsner, 2000), in which case the emotion enhancement effect appears to be a valence effect. Moreover, younger adults have sometimes been found to show an emotion enhancement effect only for negative but not for positive over neutral stimuli, even when the negative and positive stimuli were matched in arousal (e.g. Ochsner, 2000), again implying a valence effect. It has therefore been suggested that both valence and arousal of emotional stimuli influences memory for those stimuli (see Kensinger, 2004, for a review).

Besides the emotional salience of the stimuli themselves, also the emotionality of the context in which stimuli appear has been found to influence memory for those stimuli. For example, individuals with major depressive disorder have a tendency to show relatively enhanced memory for negative information and decreased memory for positive information compared to healthy controls (Leppänen, 2006). This effect, that emotional stimuli are better remembered when the mood state at retrieval matches the valence of the stimuli, is called the mood congruency effect (Kenealy, 1997; Lewis & Critchley, 2003).

Short-term memory

In contrast to research on the emotional modulation of LTM, research on the effect of stimulus emotionality on STM for stimulus content is scarce. In a few studies, stimulus emotionality generally had no effect on STM performance (e.g. Gläscher, Rose, & Büchel, 2007; Kensinger & Corkin, 2003a). In other studies, STM was superior for pleasant pictures, intermediate for neutral pictures and inferior for unpleasant pictures (Perlstein, Elbert, & Stenger, 2002), and superior for angry compared to happy and neutral faces (M. C. Jackson, Wolf, Johnston, Raymond, & Linden, 2008; M. C. Jackson, Wu, Linden, & Raymond, 2009). It is as of yet unknown which cognitive processes during which memory stages underlie the effect of emotion on STM. Stimulus emotionality might influence perception, attention, encoding, maintenance, and/or retrieval processes in STM tests, but more research is needed to clarify this issue.

Emotion regulation

Emotion regulation is the use of behavioral or cognitive strategies to generate new emotions or to up- or down-regulate current emotions. For example, people may try to hide their emotions by suppression their facial expression (e.g. trying to keep from laughing or crying) in certain situations. This suppression of facial expression is an example of a behavioral strategy to regulate one's emotions. Cognitive strategies comprise a continuum ranging from attentional control to cognitive change. Examples of attentional control are performing a distracting secondary task or concentrating on non-emotional aspects of a situation, whereas reappraising the situation is an example of cognitive change of emotions (Gross, 1998; Ochsner & Gross, 2005). Emotion regulation can be applied at different time points in the emotion generation process. In this respect, antecedent-focused emotion regulation refers to altering or preventing the occurrence of an emotional response, for example by selecting or modifying the situation you are in. Response-focused emotion regulation, on the other hand, refers to changing an ongoing emotional response, for example by reappraising the situation (Gross, 1998, 2002).

Down-regulation of emotions by cognitive strategies has been associated with increased activation of the prefrontal cortex and decreased activation of brain regions implicated in appraisal, such as the amygdala, insula, hypothalamus and orbitofrontal cortex (e.g. Beauregard, Lévesque, & Bourgouin, 2001; Goldin, McRae, Ramel, & Gross, 2008; Lévesque et al., 2003; Ochsner, Bunge, Gross, & Gabrieli, 2002). Although these functional Magnetic Resonance Imaging (fMRI) findings do not reveal whether these prefrontal and lower-level appraisal systems influence each other directly and in which direction, they seem to imply that emotion regulation can decrease emotions because the prefrontal cortex reduces activity in appraisal systems.

Event-related potentials

Both emotion and cognition have been studied extensively using event-related potentials (ERPs). In a typical ERP study, participants are presented with multiple stimuli of several conditions (e.g. unpleasant, neutral, and pleasant pictures) while their electroencephalogram (EEG) is recorded. In the analysis, an average brainwave that occurs in response to stimuli of each of the conditions is computed, which is the ERP. ERPs are a useful measure for determining from which point in time or even during which cognitive processes a certain experimental manipulation exerts its influence (Linden, 2007; Luck, 2005). This because, ERP has temporal resolution in the order of milliseconds and because prior ERP research has identified a number of ERP components that index different cognitive processes. Therefore, ERPs can be used to investigate which cognitive processes (such as attention, memory and face recognition processes) are influenced by emotionality of the stimuli and in what way.

The P1 is an early ERP component that is thought to reflect early visual processing of the stimulus (Haenschel et al., 2007). The N170 and the N250r are two later components that occur in response to face stimuli specifically. The N170 is supposed to reflect the structural processing of a face, whereas the N250r would reflect recognition of face identity (Schweinberger & Burton, 2003). Emotional modulation of one or more of these components during a task with emotional and neutral faces could thus show whether and how these visual processes are influenced by facial expression.

One ERP component that is particularly sensitive to the emotional salience of stimuli is the Late Positive Potential (LPP), or the P3b. In this thesis, the term LPP is used in Chapters 1, 3, 7, and the term P3b in Chapter 5, in line with the articles that these chapters are based on. The LPP amplitude is typically larger for emotionally arousing pictures, faces, and words than for the corresponding neutral stimuli. This enhanced LPP for emotional stimuli is thought to reflect motivated attention (Schupp et al., 2006). Individual differences in motivated attention are reflected in the LPP. Heroin and alcohol dependent participants, for example, showed an increased LPP in response to heroin and alcohol-related pictures, respectively, while non-dependent participants did not (Franken, Stam, Hendriks, & Van den Brink, 2003; Namkoong, Lee, Lee, Lee, & An, 2004).

In line with the sensitivity of the LPP to emotional salience, it has been shown that the amplitude of the LPP in response to emotional stimuli can be modulated by emotion regulation instructions. When participants were instructed to down-regulate their emotional responses to emotional pictures by using cognitive strategies, the LPP amplitude was reduced compared to when participants were instructed to merely view the emotional pictures (Hajcak, Dunning, & Foti, 2009; Hajcak & Nieuwenhuis, 2006; Krompinger, Moser, & Simons, 2008; Moser, Hajcak, Bukay, & Simons, 2006). Likewise, the LPP amplitude increased when participants were instructed to up-regulate their emotional responses to emotional stimuli (Moser, Krompinger, Dietz, & Simons, 2009). The direction of this effect is in line with the typical emotion effect on the LPP, in the sense that more intense emotional stimuli elicit a larger LPP (Schupp et al., 2006). The emotion regulation effects on the LPP suggest that down- and up-regulating emotions respectively decreases and increases the amount of motivated attention allocated to the emotional stimulus that elicits the emotion.

Where the LPP indexes motivated attention, ERP old/new effects index memory retrieval processes. Old/new effects concern the difference between ERPs that are elicited by stimuli that are presented for the first time (i.e. new stimuli) and for the second time (i.e. old stimuli) in a recognition test, where the ERP waveform for old stimuli usually is more positive going than the ERP waveform for new stimuli. There are three spatiotemporally and functionally distinct old/new effects. The early old/new effect has been taken to reflect familiarity, the parietal old/new effect is supposed to index recollection, and the late frontal old/new effect represents post-retrieval processes (Friedman & Johnson, 2000). These ERP old/new effects have been found to be affected by stimulus emotionality in multiple studies (e.g. Dietrich et al., 2001; Graham & Cabeza, 2001; Inaba, Nomura, & Ohira, 2005; Johansson, Mecklinger, & Treese, 2004; Maratos, Allan, & Rugg, 2000; Schaefer, Fletcher, Pottage, Alexander, & Brown, 2009; Van Strien, Langeslag et al., 2009).

In short, because ERP components represent different cognitive processes and can be modulated by the emotional salience of stimuli, they are a useful measure in the examination of the interaction between emotion and cognition.

Emotion and aging

As mentioned at the beginning of this chapter, it has been suggested that emotional processing and the interplay between emotion and cognition change across the adult life span. An important theory in this respect is the socioemotional selectivity theory (Carstensen, Isaacowitz, & Charles, 1999; Carstensen & Turk-Charles, 1994), which assumes that people may have two types of goals: knowledge- and emotion-related goals. Knowledge-related goals lead people to undertake activities that might not be especially pleasurable at this moment, but that do yield valuable knowledge that would be useful in the future, such as taking classes, studying for exams, and meeting new, potentially valuable people. Emotion-related goals lead people to undertake activities that do not necessarily yield benefits for the future, but that are merely pleasurable to undertake, such as meeting with family and friends. According to the socioemotional selectivity theory, the relative pursuing of these goals changes with the amount of perceived remaining life-time. Younger adults, who have a sense of an unlimited future, would have mainly knowledge-related goals. Older adults, on the other hand, would feel that their future is limited and would therefore have mostly emotion-related goals. These emotion-related goals motivate people to focus on emotions, rather than on knowledge. In correspondence to this theory, an age-related decrease has been observed in the recall of neutral information while there was no age difference in the amount of emotional information recalled (Carstensen & Turk-Charles, 1994).

Positivity effect

Emotion-related goals are sometimes dubbed emotion-regulation goals (e.g. Mather & Carstensen, 2005), because they would lead older adults to focus on the positive aspects of life (Carstensen et al., 1999; Mather & Carstensen, 2005). When comparing younger and older adults, a positivity effect may be observed. In prior work, the positivity effect is hardly explicitly defined, which has led researchers to use idiosyncratic statistical testing to assess its occurrence. In this thesis, it will be argued that a positivity effect can be defined as *a trend for adults to increasingly process positive and/or decreasingly process negative information compared with other information with advancing age*. This definition describes an age effect and should thus not be confused with an absolute increased processing of positive compared to negative information, which is called a positivity bias (Löckenhoff & Carstensen, 2007). A negativity bias is an absolute increased processing of negative compared to positive information (see e.g. Ito, Larsen, Smith, & Cacioppo, 1998). There are three patterns of biases that could make up a positivity effect: 1) younger adults show no bias and older adults show a positivity bias, 2) younger adults show a negativity bias and older adults show no bias, and 3) younger adults show a negativity bias and older adults show a positivity bias. It will further be argued in this thesis that a positivity effect should be assessed by testing the Valence x Age group interaction.

Positivity effect in long-term memory

Most work on the positivity effect concerns the LTM domain. Positivity effects have been observed in several LTM studies, with each of the three patterns of biases being represented in the data (e.g. Charles, Mather, & Carstensen, 2003; Emery & Hess, 2008; Kensinger, 2008; Leigland, Schulz, & Janowsky, 2004; Thomas & Hasher, 2006). Multiple other studies, however, could not demonstrate a positivity effect in LTM (e.g. Comblain, D'Argembeau, Van der Linden, & Aldenhoff, 2004; Denburg, Buchanan, Tranel, & Adolphs, 2003; Grühn, Smith, & Baltes, 2005; Kensinger, Brierley, Medford, Growdon, & Corkin, 2002). Therefore, the question rises as to how consistent the occurrence of the positivity effect in LTM is and what kind of preconditions for the occurrence of the positivity effect exist.

Positivity effect in short-term memory

In the one study that concerned age differences in emotional STM, younger and older adults viewed unpleasant and pleasant pictures and were instructed to memorize the feeling that a picture elicited. A positivity effect was observed, as older adults showed superior memory for pleasant versus unpleasant feelings, while younger adults showed the opposite pattern (Mikels, Larkin, Reuter-Lorenz, & Carstensen, 2005). However, because this study tested

STM memory for stimulus emotionality rather than stimulus content, it does unfortunately not provide knowledge of age differences in STM that is analogues to our knowledge of age differences in LTM. More research is needed to examine age differences in emotional STM.

Positivity effect in attention

It has been stated that the positivity effect also occurs in attention (Mather & Carstensen, 2005). Given that individual differences occur in the allocation of emotional attention and that younger and older adults appear to differ in emotional processing, a positivity effect may indeed be present in attention. Measuring the amount of attention that is allocated to certain information is, however, less straightforward than measuring memory for that information, and as a result the methodology of the different attention studies is less comparable.

Age differences in attention allocation have, for instance, been measured using the attentional blink paradigm with emotional and neutral words (Langley et al., 2008). Unfortunately, in that study a positivity effect could not be established because the valence of the emotional words (negative or positive) was varied between-subjects only. In another study, age differences in free viewing time of unpleasant, neutral, and pleasant pictures were assessed. It appeared that both younger and older adults looked longer at unpleasant than pleasant or neutral pictures (Charles et al., 2003), thus no positivity effect was present.

Age differences in motivated attention have also been studied using eye-tracking methodology and the dot-probe task (Isaacowitz, Wadlinger, Goren, & Wilson, 2006a, 2006b; Knight, Seymour, Gaunt, Nesmith, & Mather, 2007; Mather & Carstensen, 2003). In both types of studies, pairs of emotional (either positive or negative) and neutral faces are presented. In eye-tracking studies, looking behavior to each of the members of the pair is assessed. In dot-probe studies, the face pair is followed by the presentation of a dot at the location of either the emotional or the neutral face to which the participants have to respond as quickly as possible. Differences in reaction times for dots that appear behind emotional and neutral faces indicate the tendency to allocate attention toward or away from positive or negative compared to neutral faces. It has been suggested to speak of positivity and negativity preferences to describe attention for positive and negative compared to neutral stimuli respectively. In a meta-analysis of attention studies using several methodologies, age differences in preferences appeared uncommon (Murphy & Isaacowitz, 2008).

Note that establishing age differences in preferences does not yield information about the occurrence of a positivity effect, because within-subject differences between negative and positive stimuli are typically not assessed (Murphy & Isaacowitz, 2008)[2]. Interestingly, however,

[2] The reason that emotional-neutral face pairs are often used rather than negative-positive face pairs is that it is difficult to equate the arousal of negative and positive stimuli (Isaacowitz, 2009, personal communication).

Knight et al. (2007) have compared the magnitudes of negativity and positivity preferences between age groups. They found that in younger adults the negativity preference was larger than the positivity preference, whereas in older adults the positivity preference was larger than the negativity preference, thereby establishing a positivity effect. Knight and colleagues also included negative-positive stimulus pairs, which could in principle reveal negativity and positivity biases instead of preferences, and thus a positivity effect, but no significant effects were observed.

To conclude, the nature of attention makes it somewhat difficult to assess age differences in motivated attention. With one exception (i.e. Knight et al., 2007), behavioral studies so far have not revealed a positivity effect in attention.

Positivity effect in neurophysiological measures

Along with the increasing availability and popularity of neuroimaging techniques such as fMRI and ERP, age differences in emotion processing have also been investigated with these techniques. Notably, a positivity effect has been observed in such neurophysiological measures. In an fMRI study in which younger and older adults viewed pictures of negative, positive and neutral objects (such as a grenade, a diamond ring, and a hammer, respectively), brain regions in the left frontal and parietal lobes showed a positivity effect. Although formal post hoc comparisons are not reported, these brain regions appeared to show more activity in response to negative than positive objects (i.e. a negativity bias) in younger adults, and more activity in response to positive than negative objects (i.e. a positivity bias) in older adults (Leclerc & Kensinger, 2008a). In another fMRI study, younger and older adults were presented with unpleasant, pleasant and neutral pictures, and a positivity effect was observed in the amygdala, which is a key structure in emotional processing. The amygdala was equally active for unpleasant and pleasant pictures (i.e. no bias) in younger adults, and was more active in response to pleasant than to unpleasant pictures (i.e. a positivity bias) in older adults (Mather et al., 2004).

Also in the ERP, and more specifically in the LPP, positivity effects have been observed. Wood and Kisley (2006) have found that the amplitude of the LPP was larger for unpleasant than pleasant pictures (i.e. a negativity bias) in younger adults but equally large for unpleasant and pleasant pictures (i.e. no bias) in older adults. In a subsequent study, regression analysis revealed that the positivity effect in the LPP amplitude resulted from an age-related decrease in the processing of negative information, and not from an increase in the processing of positive information (Kisley, Wood, & Burrows, 2007). Because the LPP reflects motivated attention, these findings suggest the presence of a positivity effect in attention, in contrast to the above-mentioned behavioral attention studies.

The neurophysiological studies suggest that the behavioral positivity effect may have its origin in age differences in brain activation in response to emotional stimuli. However, in the neurophysiological studies cited here participants did not perform a memory or attention test, leaving the relationship between neurophysiological and behavioral positivity effects unidentified. Moreover, it has not yet been investigated whether a positivity effect occurs in ERP components reflecting other processes than the LPP, such as early and late ERP old/new effects.

Age differences in mood

Mood appears to improve when people grow older. Although it might seem that mood is a continuum with negative and positive mood on either end, negative and positive mood in fact appear to be two independent constructs (Watson, Clark, & Tellegen, 1988). Improved mood with aging can be said to occur when between age group comparisons of negative and positive mood reveal that older adults experience less negative mood and/or more positive mood than younger adults.

There are multiple studies that have tested age differences in mood state, which is the current mood, or mood trait, which is a long-term tendency to experience certain levels of negative and positive mood. Table 1 gives a (non-exhaustive) overview of previous studies that have assessed mood in younger and older adults. It can be seen that age differences in mood have been observed in most of the studies, and that these age differences were in the expected direction of less negative or more positive mood in older compared to younger adults in all cases.

Because of the observed age differences in mood, the option exists that age differences in the emotion-cognition interaction result from a mood congruency effect. That is, the older adults' less negative and/or more positive mood might lead them to increasingly process positive and/or decreasingly process negative information compared with other information than younger adults. This option deserves investigation in future research.

Table 1. Occurrence of age differences in positive and negative mood in previous studies.

Study	Participants (n)	State or trait	Negative mood	Positive mood
Charles et al. (2003), study 2	Y (32): 19-30 yrs O (32): 63-86 yrs	state	Y > O	Y = O
Ebner & Johnson (2009)	Y (32): 18-22 yrs O (24): 65-84 yrs	state	Y > O	Y < O
Emery & Hess (2008), study 1	Y (59): 18.5 yrs[a] O (58): 74.1 yrs[a]	state	Y > O	Y < O
Emery & Hess (2008), study 2	Y (46): 20.7 yrs[a] O (51): 72.7 yrs[a]	state	Y > O	Y < O
Fernandes et al. (2008), sessions 1 & 2	Y (49): 17-29 yrs O (48): 60-84 yrs	state	Y > O	Y < O
Grady et al. (2007)	Y (40): 18-29 yrs O (40): 60-81 yrs	? [b]	Y > O	Y < O
Grühn et al. (2005)	Y (72): 18-31 yrs O (72): 64-75 yrs	trait	Y > O	Y = O
Grühn et al. (2007)	Y (48): 18-31 yrs O (48): 63-77 yrs	trait	Y > O	Y = O
Knight et al. (2007)	Y (33): 18-29 yrs O (27): 65-83 yrs	? [b]	Y > O	Y = O
Langley et al. (2008), study 1a	Y (30): 18-24 yrs O (30): 60-77 yrs	? [b]	Y = O	Y = O
Langley et al. (2008), study 2a	Y (30): 18-33 yrs O (30): 63-80 yrs	? [b]	Y = O	Y < O
Mather & Knight (2005), study 1	Y (48): 18-29 yrs O (48): 65-83 yrs	? [b]	Y = O	Y < O
Mather & Knight (2005), study 2	Y (25): 18-28 yrs O (31): 65-85 yrs	? [b]	Y > O	Y < O
Mather & Knight (2005), study 3	Y (32): 18-39 yrs O (32): 64-84 yrs	? [b]	Y > O	Y < O
Phillips et al. (2008)	Y (64): 18-40 yrs O (62): 60-88 yrs	state	Y > O	Y < O
Spaniol et al. (2008), study 1	Y (24): 19-28 yrs O (24): 60-75 yrs	? [b]	Y > O	Y = O
Spaniol et al. (2008), study 2	Y (25): 18-32 yrs O (24): 61-85 yrs	? [b]	Y > O	Y = O
Tomaszczyk et al. (2008)	Y (72): 18-25 yrs O (72): 61-93 yrs	? [b]	Y > O	Y < O
Wieser et al. (2006)	Y (13): 28-38 yrs O (14): 59-76 yrs	? [b]	Y = O	Y = O

Note. Y = younger adults, O = older adults, a = age range not specified in original article, b = state or trait not specified in original article.

Age differences in emotion regulation

The positivity effects in memory and attention, as well as the improved mood with aging, have been taken to indicate that emotion regulation improves across the life span (Mather & Carstensen, 2005). Also Kensinger and Leclerc (2009) contend that emotion regulation improves with aging. They present five arguments, which I will discuss here critically. Their first argument is that aging does not appear to affect automatic, bottom-up controlled processes, but does affect goal-directed, top-down controlled processes (Mather & Carstensen, 2005). This argument is unconvincing, because although applying emotion regulation is a top-down modulation of emotional processing, top-down modulation of emotional processing does not inevitably involve emotion regulation and can thus not be taken as evidence for the occurrence of age differences in emotion regulation. Their second argument is that cognitive control, as measured by several cognitive tasks, is a prerequisite for a positivity effect to occur (Mather & Knight, 2005). Again, such argument is not persuasive, because good performance on cognitive control tasks does not necessarily imply good emotion regulation abilities, let alone implementation of emotion regulation during cognitive tasks with emotional stimuli. Their third argument is that when younger and older adults passively view emotional and neutral stimuli, age differences in brain activation are observed. These age differences often involve increased activation of the prefrontal cortex and decreased amygdala activation in older adults. Although this pattern of activation is indeed similar to the pattern observed during emotion regulation tasks, the occurrence of this pattern does of course not imply that participants were engaging emotion regulation processes. Findings of age differences brain activation in response to emotional stimuli, as well as findings of age differences in emotional memory, emotional attention, and mood, instead imply that younger and older adults differ in emotional reactivity, which may or may not result from age differences in emotion regulation. Kensinger and Leclerc's fourth argument is that age differences in brain activation in fMRI studies have only been observed when the stimuli were presented for a relatively long period (e.g. one second or more) and that age differences in the ERP have only occurred in late potentials. However, there is no reason to assume that emotion regulation processes occur only after some time. Antecedent-focused emotion regulation, for example, occurs already before an emotion has (fully) developed (Gross, 1998, 2002). Therefore, age differences in late processing stages can not be taken as evidence for age differences in emotion regulation. Kensinger and Leclerc's final argument is that older adults report that they experience to have greater control over their emotions (e.g. Gross et al., 1997). It is very well known that self-reports suffer from a variety of problems (Kimberlin & Winterstein, 2008) and that they do not always yield accurate data. Therefore, self-report data alone are insufficient for making the claim that emotion regulation improves with aging. Because the five arguments given by Kensinger and Leclerc are not fully convincing, we are in need of empirical data on age differences in emotion regulation tasks in order to be able to conclude whether age differences exist in emotion regulation, and whether these age differences indeed signify that we get better at regulation our emotions when we grow older.

Further, it is unclear from the literature what is exactly meant by improved emotion regulation. Improved emotion regulation with aging might denote that the intensity of both negative and positive emotions is decreased, given that older compared to younger adults agreed more with questionnaire items such as "I try to avoid reacting emotionally, whether the emotion is positive or negative" (Lawton, Kleban, Rajagopal, & Dean, 1992) and have reported greater control over the inner experience of both negative and positive emotions. However, the increased control over negative emotions has been found to be associated with diminished negative feelings, whereas the increased control over positive emotions was associated with enhanced positive feelings (Gross et al., 1997). It has also been observed that when younger adults were instructed to manage how they felt (i.e. to pursue emotion-related goals) while viewing unpleasant, pleasant, and neutral pictures, they paid more attention to pleasant than unpleasant pictures, whereas they did not show this positivity bias when they were instructed to try to get as much information as possible from each picture (i.e. to pursue knowledge-related goals) (Xing & Isaacowitz, 2006). These findings suggest that improved emotion regulation actually involves decreasing the intensity of negative emotions and increasing the intensity of positive emotions, which would correspond to the positivity effect and the age-related improvement in mood.

What empirical data are there up until now? To start with, there are three fMRI studies that have measured brain activation of older adults while they performed an emotion regulation task. Emotion regulation instructions modulated activity in the amygdala and the prefrontal cortex (Urry, Van Reekum, Johnstone, & Davidson, 2009; Urry et al., 2006; Van Reekum et al., 2007), which are the same regions that are affected by emotion regulation instructions in younger adults, as outlined earlier. Although these studies with older participants show that it is feasible to study emotion regulation in older adults using an experimental design (i.e. not relying on self-reports), they do not provide information on age differences because they did not include a group of younger adults. Further, there are three behavioral studies in which younger and older adults were instructed to down-regulate negative emotions elicited by film clips (Kunzmann, Kupperbusch, & Levenson, 2005; Phillips et al., 2008) or autobiographical memories (Magai, Consedine, Krivoshekova, Kudadjie-Guamfi, & McPherson, 2006). Older adults reported greater decrease in negative feelings following down-regulation than younger adults did (Magai et al., 2006; Phillips et al., 2008). In more objective measures, such as coder-rated facial expressions, skin conductance, heart rate, and blood pressure no age differences were generally observed (Kunzmann et al., 2005; Magai et al., 2006; Phillips et al., 2008). Unfortunately, in these three studies emotion regulation instruction were varied only between-subjects, and only the down-regulation of negative emotions was examined.

To summarize, it has been suggested that emotion regulation improves with aging, although it has not been very well specified what this exactly entails. Although self-report measures of experienced emotional control and of emotional feelings following emotion regulation appear to support the notion that older adults are better at regulation their emotions, more objective measures, in contrast, have failed to identify age differences in emotion regulation. In the light of the positivity effect, it would be interesting to examine age differences in emotion regulation by varying the four possible emotion regulation conditions (up- and down-regulation of both negative and positive emotion) within-subjects. The previously observed effects of emotion regulation on the LPP could then be used as an objective measure of emotion regulation.

Other effects of aging on the emotion-cognition interaction

The positivity effect has been intensively studied, but it is not the only effect of age on the interplay between emotion and cognition that may be interesting. It has for example been proposed that aging affects the recollection processes adversely (Light, Prull, La Voie, & Healy, 2000), while that is the particular process that is supposed to be affected by stimulus emotionality in younger adults (Dewhurst & Parry, 2000; Kensinger & Corkin, 2003b; Ochsner, 2000). This raises the question whether some other recognition memory process than recollection may be sensitive to emotional modulation in older adults. Given that the different ERP old/new effects are taken to reflect the different recognition processes including familiarity and recollection, these old/new effects provide a measure for investigating this issue.

Outline of this thesis

This thesis focuses on the relation between emotion and cognition in younger and older adults. The goal of the current project is to examine age differences in behavior and brain activity during emotional processing in general, and during emotional memory in particular. Chapters 2, 3 and 4 concern emotional LTM, Chapters 5 and 6 concern emotional STM, Chapter 7 concerns emotion regulation, and Chapter 8 contains a discussion of the findings, conclusions, and suggestions for future research. The following research questions are addressed in this thesis:

1) How can the positivity effect be defined and assessed?

This question is addressed in Chapter 2, and is further elaborated on in Chapter 3. The definition and suggestions for analysis proposed in Chapter 2 are applied throughout the rest of this thesis.

2) How consistently does the positivity effect occur in LTM and what are preconditions for the occurrence of a positivity effect?

In Chapter 2, a literature review is performed on the occurrence of the positivity effect in LTM. Potential preconditions identified in prior work are discussed. In Chapter 8, additional preconditions are identified using the findings of the studies reported on in this thesis.

3) Do neurophysiological and behavioral positivity effects co-occur?

Performance on all memory tests reported in this thesis is examined in a way that could identify the occurrence of a behavioral positivity effect. The issue of co-occurring neurophysiological and behavioral positivity effects is addressed in the study described in Chapter 3. Younger and older adults will intentionally encode unpleasant, pleasant, and neutral pictures, while ERPs are recorded. Subsequently, the participants will complete free and cued recall tests. It is hypothesized that positivity effects will occur in both the LPP and memory performance.

4) Does mood congruency play a role in the occurrence of a positivity effect?

In the studies reported in Chapters 3 and 4, participants complete questionnaires to asses both state and trait negative and positive mood, besides memory tests. In Chapter 8, it is assessed whether age differences in mood co-occur with age differences in emotional memory.

5) Do age differences occur in the emotional modulation of ERP old/new effects?

This question is addressed in the study described in Chapter 4. Younger and older adults complete a continuous recognition test with unpleasant, pleasant, and neutral pictures, while ERPs are recorded. Because recollection is typically enhanced by emotion, the parietal old/new effect is expected to be larger for emotional than neutral stimuli in the younger adults. Because recollection suffers from age-related decline, emotion enhancement of the parietal old/new effect is not expected in the older adults.

6) What cognitive processes at which memory stages play a role in the emotion modulation of STM?

This question is addressed in Chapter 5, testing younger adults only. Participants complete a STM task with angry, happy, and neutral faces, while ERPs are recorded. It is investigated whether the P1, N170, P3b and N250r at encoding and/or retrieval are modulated by facial expression. It is expected that the P3b at retrieval and the N250r are neural correlates of the emotional modulation of STM.

7) Do age differences occur in the emotional modulation of STM?

This question is addressed in Chapter 6 by specifically testing the effect of stimulus emotionality on STM for stimulus content, in analogy to previous LTM studies. Younger and older adults complete a STM task with angry, happy and neutral faces, and behavioral memory performance is assessed. Because this study was the first in its kind, it is tentatively hypothesized that a positivity effect would occur in emotional STM.

8) Do age differences occur in emotion regulation abilities?

This question is addressed in Chapter 7. Younger and older adults are instructed to increase or decrease the feelings that unpleasant and pleasant pictures elicited, while ERPs were recorded. The analysis focuses on the LPP, which serves as an objective measure of emotion regulation. Because emotion regulation is supposed to improve with aging, it is expected that emotion regulation effects on the LPP are larger in older than in younger adults. Alternatively, emotion regulation effects on the LPP might reveal that older compared to younger adults are particularly good at decreasing negative emotions and/or increasing positive emotions.

Chapter 2

Issues on the definition and assessment of the positivity effect, and a literature review

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Langeslag, S. J. E., & Van Strien, J. W. (submitted). Issues on the definition and assessment of the positivity effect, and a literature review.

Abstract

It has been suggested that older adults favor positive information in emotional memory, which has been called the positivity effect. However, researchers appear to have different definitions of this effect. Here it is proposed that the positivity effect should be defined as a trend for adults to increasingly process positive compared to negative and/or decreasingly process negative compared to positive information with advancing age. According to this definition, the positivity effect should be assessed by testing the Valence x Age group interaction, followed by within-subject valence comparisons. A review of the literature on age differences in long-term memory shows that the positivity effect only occurred in 30% of the studies. Suggestions for future research are made.

Introduction

It has been stated that older adults focus on the positive aspects of life more than younger adults do. Older adults would, for example, prioritize positive information when remembering emotional information (Mather & Carstensen, 2005). In the last couple of years, a large part of the literature on age differences in emotional memory has focused on this so-called positivity effect.

To our knowledge, the first mentioning of the term 'positivity effect' occurs in an article from Kennedy, Mather, and Carstensen (2004). In this article, the term is used to describe the finding that older nuns (79-101 years) tended to remember autobiographical events from 14 years ago more positively than they had experienced them at that time. Younger nuns (47-65 years), in contrast, tended to remember events more negatively than they had experienced them originally, which the authors called a negativity effect. The term positivity effect has subsequently been used in numerous articles describing experimental studies in which age differences in emotional memory were investigated. In these studies, younger and older adults were typically presented with negative, neutral, and positive stimuli, and memory for these stimuli was probed. In this literature, however, the term positivity effect has been used rather loosely (see also Murphy & Isaacowitz, 2008), sometimes denoting a within-subject valence effect (e.g. remembering more positive than negative stimuli (e.g. Fernandes, Ross, Wiegand, & Schryer, 2008)), and sometimes denoting a between-subject age effect (e.g. positive stimuli account for a larger proportion of older than younger adults' memory (e.g. Mather & Carstensen, 2005)). Apparently, different definitions of the positivity effect exist.

In this review, we start by presenting a definition of the positivity effect. We then discuss the possibilities for the statistical analysis of the positivity effect that result from this definition. Although the positivity effect seems to originate from the domain of autobiographical memory, the current review concerns only non-autobiographical memory. The existing literature on age differences in emotional long-term memory will be reviewed, keeping in mind the proposed definition and analysis methods. The goal of this review is to examine how consistently the positivity effect is observed in long-term memory. Finally, we will give suggestions for future research.

Defining the positivity effect

An explicit definition of the positivity effect was given only in a footnote in an article by Löckenhoff and Carstensen (2007, p. 135), namely "a developmental trend for adults to increasingly attend to and process positive information more than they do negative information as they grow older". This definition describes an age effect and should thus not be confused with an absolute increased processing of positive compared to negative information, which is called a positivity bias (Löckenhoff & Carstensen, 2007). A negativity bias, then, is an absolute increased processing of negative compared to positive information (see e.g. Ito, Larsen, Smith, & Cacioppo, 1998; Wood & Kisley, 2006). Because these biases merely describe within-subject differences in processing of positive and negative information, they can be observed within an individual at a certain point in time. Defining the positivity as an age effect, the positivity effect can only be observed within an individual when testing that individual at different ages (longitudinal design) or when comparing individuals of different ages (cross-sectional design). It may be clear that for practical reasons the positivity effect is usually examined using a cross-sectional approach. For completeness, the opposite of a positivity effect would be a negativity effect, which should not be confused with a negativity bias (see e.g. Grühn, Scheibe, & Baltes, 2007; Grühn, Smith, & Baltes, 2005) as defined above.

Note that the definition of the positivity effect by Löckenhoff and Carstensen only accounts for an age-related increase in processing of positive information. However, an age-related decrease in processing of negative information would also make life more positive. Older compared to younger adults have been found to experience more positive affect (e.g. Langley et al., 2008), but indeed also less negative affect (e.g. Charles, Mather, & Carstensen, 2003; Knight, Seymour, Gaunt, Nesmith, & Mather, 2007), and even a combination of more positive and less negative affect (e.g. Ebner & Johnson, 2009; Grady, Hongwanishkul, Keightley, Lee, & Hasher, 2007; Phillips, Henry, Hosie, & Milne, 2008; Tomaszczyk, Fernandes, & MacLeod, 2008). Furthermore, in experimental studies an age-related decrease in memory for negative information has been observed (e.g. Grühn et al., 2007; Grühn et al., 2005). This age-related decrease in processing of negative information could therefore be integrated in the definition of the positivity effect. The positivity effect may then be defined as *a trend for adults to increasingly process positive compared to negative information and/or decreasingly process negative compared to positive information with advancing age*. From this definition, it follows that there are three patterns of biases that could make up a positivity effect: 1) younger adults show no bias and older adults show a positivity bias (see Figure 1a), 2) younger adults show a negativity bias and older adults show no bias (see Figure 1b), and 3) younger adults show a negativity bias and older adults show a positivity bias (see Figure 1c).

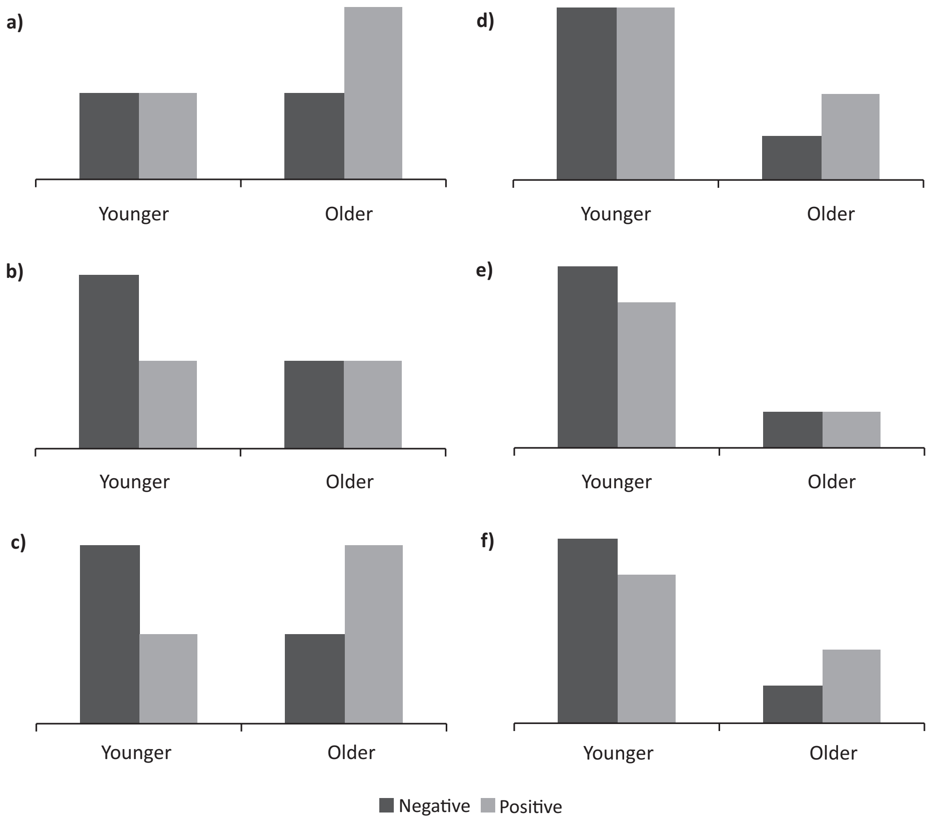

Figure 1. Prototypical examples of positivity effects that are made up by different patterns of biases in younger and older adults.

Analyzing the positivity effect

From the proposed definition it follows which statistical comparisons are needed when examining the positivity effect. When studying the positivity effect in a cross-sectional design, one at least needs to test two age groups using a task with negative and positive conditions. The analysis of variance (ANOVA) will then have two factors with two levels each: the factor Valence (negative, positive) and the factor Age group (younger, older). Optionally, a neutral condition and/or a group of middle-aged adults (e.g. Charles et al., 2003) could be included, leading to three levels per factor.

A positivity effect could be present when the Valence x Age group interaction is significant. Such a significant interaction implies that the effect of Valence differs per level of the factor Age group and/or that the effect of Age group differs per level of the factor Valence. If additional factors are included in the analysis and three- or higher-order interactions are significant, then the significance of the two-way Valence x Age group interaction should be assessed per level of the other factor(s) separately (e.g. Emery & Hess, 2008) in order to test whether a positivity effect is present.

In the case of a significant Valence x Age group interaction, two types of comparisons could be performed to identify the underlying pattern of the interaction. To start with, the valence differences within each age group could be tested by analyzing simple valence effects, for example by means of paired samples *t*-tests, within each age group. By directly testing whether any difference between negative and positive stimuli is significant, it could be determined what type of bias (positivity bias, negativity bias, or no bias) occurred in each age group. If the observed pattern of biases reflects any of the three above mentioned patterns (see Figure 1), it can be concluded that a positivity effect occurred. So, it is this type of comparison that is necessary to assess the occurrence of a positivity effect.

Besides testing valence differences within each age group, the age differences within each valence condition could be tested as well by analyzing simple age group effects, for example by means of independent samples *t*-tests, within each valence. In this way, it could be determined whether there is an age-related increase in processing of positive information and/or an age-related decrease in processing of negative information.

In most cases, both types of simple effects should be analyzed only when the Valence x Age group interaction is significant, or at least nearly significant. Reporting these comparisons under the guise of exploratory analysis in the absence of a significant Valence x Age group interaction (e.g. Leigland, Schulz, & Janowsky, 2004; Spaniol, Voss, & Grady, 2008) will greatly increase the chance of a type I errors (Stevens, 2002) and will lead to an overestimation of the cases in which a positivity effect is present. In some cases, with an appropriate design and clear directional hypotheses, planned comparisons could in principle be conducted without the need for a significant Valence x Age group interaction, but then the data would have to be interpreted with caution because of the increased chance of a Type I error.

In a situation in which the general task performance is rather similar in younger and older adults, it is very well possible that the valence differences within each age group are significant, whereas none of the age differences within each valence condition would be. Consider, for example, the situation depicted in Figure 1c, where the valence differences within each age group are of similar magnitude as the age differences within each valence condition. Because within-subject comparisons typically have more power than between-subject comparisons, the latter may not reach significance when the former would. In that case, it would be unclear whether any observed positivity effect is due to an age-related increase in processing of positive information or an age-related decrease in processing of negative information.

In addition, in a situation in which task performance in general differs greatly between younger and older adults, the analysis of age differences within each valence condition may not yield novel information. Consider, for example, the situations depicted in Figure 1d-f. Assuming that the valence differences within each age group are significant, it could be that the age differences within each of the valence conditions, which are numerically greater, are significant as well. This would lead to the conclusion that there was an age-related decline in the processing of both negative and positive information. However, even if an age-related decrease is found in processing of positive information, there could still be a positivity effect if this decrease was smaller than the age-related decrease in processing of negative information. This can be determined by establishing age differences in bias patterns, as outlined above.

Proportional scores can be computed as the number of negative or positive items remembered divided by the total number of items remembered, and can thus be used to nullify age differences in task performance in general (e.g. Mather & Knight, 2005). However, the use of proportional scores also eliminates the possibility to identify any age-related increase in processing of positive information or decrease in processing of negative information. Therefore, the use of raw scores is recommended instead (see also Uttl & Graf, 2006).

Literature review

A literature review was conducted to examine whether the positivity effect has consistently been observed in previous studies on emotional long-term memory. To be included in this review, a study had to meet a few criteria. First, at least a group of young adult participants (age < 35 yrs) and a group of healthy older participants (age > 60 yrs) should have been tested. Second, participants should have been presented with both negative and positive stimuli, and third, participants should have completed a memory test for the content of the presented stimuli. These criteria led to the exclusion of studies concerning autobiographical memory (e.g. Schlagman, Schulz, & Kvavilashvili, 2006). The reviewed studies are summarized in Table 1, listing the composition of the participant sample, the type of stimuli (e.g. words, pictures, faces), the type of encoding (incidental, intentional), and the memory measure (free recall, cued recall, discrimination, response bias, etc.). If a condition with neutral stimuli was used, this condition is included in the study summary in Table 1. Therefore, negative stimuli are denoted with the letter U (referring to unpleasant), neutral stimuli with the letter N, and positive stimuli with the letter P.

Table 1. Review of studies examining age differences in emotional long-term memory.

Study	Participants (n)	Stimuli	Encoding	Measure	Valence x Age group interaction	Post hoc comparisons	Negativity bias	Positivity bias	No bias	Positivity effect
Charles et al. (2003), study 1	Y (48): 18-29 yrs M (48): 41-53 yrs O (48): 65-80 yrs	pictures	incidental	free recall	significant, $p < .001$	no statistical comparisons Y: U = P > N M & O: P > U > N		 M & O	 Y	 ●
				study-test recognition (discrimination)	significant, $p < .05$	*p*-values not reported Y: U > P = N M & O: U = P = N	 Y		 M & O	 ●
				study-test recognition (bias)	not significant, $p > .13$	*p*-values not reported U = P > N			 Y, M & O	
Charles et al. (2003), study 2	Y (32): 19-30 yrs O (32): 63-86 yrs	pictures	incidental	free recall	significant, $p < .001$	*p*-values not reported Y: U > P > N O: U = P > N	 Y		 O	 ●
				study-test recognition (discrimination)	significant, $p < .05$	*p*-values not reported Y: U > P = N O: U = P = N	 Y		 O	 ●
				study-test recognition (bias)	not significant, $p > .70$	*p*-values not reported U > P = N	 Y & O			
Comblain et al. (2004)	Y (20): 18-25 yrs O (20): 60-70 yrs	pictures	incidental	study-test recognition (discrimination)	not significant, $p > .05$	U > P = N	Y & O			
				study-test recognition (bias)	not significant, $p > .05$	U = P > N			Y & O	
D'Argembeau & Van der Linden (2004)	Y (32): 20-25 yrs O (32): 60-70 yrs	faces	intentional	study-test recognition (discrimination)	not explicitly reported	no comparisons				
				study-test recognition (bias)	not explicitly reported	no comparisons				

Study	Participants (n)	Stimuli	Encoding	Measure	Valence x Age group interaction	Post hoc comparisons	Negativity bias	Positivity bias	No bias	Positivity effect
Ebner & Johnson (2009)	Y (32): 18-22 yrs O (24): 65-84 yrs	faces	not specified	study-test recognition (discrimination)	not explicitly reported	Y: U = P O: P > U		O	Y	○
Emery & Hess (2008), study 1	Y (59): 18.5 yrs O (58): 74.1 yrs	pictures	incidental	free recall	trend, $p = .08$	Y: U > P > N O: U = P > N	Y		O	●
				study-test recognition (discrimination)	significant, $p < .001$	Y: U = P = N O: N > U (P ns.)			Y & O	
Emery & Hess (2008), study 2	Y (46): 20.7 yrs O (51): 72.7 yrs	pictures	incidental	free recall	not significant, $p > .10$	U = P > N			Y & O	
				study-test recognition (discrimination)	not significant, $p > .10$	N > U (P ns.)			Y & O	
Fernandes et al. (2008)	Y (49): 17-29 yrs O (48): 60-84 yrs	pictures	incidental	free recall (hits)	not significant, $p > .30$	Y: U = P > N O: P > U > N		O	Y	○
				free recall (false alarms)	not significant, p not reported	N > P > U		Y & O		
		words	incidental	free recall (hits)	not significant, p not reported	U > N (P ns.)			Y & O	
				free recall (false alarms)	significant, $p < .05$	Y: U = P = N O: P > U = N		O	Y	●
Grady et al. (2007)	Y (40): 18-29 yrs O (40): 60-81 yrs	faces	incidental	study-test recognition (discrimination)	not explicitly reported	only Helmert contrasts Y: U > N> P O: U = N > P	Y & O			
Grühn et al. (2005)	Y (72): 18-31 yrs O (72): 64-75 yrs	words	intentional	free recall (heterogeneous list)	not significant, $p > .12$	U > P = N	Y & O			
				free recall (homogenous list)	not significant, $p > .36$	P > N (U ns.)			Y & O	

Study	Participants (n)	Stimuli	Encoding	Measure	Valence x Age group interaction	Post hoc comparisons	Negativity bias	Positivity bias	No bias	Positivity effect
Grühn et al. (2007)	Y (48): 18-31 yrs O (48): 63-77 yrs	pictures	not specified	study-test recognition (discrimination)	significant, $p < .01$	unclear statistical comparisons				●
						Y: U > N = P	Y			
						O: N > U (P ns.)			O	
Kapucu et al. (2008)	Y (22): 19.6 yrs O (23): 71.9 yrs	words	intentional	study-test recognition (hits)	not significant, $p > .18$	U > P > N	Y & O			
				study-test recognition (false alarms)	significant, $p < .05$	no statistical comparisons				●
						Y: U > P = N	Y			
						O: U = P > N			O	
				study-test recognition (discrimination)	not explicitly reported	no statistical comparisons U = P = N			Y & O	
				study-test recognition (bias)	not explicitly reported	no statistical comparisons U > P > N	Y & O			
Kensinger (2008), study 1	Y (30): 18-35 yrs O (30): 64-80 yrs	words	intentional	free recall	significant, $p < .01$	arousing words U = P > N			Y & O	
						nonarousing words				●
						Y: U > P > N	Y			
						O: P > U = N		O		
Kensinger (2008), study 2	Y (30): 18-35 yrs O (30): 64-78 yrs	words	incidental	study-test recognition (discrimination)	significant, $p < .05$	arousing words U = P > N			Y & O	
						nonarousing words				●
						Y: U > P > N	Y			
						O: P > U = N		O		

Study	Participants (n)	Stimuli	Encoding	Measure	Valence x Age group interaction	Post hoc comparisons	Negativity bias	Positivity bias	No bias	Positivity effect
Kensinger et al. (2002)	Y (20): 20.5 yrs O (20): 73.3 yrs	pictures	not specified	free recall	not significant, $p > .40$	U = P > N			Y & O	
		words	not specified	free recall	not significant, $p > .50$	U = P > N			Y & O	
Kensinger & Schacter (2008)	Y (17): 19-31 yrs O (20): 62-79 yrs	pictures	incidental	study-test recognition (general recognition)	significant, $p < .01$	no statistical comparisons Y: U > P = N O: U = P > N	 Y 		 O	●
				study-test recognition (specific recognition)	not significant	no statistical comparisons U > P = N	 Y & O			
				study-test recognition (nonspecific recognition)	significant, $p < .01$	no comparisons reported				
Langeslag & Van Strien (2008)	Y (20): 17-27 yrs O (20): 63-77 yrs	pictures	intentional	continuous recognition (discrimination)	not explicitly reported	U = P = N			Y & O	
				continuous recognition (bias)	not explicitly reported	U > N (P ns.)			Y & O	
				free recall	significant, $p < .003$	Y: U = P > N O: P > N (U ns.)			Y & O	
Langeslag & Van Strien (2009)	Y (19): 19-26 yrs O (19): 65-82 yrs	pictures	intentional	free recall	significant, $p < .03$	Y : U > P > N O: U = P > N	Y		 O	●
				cued recall	significant, $p < .002$	Y: U = P > N O: N > U (P ns.)			Y & O	

Study	Participants (n)	Stimuli	Encoding	Measure	Valence x Age group interaction	Post hoc comparisons	Negativity bias	Positivity bias	No bias	Positivity effect
Leigland et al. (2004)	Y (25): 18-35 yrs O (36): 63-81 yrs	words	incidental	free recall (short delay)	not significant, $p > .50$	U = P = N			Y & O	
				free recall (longer delay)	not significant, $p > .50$	P > U = N		Y & O		
				study-test recognition (hits)	significant, $p < .001$	Y: U = P > N O: P > U > N		O	Y	●
		faces	incidental	study-test recognition (hits)	not significant, $p > .10$	N = P > U		Y & O		
Mather & Carstensen (2003), study 1	Y (52): 18-35 yrs O (52): 62-94 yrs	faces	not specified	study-test recognition (discrimination)	not explicitly reported	Y: U = P O: P > U		O	Y	◐
Mather & Carstensen (2003), study 2	Y (52): 18-35 yrs O (52): 60-81 yrs	faces	not specified	forced-choice recognition	not explicitly reported	Y: U = P O: P > U		O	Y	◐
Mather & Knight (2005), study 1	Y (48): 18-29 yrs O (48): 65-83 yrs	pictures	incidental	free recall (short delay) (proportions)	not explicitly reported	no tests of within-subject valence differences, no statistical comparisons U: Y > O P: O > Y				
				free recall (longer delay) (proportions)	significant, $p < .05$	no tests of within-subject valence differences, no statistical comparisons U: Y > O P: O > Y				

Study	Participants (n)	Stimuli	Encoding	Measure	Valence x Age group interaction	Post hoc comparisons	Negativity bias	Positivity bias	No bias	Positivity effect
Mather & Knight (2005), study 2	Y (25): 18-28 yrs O (31): 65-85 yrs	pictures	incidental	free recall (proportions)	significant, $p < .05$	no tests of within-subject valence differences, no statistical comparisons U: Y > O P: O > Y				
Mather & Knight (2005), study 3	Y (32): 18-39 yrs O (32): 64-84 yrs	pictures	incidental	free recall (proportions)	not explicitly reported	no tests of within-subject valence differences, no statistical comparisons U: Y > O P: O > Y				
Mickley & Kensinger (2009), study 1	Y (26): 19.2 yrs O (26): 78.2 yrs	pictures	incidental	study-test recognition (discrimination)	arousing pictures not significant, $p > .25$	U = P			Y & O	
					nonarousing pictures significant, $p < .05$	Y: P > U O: U = P		Y	 O	
Mickley & Kensinger (2009), study 2	Y (25): 19.6 yrs O (24): 75.6 yrs	pictures	incidental	study-test recognition (discrimination)	arousing pictures significant, $p < .01$	incomplete statistical comparisons Y: U = P O: U > P	 O		Y	
					nonarousing pictures significant, $p < .05$	incomplete statistical comparisons Y: U = P O: U > P	 O		Y	

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Study	Participants (n)	Stimuli	Encoding	Measure	Valence x Age group interaction	Post hoc comparisons	Negativity bias	Positivity bias	No bias	Positivity effect
Spaniol et al. (2008), study 1	Y (24): 19-28 yrs O (24): 60-75 yrs	faces	incidental	study-test recognition (discrimination)	not significant, *p* not reported	U > N > P	Y & O			
				study-test recognition (bias)	not significant, *p* > .32	U = P > N			Y & O	
		pictures	incidental	study-test recognition (discrimination)	not significant, *p* not reported	U > N = P	Y & O			
				study-test recognition (bias)	not significant, *p* > .32	U = P > N			Y & O	
		words	incidental	study-test recognition (discrimination)	not significant, *p* not reported	U = P = N			Y & O	
				study-test recognition (bias)	not significant, *p* > .32	U = P > N			Y & O	
Spaniol et al. (2008), study 2	Y (25): 18-32 yrs O (24): 61-85 yrs	pictures	incidental	study-test recognition (discrimination)	not explicitly reported	U > P = N	Y & O			
				study-test recognition (bias)	not significant, *p* > .60	U = P = N			Y & O	
Thapar & Rouder (2009)	Y (30): 18-22 yrs O (30): 60-76 yrs	words	intentional	forced-choice recognition (discrimination)	not reported	no statistical comparisons U = P = N			Y & O	
				forced-choice recognition (bias)	not reported	no statistical comparisons Y: U > P > N O: P > U > N	Y	O		●
Thomas & Hasher (2006)	Y (48): 18-28 yrs O (48): 60-75 yrs	words	incidental	study-test recognition (discrimination)	significant, *p* not reported	Y: U > P (N ns.) O: P > U = N	Y	O		●

Study	Participants (n)	Stimuli	Encoding	Measure	Valence x Age group interaction	Post hoc comparisons	Negativity bias	Positivity bias	No bias	Positivity effect
Tomaszczyk et al. (2008)	Y (72): 18-25 yrs O (72): 61-93 yrs	pictures	incidental	free recall	significant, *p* < .01	Y: U > P > N O: P > U > N	Y	O		●
				study-test recognition (accuracy)	not significant, *p* > .10	P = N > U		Y & O		
Waring & Kensinger (2009)	Y (24): 19.6 yrs O (24): 72.8 yrs	pictures	incidental	study-test recognition (short delay) (discrimination)	not explicitly reported	U = P > N			Y & O	
				study-test recognition (longer delay) (discrimination)	not significant, *p* > .12	U > P > N	Y & O			

Note. Y = younger adults, M = middle-aged adults, O = older adults, higher discrimination signals better performance, higher bias signals more liberal response bias, U = negative, P = positive, N = neutral, ns. = non-significantly different in-between.

The significance of the Valence x Age group interaction and the results of follow-up comparisons are included in the table. If the appropriate follow-up analyses were conducted, the presence of negativity and positivity biases in either age group was established. When the observed pattern matched one of the three patterns that result in a positivity effect, this is indicated by a dot in the most right column of the table. In some studies, post hoc comparisons were conducted without explicit report of the significance of the Valence x Age group interaction (e.g. Ebner & Johnson, 2009; Grady et al., 2007; Mather & Carstensen, 2003; Mather & Knight, 2005) and in some other studies post hoc comparisons were performed when the Valence x Age group interaction was not (nearly) significant (e.g. Fernandes et al., 2008). In addition, in some studies post hoc comparisons were merely non-statistical descriptions of the data instead of statistical comparisons (e.g. Charles et al., 2003; Kapucu, Rotello, Ready, & Seidl, 2008; Kensinger & Schacter, 2008; Thapar & Rouder, 2009) or were not the required within-subject valence comparisons (e.g. Grady et al., 2007; Grühn et al., 2007; Mather & Knight, 2005). Because in these cases the data should be interpreted with caution, the data reported in the original article are indicated in grey.

It can be seen in Table 1 that only in approximately 30% of the memory tests (20 out of 70) a positivity effect was observed, and that in about half of those cases (9 out of 20) the data have to be interpreted with caution for reasons outlined above. The question rises as to how the studies that do and do not show a positivity effect differ from each other. From Table 1, no clear differences between these studies emerge. Positivity effects have occurred under both incidental and intentional encoding conditions, and with all different stimulus types (words, pictures, faces), suggesting that these factors do not influence the occurrence of a positivity effect. Moreover, positivity effects have been observed in both true as well as false memory measures such as false alarms or response bias. The conclusion that follows from the current literature review is that the positivity effect in long-term memory occurs less consistently than is sometimes suggested (e.g. Mather, 2006; Mather & Carstensen, 2005; Xing & Isaacowitz, 2006).

Some preconditions for the occurrence of a positivity effect have been identified prior studies. It has been suggested that a positivity effect only occurs when goal-directed, top-down processing is involved (Mather & Carstensen, 2005). In line with this suggestion, a positivity effect was observed only in participants who scored high on tasks involving cognitive control (Mather & Knight, 2005). However, in other studies in which multiple memory tests were completed by the same sample of participants, a positivity effect occurred only in a subset of the memory tests (e.g. Emery & Hess, 2008; Fernandes et al., 2008; Leigland et al., 2004; Tomaszczyk et al., 2008). This implies that, in addition to participant characteristics, task characteristics other than stimulus type and type of encoding might influence the occurrence of a positivity effect. It has, for example, been proposed that a positivity effect only occurred when attention was not divided among multiple tasks (Mather & Knight, 2005), when stimuli that were low in personal relevance were used (Tomaszczyk et al., 2008), and when stimuli that were low in arousal were used (Kensinger, 2008), although this latter finding was not replicated in a later study (Mickley & Kensinger, 2009).

Future directions

Although the positivity effect has been studied frequently, there still are many open questions. If future studies are to be comparable, it is important that there is consensus on the definition and assessment of the positivity effect. Although some preconditions for the occurrence of a positivity effect have been identified in previous research, more research is needed to replicate those findings and to identify potential other preconditions. Furthermore, we need to get a better understanding of the differences and similarities between the three different patterns of biases that can underlie a positivity effect.

This review has focused on the long-term memory domain, but it is important to examine whether the positivity effect generalizes to other domains. The definition contains the verb 'process', thereby leaving the possibility for generalization open to any domain. The question rises, for example, whether a positivity effect also occurs in emotional short-term memory tests. In the one study that concerned age differences in short-term memory, younger and older adults viewed unpleasant and pleasant pictures and were instructed to memorize the feeling that a picture elicited. A positivity effect was observed, as older adults showed superior memory for pleasant versus unpleasant feelings (i.e. a positivity bias), while younger adults showed the opposite pattern (i.e. a negativity bias) (Mikels, Larkin, Reuter-Lorenz, & Carstensen, 2005). However, because this study tested short-term memory for feeling rather than stimulus content, it does unfortunately not provide knowledge of age differences in short-term memory that is analogues to our knowledge of age differences in long-term memory. More research is definitely needed to examine age differences in emotional short-term memory.

It has further been proposed that a positivity effect occurs in attention as well (Mather & Carstensen, 2005). But because negative and positive stimuli are often not directly compared in the attention tests, such as attentional blink, dot probe or eye tracking tasks (see e.g. Isaacowitz, Wadlinger, Goren, & Wilson, 2006a, 2006b; Knight et al., 2007; Langley et al., 2008; Mather & Carstensen, 2003), the occurrence of a positivity effect can often not be established (Murphy & Isaacowitz, 2008). In those kinds of attention tests, negative and positive stimuli are usually compared against neutral stimuli, and it has been suggested to speak of *positivity* and *negativity preferences* to describe attention for positive and negative compared to neutral stimuli respectively. In a meta-analysis of attention studies using several methodologies, age differences in these preferences appeared uncommon (Murphy & Isaacowitz, 2008). It would be interesting to try to devise attention tests that do allow direct comparison between negative and positive stimuli (e.g. Charles et al., 2003; Knight et al., 2007), to examine the presence of a positivity effect in attention.

Age differences in emotional processing have also been investigated with neuroimaging techniques such as functional Magnetic Resonance Imaging (fMRI), and positivity effects have been observed. In an fMRI study in which younger and older adults viewed negative, positive and neutral objects, brain regions in the left frontal and parietal lobes showed a positivity effect. Although formal post hoc comparisons were not reported, these brain regions appeared to show more activity in response to negative than positive objects (i.e. a negativity bias) in younger adults, and more activity in response to positive than negative objects (i.e. a positivity bias) in older adults (Leclerc & Kensinger, 2008a). In another fMRI study, younger and older adults were presented with unpleasant, pleasant and neutral pictures, and a positivity effect was observed in the amygdala. The amygdala was equally active for unpleasant and pleasant pictures (i.e. no bias) in younger adults, and was more active in response to pleasant than to unpleasant pictures (i.e. a positivity bias) in older adults (Mather et al., 2004). Also in the event-related potential (ERP), in the Late Positive Potential (LPP) in particular, positivity effects have been observed. Wood and Kisley (2006) have found that the amplitude of the LPP was larger for unpleasant than pleasant pictures (i.e. a negativity bias) in younger adults but equally large for unpleasant and pleasant pictures (i.e. no bias) in older adults. In a subsequent study, regression analysis revealed that the positivity effect in the LPP amplitude resulted from an age-related decrease in the processing of negative information, and not from an increase in the processing of positive information (Kisley, Wood, & Burrows, 2007), supporting the integration of age-related decrease in the processing of negative information into the definition of the positivity effect.

These neurophysiological studies suggest that the behavioral positivity effect may have its origin in age differences in the neural response to emotional stimuli. However, in the above-mentioned studies participants did not perform a behavioral test, leaving the relationship between neurophysiological and behavioral positivity effects unidentified. In another study, positivity effects were observed in both the LPP, obtained during encoding, and in subsequent memory performance (Langeslag & Van Strien, 2009), showing that behavioral and neurophysiological positivity effects co-occur. The relationship between neurophysiological and behavioral positivity effects could be further specified in future studies.

Conclusions

Different definitions of the positivity effect appear to be in use. However, if our goal is a better understanding of age-related changes in emotional processing, we need to reach consensus on how to define the effect under study. Here, we propose that the positivity effect can be defined as *a trend for adults to increasingly process positive compared to negative information and/ or decreasingly process negative compared to positive information with advancing age*. From this definition it follows that testing the Valence x Age group interaction, if (nearly) significant followed by within-subject valence comparisons, is a prerequisite for establishing whether a positivity effect is present. A review of the literature on emotional long-term memory revealed that a positivity effect was observed in 30% of the studies, at the most. This suggests that the positivity effect is not a robust finding, but that its occurrence may heavily depend on task characteristics. Identifying the preconditions for the positivity effect requires more research. Future research may lead to a further sharpening of the definition and could determine the functional difference of the three possible patterns of biases that may underlie the positivity effect. Likewise, it remains an open question whether a positivity effect might also occur in emotional short-term memory and attention. Finally, the relation between positivity effects in brain and behavior could be further explored.

Chapter 3

Aging and emotional memory: The co-occurrence of neurophysiological and behavioral positivity effects

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Do memories get more pleasant when we grow older? An event-related potential (ERP) study investigating the subsequent memory effect for emotional pictures in young and older adults [Poster]. NWO Autumn School "Active Memory", Doorwerth, The Netherlands.

Abstract

The positivity effect is a trend for adults to increasingly process positive and/or decreasingly process negative information compared with other information with advancing age. The positivity effect has been observed with behavioral measures, such as in attention and memory tests, and with measures of neurophysiological activity, such as in amygdala activation and the Late Positive Potential (LPP). In this study, it was investigated whether these behavioral and neurophysiological positivity effects co-occur. The electroencephalogram of younger (19-26 years) and older (65-82 years) adults was recorded while they encoded unpleasant, neutral, and pleasant pictures for retrieval in free and cued recall tests. Positivity effects occurred in the late LPP amplitude (700-1,000 ms) and in the free recall test, with negativity biases in younger adults and no biases in older adults. The occurrence of a valence bias in the LPP was substantially but nonsignificantly correlated with the occurrence of a similar valence bias in memory in the older adults. In conclusion, neurophysiological and behavioral positivity effects appear to co-occur, a finding that awaits expansion using different neurophysiological and behavioral measures.

Introduction

Older adults feel better, attend more to positive information, and remember relatively more positive information than younger adults do (Mather & Carstensen, 2005). This "developmental trend for adults to increasingly (…) process positive information more than they do negative information as they grow older" (Löckenhoff & Carstensen, 2007, pp. 135) has been called the *positivity effect*. Interesting to note, neuroimaging studies employing Event-Related Potential (ERP) or functional MRI (fMRI) techniques have demonstrated a positivity effect for neurophysiological activation elicited by emotional stimuli (Kisley, Wood, & Burrows, 2007; Mather et al., 2004; Wood & Kisley, 2006). To our knowledge however, the co-occurrence of behavioral and neurophysiological positivity effects has not been investigated yet.

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To avoid terminological confusion, it is important to note that the definition of the positivity effect as given earlier, describes a life span change. The positivity effect must not be confused with the *positivity bias* (Löckenhoff & Carstensen, 2007), which refers to an absolute increased processing of positive compared with negative information. A *negativity bias*, on the other hand, refers to an absolute increased processing of negative compared with positive information. And a *negativity effect* would imply that people would process negative information more than they do positive information as they grow older. Thus, while positivity or negativity biases can be observed within age groups, positivity or negativity effects can only be observed when comparing younger and older adults. Thus, there are three patterns of biases that result in a positivity effect: (1) younger adults show no bias and older adults show a positivity bias, (2) younger adults show a negativity bias and older adults show no bias, and (3) younger adults show a negativity bias and older adults show a positivity bias.

Behaviorally, positivity effects have been observed in mood, attention and memory (see Mather & Carstensen, 2005, for a review). In dot-probe tests and eye-tracking studies, older adults tended to exhibit attentional biases away from negative stimuli and towards positive stimuli, while younger adults did not exhibit such biases (Isaacowitz, Wadlinger, Goren, & Wilson, 2006a, 2006b; Mather & Carstensen, 2003). Positivity effects have also been observed in memory studies, with all of the earlier mentioned patterns of biases being found to make up the positivity effect in memory (e.g. Charles, Mather, & Carstensen, 2003; Emery & Hess, 2008; Kensinger, 2008; Leigland, Schulz, & Janowsky, 2004; Thomas & Hasher, 2006). Several other studies, however, could not demonstrate a positivity effect in memory (e.g., Comblain, D'Argembeau, Van der Linden, & Aldenhoff, 2004; Denburg, Buchanan, Tranel, & Adolphs, 2003; Grühn, Smith, & Baltes, 2005; Kensinger, Brierley, Medford, Growdon, & Corkin, 2002).

In an fMRI study by Mather et al. (2004), a positivity effect has been observed in amygdala activation in response to emotional pictures. The younger adults' amygdala was equally active in response to pleasant and unpleasant pictures, whereas the older adults' amygdala was more active in response to pleasant than unpleasant pictures. In other words, the younger adults did not show a bias, while the older adults showed a positivity bias. In two ERP studies, age differences in the processing of negative and positive information have been examined using the Late Positive Potential (LPP). The LPP is a positive deflection in the waveform that appears from 400 ms after stimulus onset and is maximal at centro-parietal sites. In younger adults, the LPP is usually enhanced for emotional compared with neutral stimuli (see Schupp, Flaish, Stockburger, & Junghöfer, 2006, for a review). In some studies with younger participants, the LPP showed a negativity bias, being particularly enhanced for negative stimuli (Huang & Luo, 2006; Ito & Cacioppo, 2000; Ito, Larsen, Smith, & Cacioppo, 1998; Schupp, Öhman et al., 2004). In an ERP study with younger and older participants, Wood and Kisley (2006) have found that the LPP was larger for unpleasant than pleasant pictures in younger adults but equally large for unpleasant and pleasant pictures in older adults. In another ERP study by Kisley et al. (2007) regression analysis revealed that the positivity effect in the LPP amplitude resulted from an age-related decrease in the processing of negative information, and not from an increase in the processing of positive information. In these three studies of the neurophysiological positivity effect, the participants performed an arousal or valence categorization task while their brain activation was measured. However, none of these studies included a test that could reveal a behavioral positivity effect.

In the present study, we investigated whether the positivity effect in LPP amplitude is accompanied by a behavioral positivity effect. We employed a visual memory test in which emotional pictures were presented one at a time. This allowed us to measure the neurophysiological activation in response to the pictures as well as the participants' memory performance. We expected that positivity effects would occur in both the LPP amplitude and in memory performance. More specifically, we hypothesized that the younger adults would show a negativity bias in their LPP amplitude and that the older adults would show no bias in their LPP amplitude (cf. Kisley et al., 2007; Wood & Kisley, 2006). Because the LPP has been associated with the encoding of information into memory (Olofsson, Nordin, Sequeira, & Polich, 2008), we further hypothesized that the same pattern of biases would occur in memory performance.

Method

Participants

Nineteen younger (mean age = 21.2 years; age range = 19-26 years; 9 men) and 19 older (mean age = 71.3 years; age range = 65-82 years; 10 men) participants provided useable data. All participants were right-handed as determined by a hand preference questionnaire (Van Strien, 1992) and not depressed as determined by the Beck Depression Inventory (BDI; Beck, Ward, Mendelson, Mock, & Erbaugh, 1961; Lasa, Ayusi-Mateos, Vázquez-Barquero, Díez-Manrique, & Dowrick, 2000) or the Geriatric Depression Scale (GDS; Yesavage et al., 1983). Younger participants were included if they scored less than 13 on the BDI, and older adults if they scored less than 11 on the GDS. The Mini Mental State Exam (MMSE) was used to screen for dementia, and all older participants had a score of at least 27 (Derix et al., 2003; Folstein, Folstein, & McHugh, 1975). All participants reported to be in good neurological and psychiatric health and did not use centrally active drugs. Participants had normal or corrected-to-normal vision. The older adults had fewer years of formal education than the younger adults (see Table 1). The participants were rewarded with course credit or 20 Euros. The study was approved by the local ethics committee and the participants gave written informed consent prior to testing.

Table 1. Education and affect in each age group and the *p*-values associated with the difference between the age groups.

	Younger		Older		*p*-values
	Mean	**Range**	**Mean**	**Range**	
Education	7.0	7	6.0	3-8	**.015**
Positive Affect (past two weeks)	38.0	31-47	34.0	22-45	.056
Negative Affect (past two weeks)	15.0	10-29	14.2	10-24	.562
Positive Affect (at this moment)	31.4	18-46	33.1	22-42	.415
Negative Affect (at this moment)	11.5	10-24	10.7	10-13	.321

Note. Education ranged from 1 (primary education) to 8 (master's degree) (De Bie, 1987). Significant *p*-values are presented in bold.

Stimuli

The stimuli were 60 unpleasant, 60 neutral, and 60 pleasant pictures from the International Affective Picture System (IAPS) (Lang, Bradley, & Cuthbert, 2005). Because the memory tests involved writing down the pictures that were remembered, pictures that were sufficiently different and well describable were selected. The pictures were presented in three blocks of 60 stimuli (20 of each valence) in a pseudo random order, with the constraint that no more than two pictures of the same valence succeeded each other. To decrease primacy and recency effects, three neutral filler pictures were included at the beginning and end of each block. Three additional pictures were presented as practice trials.

Procedure

Upon arrival in the lab, the participants completed the informed consent and the Positive and Negative Affect Schedule (PANAS; past two weeks; Peeters et al., 1999; Watson, Clark, & Tellegen, 1988). Next, they were seated in a comfortable chair in a dimly-lit, sound-attenuated room where the electrode cap was attached. After a 1-minute baseline EEG recording (data not reported here), the participants completed the three blocks of the memory test, each of which consisted of an encoding and a test phase.

During the encoding phase, the participants viewed the pictures while their EEG was recorded. They were told that they would be viewing photographs of people, animals, objects and landscapes, so they were unaware that the valence of the pictures was relevant. Participants were instructed to remember the photographs in order to report them in two recall tests, hence encoding was intentional. The structure of each trial was as follows: fixation cross with variable duration (range = 1,000 – 1,350 ms), IAPS picture for 1,000 ms, fixation cross for 1,000 ms and a blank screen for 2,000 ms. The participants were instructed to limit movement and to blink during the blank screen only. In the test phase, the participants first completed an immediate free recall test that involved writing down a description in catchwords or short sentences of each remembered picture. Next, the participants received sheets with short descriptions (one to four words) of each presented stimulus for the cued recall test. When they could remember having seen a picture, they reported details such as age, gender, (skin) color, quantity of the objects on the pictures, position on the picture, or view point to demonstrate that they indeed remembered it. Both recall tests were self-paced.

After completion of the three blocks, the electrode cap was removed, and the participants completed another PANAS (at this moment). Finally, they rated the valence and arousal of each picture with a computerized version of the Self-Assessment Manikin (SAM; Lang, 1980).

EEG recording and signal processing

The EEG was recorded using a 64-channel amplifier and data acquisition software (ActiveTwo System, Biosemi, Amsterdam, the Netherlands). The Ag-AgCl Active electrodes were placed upon the scalp by means of a head cap (Biosemi), according to the 10-10 International System (American Clinical Neurophysiology Society, 2003). Vertical electro-oculogram and horizontal electro-oculogram were recorded by attaching electrodes (UltraFlat Active electrodes, BioSemi) above and below the left eye, and at the outer canthi of both eyes. Additional electrodes were attached to the left and right mastoids. An active electrode (CMS, common mode sense) and a passive electrode (DRL, driven right leg) were used to comprise a feedback loop for amplifier reference. All signals were digitized with a sampling rate of 512 Hz, a 24-bit A/D conversion, and a low pass filter of 134 Hz.

A maximum of two bad channels per participant were corrected using spherical spline interpolation in accordance with the guidelines of Picton et al. (2000). Offline, a mathematically linked mastoids reference was applied and the data were filtered using a 0.15- to 30-Hz band pass filter (phase shift-free Butterworth filters; 24 dB/octave slope). Data were segmented in epochs from 100 ms before stimulus onset until 1,250 ms after stimulus onset. Ocular artifact correction was performed according to the Gratton & Coles algorithm (Gratton, Coles, & Donchin, 1983) and the mean 100-ms prestimulus period was used for baseline correction. Artifact rejection criteria were minimum and maximum baseline-to-peak -75 to +75 µV, and a maximum allowed voltage skip (gradient) of 50 µV. Two participants (a younger man and an older woman) were excluded because of excessive artifacts, leaving the previously reported number of 38 participants. Epochs were classified according to picture valence; the mean percentage of accepted trials per valence category was 79%, that is 47.3 (SD = 10.1) trials. The percentage of rejected trials was similar across valences, $F(2,74) < 1.0$, *ns*.

Analyses

The participants' descriptions of the pictures in the free and cued recall tests were scored by two independent raters that deliberated about any initial disagreements and reached consensus in all cases. Only those descriptions that allowed sufficient identification of and discrimination between the pictures were scored as remembered. The behavioral data (i.e., the ratings, memory performance and questionnaire scores) were tested with one-way or repeated measures ANOVAs with the factors Valence (unpleasant, neutral, pleasant) and/or Age group (younger, older).

Although the two previous studies regarding the positivity effect in the LPP amplitude performed peak detection, the LPP elicited in the current study appeared to be a positive slow wave occurring between 400 and 1,000 ms after stimulus onset instead of a clear peak, see Figure 1. Moreover, visual inspection of the data suggested that the effects of valence on LPP amplitude were different in the early and the late portion of the LPP, see Figure 1 (electrode Pz for the younger adults and electrode Cz for the older adults). Therefore, the ERP waveforms were quantified by mean amplitude measures in two time windows: 400 to 700 ms and 700 to 1,000 ms, corresponding with the early and late LPP respectively (cf. Franken, Nijs, Muris, & Van Strien, 2007; Schupp, Cuthbert et al., 2004). Preliminary ANOVAs with factors Caudality (frontal, central, parietal), Laterality (left, midline, right), Valence, and Age group yielded no significant interactions of Valence and Laterality, indicating that emotion effects were not left or right lateralized, see Figure 2 (cf. Cuthbert, Schupp, Bradley, Birbaumer, & Lang, 2000; Schupp et al., 2000; Schupp, Cuthbert et al., 2004). Therefore, the effect of picture valence on the ERP was tested only at the three midline electrodes (cf. Ito & Cacioppo, 2000; Ito et al., 1998; Stormark, Nordby, & Hugdahl, 1995; Wood & Kisley, 2006), using ANOVAs with the factors Time window (400-700 ms, 700-1,000 ms), Electrode (Fz, Cz, Pz), Valence, and Age group. Only effects relevant for the research question (i.e. involving the factor Valence) were considered.

When applicable, degrees of freedom were corrected with the Greenhouse-Geisser correction. The *F* values, the uncorrected *df*s, the epsilon (ε) values and corrected probability levels are reported. Significant effects were clarified with paired-samples *t*-tests in the case of within age group comparisons, and independent-samples *t*-tests in the case of between age group comparisons. A two-sided significance level of 5% was selected except when testing the directional hypotheses formulated in the introduction (i.e. the comparisons between unpleasant and pleasant pictures in the younger adults), which were tested with a one-sided significance level of 5%.

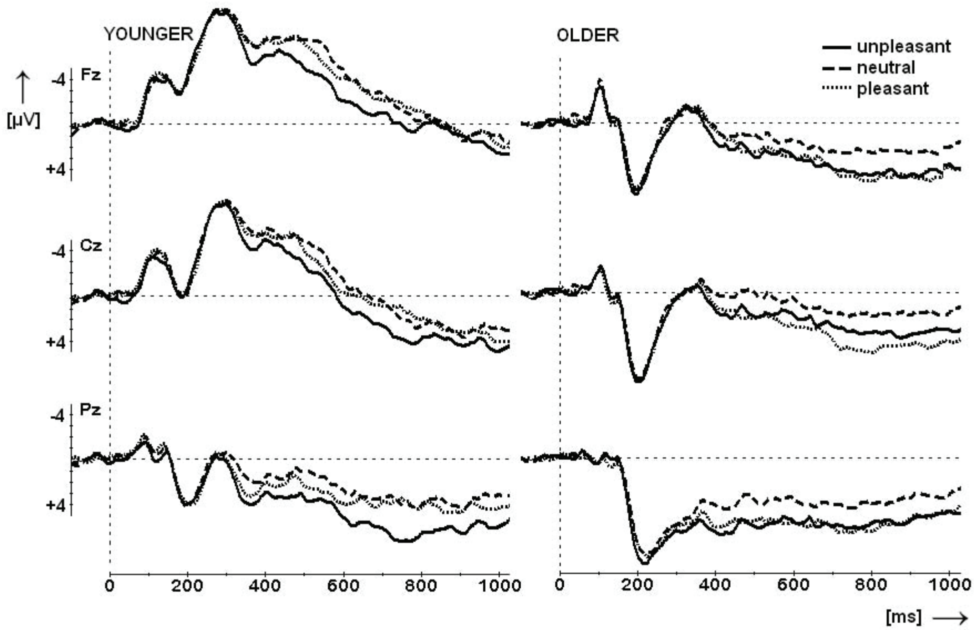

Figure 1. Grand-average ERPs at electrodes Fz, Cz and Pz for unpleasant (solid line), neutral (dashed line), and pleasant (dotted line) pictures, separately for the younger and older participants, positive down.

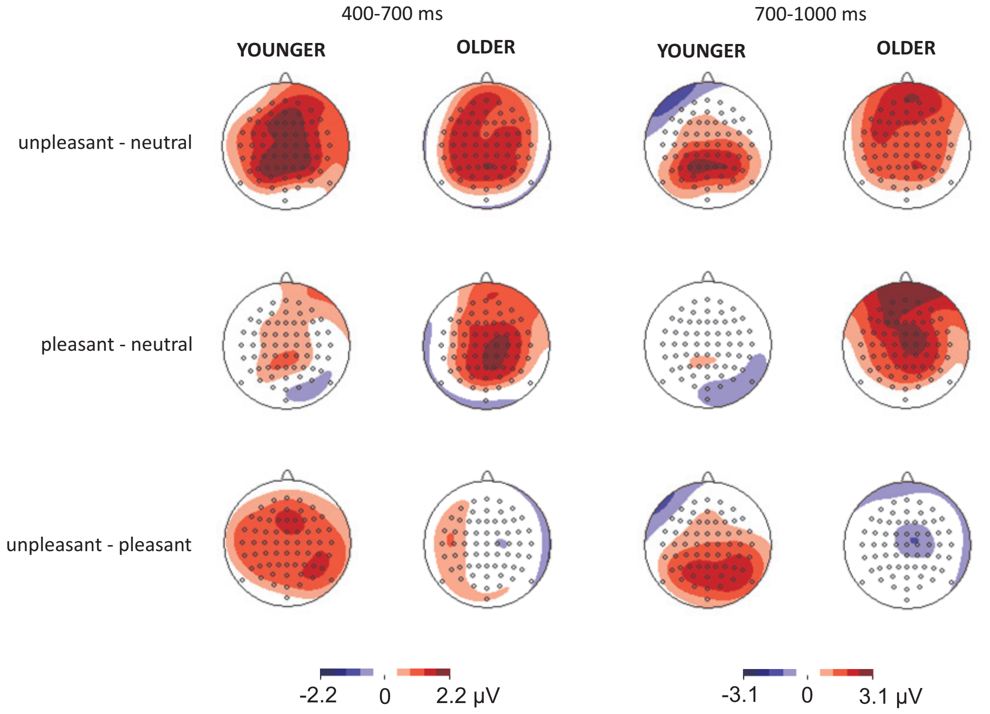

Figure 2. Voltage scalp topographies of the emotion effects, separately for the younger and older participants, for the time windows 400-700 ms and 700-1,000 ms.

Results

Valence and arousal ratings

Table 2 displays the valence and arousal of the pictures as rated by the participants. The ratings are shown collapsed across the age groups, because no age differences occurred, all *F*s < 2.4, all *p*s > .13. In line with the expectation, lowest valence was assigned to unpleasant pictures, intermediate valence to neutral pictures and highest valence to pleasant pictures, all *p*s < .001. Furthermore, arousal was highest for unpleasant pictures, intermediate for pleasant pictures and lowest for neutral pictures, all *p*s < .001.

3

Table 2. Mean valence and arousal ratings (SD in parentheses) of the pictures, collapsed across age groups.

	Unpleasant	Neutral	Pleasant
Valence	3.2 (0.9)	5.2 (0.6)	6.4 (0.9)
Arousal	4.9 (1.3)	3.3 (1.5)	3.7 (1.5)

Note. Valence and arousal ratings ranged from 1 (extremely unpleasant or calming) to 9 (extremely pleasant or arousing) (Lang, 1980).

Memory performance

The numbers of recalled pictures per valence in the free and cued recall tests are displayed in Figure 3.

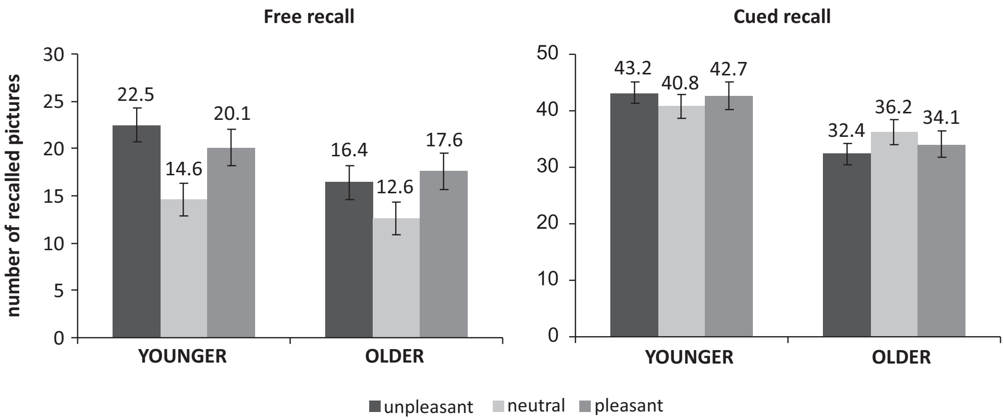

Figure 3. Number of recalled pictures per valence in the free and cued recall tests, separately for the younger and older participants, error bars depict standard errors of the mean.

Free recall

The younger participants remembered on average 57.2 pictures (range = 19-112) and the older participants 46.6 (range = 13-78), which was not significantly different as apparent from the absence of a main effect of Age group, $F(1,36) = 2.2$, $p = .15$. A main effect of Valence was found, $F(2,72) = 32.8$, $\varepsilon = .94$, $p < .001$, in combination with a significant Valence x Age group interaction, $F(2,72) = 3.9$, $\varepsilon = .94$, $p = .027$. In the younger participants, there was a memory advantage for emotional over neutral pictures, both *p*s < .001, as well as an advantage for unpleasant over pleasant pictures, $p = .037$ (one-sided). The younger participants thus demonstrated a negativity bias. The older participants also recalled more emotional than neutral pictures, both *p*s < .008, but remembered unpleasant and pleasant pictures equally well, *p* = .36. Thus, the older participants showed no bias. When comparing between age groups, the older participants recalled fewer unpleasant pictures than the younger participants, *p* = .023, but similar numbers of pleasant and neutral pictures, both *p*s > .35.

Cued recall

The younger participants remembered on average 126.6 pictures (range = 82-165) and the older participants 102.7 (range = 34-143), which was different as evident from a significant main effect of Age group, $F(1,36) = 7.3$, $p = .010$. No main effect of Valence occurred, $F(2,72) < 1.0$, *ns*, but the interaction of Valence and Age group was significant, $F(2,72) = 8.1$, $\varepsilon = .94$, $p = .001$. The younger participants recalled more emotional than neutral pictures, both *p*s < .050, and recalled unpleasant and pleasant pictures equally well, *p* = .32 (one-sided). The older participants recalled neutral pictures better than unpleasant pictures, *p* = .003, with pleasant pictures nonsignificantly different in-between, both *p*s > .058. Neither the younger, nor the older participants demonstrated a bias in cued recall. When comparing between age groups, the older participants recalled fewer unpleasant and pleasant pictures than the younger participants, both *p*s < .017, but similar numbers of neutral pictures, *p* = .15.

Positive and negative affect

See Table 1 for the positive and negative affect scores. These scores did not differ between the age groups, all *F*s(1,36) < 3.9, all *p*s > .056, implying that the younger and older participants had similar levels of positive and negative mood during the past two weeks and at testing.

Event-related potentials

The ERP waveforms are depicted in Figure 1 and the scalp topographies of the emotion effects in Figure 2. In addition to several other significant main and interaction effects, there was a significant Time window x Electrode x Valence x Age group interaction, $F(4,144) = 11.9$, $\varepsilon = .75$, $p < .001$. Therefore, additional analyses were performed per time window separately.

400-700 ms

There was a main effect of Valence, $F(2,72) = 10.9$, $\varepsilon = .92$, $p < .001$. The waveform was most positive for unpleasant pictures, intermediate for pleasant pictures and least positive for neutral pictures, all *p*s < .044. Although visual inspection of the waveforms suggests the occurrence of age differences in emotional modulation of the early LPP, the Valence x Age group interaction was not significant, $F(2,72) = 1.7$, $\varepsilon = .92$, $p = .19$. The other interaction effects involving the factor Valence were also not significant, all *F*s < 1.8, all *p*s > .16. In conclusion, both younger and older participants demonstrated a negativity bias in the early LPP.

700-1,000 ms

Besides all main and two-way interaction effects, the Electrode x Valence x Age group interaction was significant, $F(4,144) = 3.3$, ε = .79, $p = .020$. Therefore, further analyses were performed per electrode separately. The amplitudes of the waveform at each electrode for the younger and older participants are displayed in Figure 4.

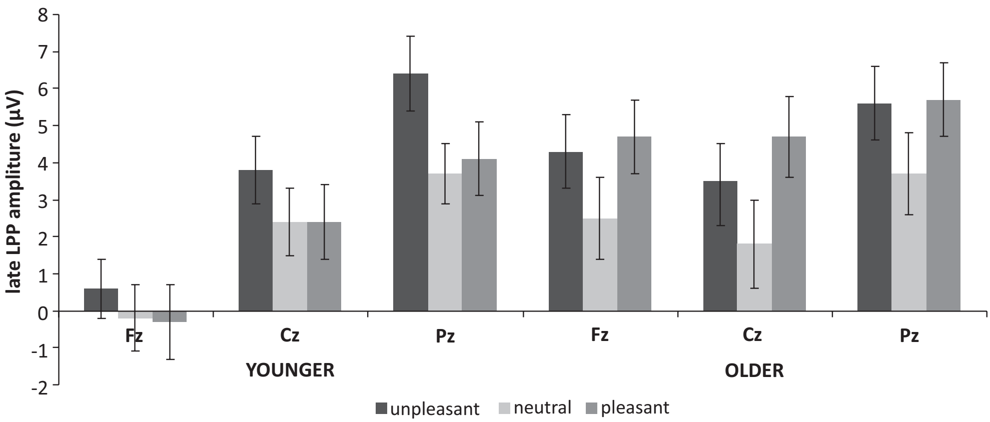

Figure 4. Late positive potential (LPP) amplitude (700-1,000 ms) per electrode, separately for the younger and older participants, error bars depict standard errors of the mean.

At Electrode Fz, there was a main effect of Valence, $F(2,72) = 4.1$, ε = .93, $p = .023$. The waveform for unpleasant pictures was more positive than the waveform for neutral pictures, $p = .013$, with the waveform for pleasant pictures non-significantly different in-between, both *p*s > .066. The Valence x Age group interaction did not reach significance, $F(2,72) = 2.8$, ε = .93, $p = .071$.

At Electrode Cz, besides a significant main effect of Valence, the Valence x Age group interaction was significant, $F(2,72) = 5.8$, ε = .93, $p = .006$. In the younger participants, the waveform was larger for unpleasant compared with pleasant pictures, $p = .029$ (one-sided). The waveform for neutral pictures did not differ from the waveforms for unpleasant, $p = .099$, and pleasant pictures, $p = .98$. In the older participants, the waveform was most positive for pleasant pictures, intermediate for unpleasant pictures and least positive for neutral pictures, all *p*s < .022. Thus, a positivity effect was observed in the late LPP at electrode Cz, because the younger participants showed a negativity bias while the older participants showed a positivity bias. Additional inspection of the Valence x Age interaction revealed no between age group differences in LPP amplitudes at Cz for unpleasant, pleasant or neutral pictures, all *p*s > .13.

At Electrode Pz, besides a significant main effect of Valence, the Valence x Age group interaction was significant, $F(2,72) = 3.3$, $\varepsilon = .92$, $p = .046$. In the younger participants, the waveform was more positive for unpleasant than pleasant, $p = .002$ (one-sided), and neutral pictures, $p = .004$, but was not different between the pleasant and neutral pictures, $p = .58$. In the older participants, the waveform was more positive for emotional than neutral pictures, both *p*s < .013, but not different for unpleasant and pleasant pictures, $p = .73$. In short, a positivity effect was observed in the late LPP at electrode Pz, as the younger participants exhibited a negativity bias and the older participants exhibited no bias. Additional inspection of the Valence x Age interaction revealed no between age group differences in LPP amplitudes at Pz for unpleasant, pleasant or neutral pictures, all *p*s > .24.

Correlations

To examine the relationship between the neurophysiological and behavioral positivity effects, the ERP amplitude difference between unpleasant and pleasant pictures was correlated with the difference in number of unpleasant and pleasant pictures recalled in the free recall test. Positive correlations were observed, although only border significant: at electrode Cz, $r(36) = .30$, $p = .072$; at electrode Pz, $r(36) = .26$, $p = .12$. These correlations were present only in the older participants: at electrode Cz, $r(17) = .38$, $p = .11$; at electrode Pz, $r(17) = .39$, $p = .11$, but not in the younger participants: at electrode Cz, $r(17) = .04$, $p = .88$; at electrode Pz, $r(17) = -.04$, $p = .88$, see Figure 5. These correlations suggest that a negativity or positivity bias in the LPP was associated with a similar valence bias in free recall in the older participants only.

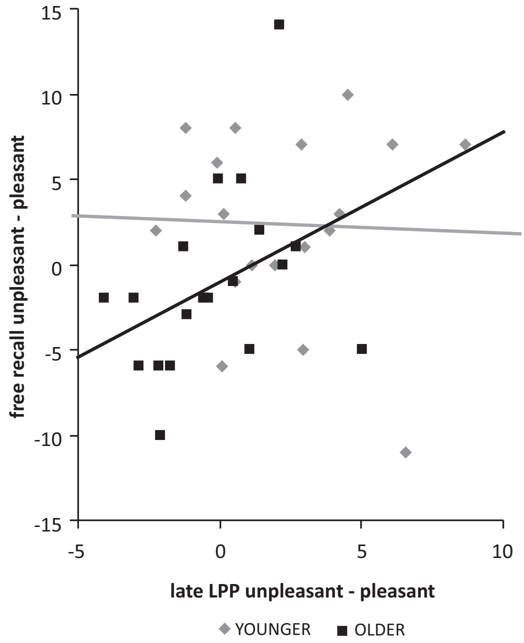

Figure 5. Scatterplot showing the relation between valence biases in the free recall and the late LPP amplitude at electrode Pz, separately for the younger and older participants.

Discussion

The goal of this study was to examine whether neurophysiological and behavioral positivity effects co-occur, as these have previously been observed and investigated only separately. To this end, younger and older participants intentionally encoded unpleasant, neutral and pleasant pictures while their EEG was recorded. In subsequent free and cued recall tests they reported which pictures they remembered.

In the free recall test, both younger and older adults demonstrated an emotion enhancement effect on memory (cf. Carstensen & Turk-Charles, 1994; Kensinger et al., 2002; May, Rahhal, Berry, & Leighton, 2005), because both age groups remembered more emotional than neutral pictures. More relevant for the current research question, however, is the finding that younger adults remembered more unpleasant than pleasant pictures whereas older adults remembered unpleasant and pleasant pictures equally well. Thus, the younger adults showed a negativity bias while the older adults did not show a bias, thereby revealing a behavioral positivity effect.

In the cued recall test, an emotion enhancement effect occurred in the younger adults while the older adults recalled mostly neutral pictures. Moreover, neither of the age groups showed a negativity or positivity bias, thus a positivity effect was not present. Prior work has shown that within one study sample, a positivity effect may be present in free recall but not in recognition tests (Charles et al., 2003). It has been suggested that the more externally constraint a task is, the less likely it is that a positivity effect will occur (Mather, 2006) and the current disparity between free and cued recall supports this notion.

The neurophysiological positivity effect was investigated through the LPP, which consisted of an early and a late portion. The early LPP was larger for emotional than neutral pictures (cf. Schupp et al., 2006) and showed a negativity bias (cf. Huang & Luo, 2006; Ito & Cacioppo, 2000; Ito et al., 1998; Schupp, Öhman et al., 2004). The emotional modulation of the late LPP varied as a function of age group. The younger adults demonstrated a negativity bias, while the older adults demonstrated no bias at the parietal electrode (cf. Kisley et al., 2007; Wood & Kisley, 2006) and a positivity bias at the central electrode. Thus, there was a positivity effect in the late LPP.

In accordance with our expectations, behavioral and neurophysiological positivity effects co-occurred. The positivity effect in the free recall test was accompanied by a positivity effect in the LPP during the encoding of the pictures. Moreover, the occurrence of a valence bias in the late LPP was substantially, yet non-significantly, correlated with the occurrence of a similar valence bias in memory performance in the older adults. Indeed, the LPP has been associated with memory formation as well as with top-down control of emotional processes (see Olofsson et al., 2008), which will be discussed in more detail below. Notably, the underlying patterns causing the positivity effects in the LPP and memory were the same (negativity bias in the younger adults, no bias in the older adults), with the exception of the observed positivity bias in the late LPP at the central electrode in the older adults. As outlined in the introduction, a positivity effect can be made up from three different patterns of biases. The functional significance of the different patterns that result in a positivity effect requires additional investigation, because the differences and similarities between positivity effects with different underlying patterns are unclear. It could, for example, be argued that the current results revealed a divergence between neurophysiological and behavioral positivity effects, because the older adults' positivity bias in the LPP did not occur in memory performance. Alternatively, it could equally well be argued that the observed positivity bias at the central electrode in the older adults simply contributed to the occurrence of a neurophysiological positivity effect. Then, the current results could be taken to reveal that neurophysiological and behavioral positivity effects co-occur, albeit with a different underlying pattern. We would favor this latter explanation because it can hardly be assumed that brain activation measured at the scalp (or in a certain brain region) has an exclusive and one-to-one relationship to behavior.

In the previous studies where participants had to categorize the pictures as negative, neutral or positive after a 1-s viewing period, the LPP was rather confined in time with a clear peak between 500 and 600 ms (Kisley et al., 2007; Wood & Kisley, 2006). In the current study, in contrast, participants were intentionally encoding the pictures for subsequent recall during a 1-s viewing period. Intentional encoding is presumably a more effortful and more prolonged process than valence categorization, which could account for the more extended LPP in the current study. What is interesting is that neurophysiological and behavioral positivity effects were observed even though the participants were not explicitly instructed to consider the emotional salience of the pictures (see also Emery & Hess, 2008), which is actually in line with the theoretical foundation of the positivity effect. The socioemotional selectivity theory states that because older adults perceive their remaining life-time as limited, they have emotion-oriented goals and are focused on the positive aspects of life, whereas younger adults would pursue knowledge-oriented goals in order to maximize benefits in the future (Carstensen, Isaacowitz, & Charles, 1999). Mather and Carstensen (2005) have suggested that the older adults' emotional goals influence the top-down but not the automatic bottom-up processing of emotional stimuli. Thus, bottom-up influences would increase the processing of emotionally arousing over neutral stimuli regardless of age (see also Leclerc & Kensinger, 2008b), whereas top-down control would decrease the processing of negative stimuli and/or increase the processing of positive stimuli in the older adults. The theory does not assume that these processes would occur only when people are explicitly determining the emotional salience of stimuli, and the current findings clearly show that the neurophysiological positivity effect may also emerge following non-emotional instructions.

As mentioned in the introduction, Kisley et al. (2007) have elegantly shown that their positivity effect in LPP amplitude resulted from an age-related decrease in the processing of negative information as opposed to an increase in the processing of positive information. The current ERP data do not provide evidence in favor or against that finding, because no between age group differences in LPP amplitudes for the different valences were observed. In the free recall test, however, the older adults' memory was selectively impaired for unpleasant pictures when compared with the younger adults' memory (cf. Grühn, Scheibe, & Baltes, 2007). In our opinion, this age-related decrease in processing of negative information should be integrated in the definition of the positivity effect. The positivity effect may then be defined as *a trend for adults to increasingly process positive and/or decreasingly process negative information compared with other information with advancing age*, rather than as a trend to process positive information more than negative information (cf. Löckenhoff & Carstensen, 2007).

Although the socioemotional selectivity theory predicts that older adults experience more positive and/or less negative affect than younger adults (Carstensen et al., 1999; see also

Grühn et al., 2005; Mroczek & Kolarz, 1998), this was not the case in the current study. This suggests that the observed positivity effect was not the result of a mood congruency effect, which entails that people preferably remember information that is congruent with their mood (Lewis & Critchley, 2003).

Despite our effort to recruit highly educated older adults, they had taken less education than the younger, which is a nearly inevitable consequence of generational differences in educational possibilities. It was not possible to statistically control for education differences because there was no variance (Stevens, 2002) in the younger adults education scores, since they all were undergraduate students with an educational level of 7. Nonetheless, the education difference was very small: the average education in both age groups was university level, though scientifically oriented in the younger and practically oriented in the older adults. In addition, given that the younger and older adults remembered rather similar numbers of pictures in the free recall test and that a positivity effect in the LPP has occurred previously when controlling for education (Kisley et al., 2007), we are confident that age differences in education can not account for our findings.

To conclude, we report here the first evidence, to our knowledge, of co-occurring neurophysiological and behavioral positivity effects. More specifically, a positivity effect was observed in the LPP as well as during a free recall memory test. Obviously, this finding of co-occurring neurophysiological and behavioral positivity effects awaits replication using other neurophysiological measures such as amygdala activation, and other behavioral domains such as attention.

Chapter 4

Age differences in the emotional modulation of ERP old/new effects

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This study has been presented as:
Langeslag, S. J. E., & Van Strien, J. W. (December 14, 2007). Attention, rather than retrieval, contributes to age differences in emotional memory: An event-related potential study [Poster]. NVP Winter Conference 2007, Egmond aan Zee, The Netherlands.

Abstract

The emotional salience of stimuli influences ERP old/new effects, but despite proven age differences in emotional processing, the influence of emotion on old/new effects has previously been investigated in younger adults only. Therefore, we set out to examine age differences in the emotional modulation of old/new effects. To this end, the electroencephalogram of younger (17-27 years) and older (63-77 years) adults was recorded while they completed a continuous recognition test with unpleasant, neutral and pleasant pictures. Because recollection is typically enhanced by emotion, the parietal old/new effect was expected to be larger for emotional than neutral stimuli in the younger adults. Because recollection suffers from age-related decline, emotion enhancement of the parietal old/new effect was not expected in the older adults. The results showed that, in both age groups, recognition accuracy was not affected by emotion and that the response bias was more liberal for unpleasant pictures. The younger adults displayed an early, a parietal and a late frontal old/new effect, whereas the older adults showed an early, no parietal and an inverse left-lateralized late frontal old/new effect. Further, the emotional modulation of the old/new effects differed with age. Importantly, emotion enhanced the parietal and late frontal old/new effects in younger adults, and the early old/new effect in older adults. This suggests that whereas recollection and post-retrieval processes are augmented in emotional recognition memory in younger adults, familiarity is enhanced by emotional salience in older adults.

Introduction

Emotional information is better remembered than neutral information and this emotion enhancement effect on memory occurs because emotional stimuli are better perceived, encoded, consolidated and retrieved than neutral stimuli (Hamann, 2001; LaBar & Cabeza, 2006; Phelps, 2004). In event-related potential (ERP) studies, the effect of the emotional salience of stimuli on retrieval has been investigated using the ERP old/new effect. Nevertheless, while there is abundant evidence to suggest that younger and older adults differ in the way they process emotional information (Mather & Carstensen, 2005), the influence of emotion on the old/new effect has previously been studied in younger adults only.

The ERP old/new effect is obtained by measuring participants' brain activity while they perform a recognition test in which each stimulus is presented twice and the participant has to identify the stimuli as being presented for the first time ('new' stimulus) or for the second time ('old' stimulus). Typically, one of two different recognition test paradigms is used; in the continuous recognition paradigm the first and second stimulus presentations occur intermixed, whereas in the study-test paradigm first presentations occur in a study phase that is followed by a test phase in which second presentations have to be recognized from a list of old target and new distractor stimuli. The old/new effect concerns the difference between the ERPs elicited by new and old stimuli, where the ERP waveform for old stimuli usually is more positive going than the ERP waveform for new stimuli. The old/new effect consists of three spatiotemporally and functionally distinct components that are, in order of appearance following stimulus onset, the early old/new effect, the parietal old/new effect, and the late frontal old/new effect (see Friedman, 2000; Friedman & Johnson, 2000; Rugg, 1995; Rugg & Allan, 2000; Yonelinas, 2002, for reviews). Notably, all of these old/new effects have been shown to be influenced by the emotional salience of the stimuli in younger adults. The early old/new effect occurs bilaterally at frontal electrodes and has been taken to represent familiarity (e.g. Curran & Cleary, 2003; but see Yovel & Paller, 2004), which is the mere sense of having seen a stimulus previously without being able to recall any details of the circumstances (Yonelinas, 2001, 2002). This early frontal old/new effect has been found to be larger for unpleasant compared to pleasant pictures (Van Strien, Langeslag, Strekalova, Gootjes, & Franken, 2009), and larger for negative and positive than for neutral words (Inaba, Nomura, & Ohira, 2005). The subsequent parietal old/new effect is sensitive to memory trace strength (Van Strien, Hagenbeek, Stam, Rombouts, & Barkhof, 2005), and is thought to reflect the successful retrieval and recollection of a stimulus, where recollection refers to the explicit memory of the circumstances in which a stimulus was previously encountered (Yonelinas, 2001, 2002). The parietal old/new effect has been found to be larger for positive and negative compared to neutral words (Dietrich et al., 2001), to be largest for negative words, intermediate for positive and smallest for neutral words (Inaba et al., 2005), to be larger and of longer duration for neutral compared to negative words (Maratos, Allan, & Rugg, 2000), and to occur for negative but not for positive or neutral faces (Johansson, Mecklinger, & Treese, 2004). The late frontal old/new effect reflects post-retrieval processes (Rugg & Allan, 2000) and has been found to occur for neutral but not for negative words (Maratos et al., 2000), and to be left-lateralized for happy and right-lateralized for neutral faces (Graham & Cabeza, 2001). The differences in the observed influence of emotion on the old/new effects may originate from differences in stimulus type (words, faces, pictures) and paradigm (continuous recognition, study-test) used.

Prior studies have investigated age differences in old/new effects elicited by non-emotional stimuli. In accordance with the age-related decline in episodic memory retrieval (Langley & Madden, 2000), ERP old/new effects appear to decline with age as well. The parietal old/new effect in older adults has been found to be smaller, delayed or distributed more frontally than in younger adults (Gutchess, Ieuji, & Federmeier, 2007; Mark & Rugg, 1998; Nielsen-Bohlman & Knight, 1995; Rugg, Mark, Gilchrist, & Roberts, 1997; Swick & Knight, 1997; Walhovd et al., 2006), which is in line with the notion that recollection declines with age (Light, Prull, La Voie, & Healy, 2000). In addition, the early and late frontal old/new effects have been found to be smaller or even absent in older adults (Gutchess et al., 2007; Swick, Senkfor, & Van Petten, 2006; Trott, Friedman, Ritter, & Fabiani, 1997; Trott, Friedman, Ritter, Fabiani, & Snodgrass, 1999; Wegesin, Friedman, Varughese, & Stern, 2002), indicating that familiarity and post-retrieval processes are also vulnerable to age-related decline.

So, although both the emotional modulation of ERP old/new effects in younger adults as well age differences in old/new effects for non-emotional stimuli have been investigated in previous studies, age differences in the emotional modulation of old/new effects have not yet been a topic of investigation. This is, however, an important research topic, given the notion that age differences in emotional processing exist. With advancing age, for example, there appears to be a trend to increasingly process positive and/or decreasingly process negative information, and this has been called the positivity effect (Löckenhoff & Carstensen, 2007; Mather & Carstensen, 2005). The positivity effect is consistent with the socioemotional selectivity theory that states that because older adults face shorter futures, they focus more on the positive aspects of life than younger adults do (Carstensen, Isaacowitz, & Charles, 1999). Positivity effects have been observed in mood (Grühn, Smith, & Baltes, 2005; Mather & Knight, 2005; Mroczek & Kolarz, 1998), in attention (Isaacowitz, Wadlinger, Goren, & Wilson, 2006a, 2006b; Mather & Carstensen, 2003) and in memory (Charles, Mather, & Carstensen, 2003; Emery & Hess, 2008; Kensinger, 2008; Leigland, Schulz, & Janowsky, 2004; Thomas & Hasher, 2006). Nevertheless, a positivity effect in memory was not observed in several other studies

(Comblain, D'Argembeau, Van der Linden, & Aldenhoff, 2004; Denburg, Buchanan, Tranel, & Adolphs, 2003; Grühn et al., 2005; Kensinger, Brierley, Medford, Growdon, & Corkin, 2002). The origin of this discrepancy is still unclear, yet may have to do with differences in the type of stimuli (words, faces, pictures), type of encoding (incidental, intentional) and type of memory test (free recall, cued recall, study-test recognition paradigm).

Importantly, age differences in emotional modulation have been observed in neuroimaging measures as well. In a functional Magnetic Resonance Imaging (fMRI) study, the younger adults' amygdala was equally active in response to pleasant and unpleasant pictures, whereas the older adults' amygdala was more active in response to pleasant than unpleasant pictures (Mather et al., 2004). In three ERP studies, age differences in the emotional modulation of the Late Positive Potential (LPP) have been observed as the younger adults' LPP amplitude was largest for unpleasant pictures, while the older adults' LPP amplitude was comparable for unpleasant and pleasant pictures (Kisley, Wood, & Burrows, 2007; Langeslag & Van Strien, 2009; Wood & Kisley, 2006). Considering the previously observed age differences in the emotional modulation of amygdala activation and the LPP amplitude, it appears plausible that age differences will occur in ERP old/new effects in response to emotional stimuli as well.

The aim of the present study was to investigate age differences in the emotional modulation of the ERP old/new effects. To this end, younger and older adults performed a continuous recognition test with unpleasant, neutral and pleasant pictures while their electroencephalogram was recorded. It was hypothesized that the younger adults would show mainly emotional modulation of the parietal old/effect as this reflects recollection which is supposed to be more sensitive to the emotional salience of stimuli than familiarity (Dewhurst & Parry, 2000; Ochsner, 2000). In contrast, as recollection declines with aging, any emotional modulation of the old/new effects in older adults will probably not occur in the parietal old/new effect. Furthermore, we also expected effects of emotion and age on behavioral performance in both the continuous recognition test and in a subsequent surprise free recall test.

Method

Participants

Participants were 20 younger (mean age 19.8 years, range 17-27 years, 10 men) and 20 older (mean age 68.5 years, age range 63-77 years, 10 men) adults. The younger participants were undergraduate psychology students and the older participants were recruited by distributing letters at a special university program for older adults. All participants were right-handed, not demented, not depressed[1] and reported no history of neurological or neurovascular disorders (such as epilepsy or stroke) or use of drugs that are known to affect the central nervous system. Participants were rewarded with course credit or 20 Euros. The study was approved by the local ethics committee and the participants gave written informed consent prior to testing.

Table 1 depicts participants' characteristics. The older participants had completed significantly less formal education than the younger. All participants asserted sufficient capability to view the pictures and had a visual acuity (if necessary corrected with glasses or contact lenses) of at least 0.7 as assessed by a Landolt-C card. The younger participants had a higher visual acuity and a higher trait anxiety as measured with the State-Trait-Anxiety Inventory (Van der Ploeg, Defares, & Spielberger, 1980), and reported more negative affect during the past 2 weeks, less positive affect at this moment and more negative affect at this moment as measured with the Positive and Negative Affect Schedule (PANAS) (Peeters et al., 1999; Watson, Clark, & Tellegen, 1988).

Table 1. Characteristics of the participants in each age group and the *p*-values associated with the difference between the age groups.

	Younger		**Older**		***p*-values**
	Mean	**Range**	**Mean**	**Range**	
Education	7.0	7	4.9	1-8	**< .001**
Alcohol [glasses last week]	6.6	0-40	11.2	0-28	.147
Visual Acuity	1.4	0.7-2.5	1.1	0.8-2.0	**.004**
State Anxiety	29.6	21-39	27.9	20-40	.290
Trait Anxiety	33.5	22-43	28.9	14-36	**.016**
Positive Affect (past 2 weeks)	34.7	22-44	35.7	26-44	.583
Negative Affect (past 2 weeks)	15.6	10-26	12.5	10-16	.003
Positive Affect (at this moment)	32.0	18-42	36.1	27-45	**.029**
Negative Affect (at this moment)	11.6	10-19	10.1	10-11	**.014**

Note. Education ranged from 1 (primary education) to 8 (master degree) (De Bie, 1987). Significant *p*-values are presented in bold.

Stimuli

The stimuli were 60 unpleasant, 60 neutral and 60 pleasant pictures from the International Affective Picture System (IAPS) (Lang, Bradley, & Cuthbert, 2005). Many of the neutral pictures

[1] Handedness was determined by a hand preference questionnaire (Van Strien, 1992). The Mini Mental State Exam (MMSE) was used to screen for dementia, and all older participants had a score of at least 26 (Derix et al., 2003; Folstein, Folstein, & McHugh, 1975). Younger participants were considered non-depressed if they scored less than 13 on the Beck Depression Inventory (BDI) (Beck, Ward, Mendelson, Mock, & Erbaugh, 1961; Lasa, Ayusi-Mateos, Vázquez-Barquero, Díez-Manrique, & Dowrick, 2000) and older adults if they scored less than 11 on the Geriatric Depression Scale (GDS) (Yesavage et al., 1983).

in the IAPS database depict simple objects against a neutral background (e.g. a clock on a white wall), whereas the emotional pictures often depict entire scenes (e.g. four men with bats and guns attacking a car). Therefore, especially the more complex neutral pictures (e.g. woman with trolley in supermarket) were selected in order to equate the complexity of emotional and neutral pictures. Moreover, no erotic pictures were included, because these may be experienced differently by the younger and older participants. Further, because a free recall test was administered that involved writing down the pictures that were remembered, pictures that were sufficiently different and well describable were selected. The pictures were presented against a black background and subtended a maximal visual angle of 11° horizontally and 8° vertically.

The continuous recognition test was divided into six blocks that contained 60 experimental stimuli, evenly distributed across the valences. The stimuli were pseudo randomly presented, with no more than two pictures of the same valence succeeding each other. Each picture was presented twice and both presentations took place within the same block, at least four and at most 30 stimuli apart. At the beginning and at the end of each block, three neutral filler pictures that could be new or old were additionally presented. From the participant's perspective (i.e. including the filler pictures), the first half of each block contained on average 63% new and 37% old pictures and the second half of each block contained on average 44% new and 56% old pictures. This design resulted in an even distribution of the presentations of new and old pictures across the entire experiment as well as within blocks, thereby reducing the effect of time-on-task influences, such as fatigue and habituation.

Procedure

Upon arrival in the lab the participants completed the above-mentioned screening procedures and questionnaires. Next, they were seated in a comfortable chair in a dimly-lit, sound-attenuated room, the electrode cap was attached, and a response box was put on the participants lap. The participants were instructed that they would be viewing photographs of people, animals, objects and landscapes, but they were unaware of the fact that the emotional content of the pictures was relevant. They were told that each picture would be presented twice and that they had to indicate by a button press whether the picture on the screen was presented for the first or for the second time. The participants were instructed to respond as quickly and accurately as possible. They used either their thumbs or index fingers of their left and right hands to respond; the assignment of left and right hand button presses to new and old responses was counterbalanced across participants. After a one-minute baseline EEG recording (data not reported here), the participants completed ten practice trials and the six blocks of the continuous recognition test. All trials consisted of the following four events:

fixation cross with variable duration between 400 and 600 ms, picture for 1000 ms, again a fixation cross for 1000 ms and a blank screen for 1500 ms. Trials with button presses that were given earlier than 150 ms or later than 2000 ms after picture onset were discarded. The participants were encouraged to limit movements and to blink only during the blank screen.

After the final block, the electrode cap was removed and the participants completed another PANAS ("at this moment"). Then, the participants completed a surprise free recall test, which involved writing down a description in catchwords or short sentences of each picture they recalled, at their own pace. Finally, the participants rated the valence and arousal of each picture with a computerized version of the Self-Assessment Manikin (SAM) (Lang, 1980).

Electroencephalogram (EEG) recording and signal processing

The electroencephalogram (EEG) was recorded using a 64-channel amplifier and data acquisition software (ActiveTwo System, Biosemi). The Ag-AgCl Active electrodes were placed upon the scalp by means of a head cap (Biosemi), according to the 10-10 International System (American Clinical Neurophysiology Society, 2003). Vertical and horizontal electro-oculogram were recorded by attaching additional electrodes (UltraFlat Active electrodes, BioSemi) respectively above and below the left eye, and at the outer canthi of both eyes. Additional electrodes were attached to the left and right mastoids. An active electrode (CMS – common mode sense) and a passive electrode (DRL – driven right leg) were used to comprise a feedback loop for amplifier reference. All signals were digitized with a sampling rate of 512 Hz, a 24-bit A/D conversion, and a low pass filter of 134 Hz.

In four participants, one to three bad channels were corrected using spherical spline interpolation in accordance with the guidelines of Picton et al. (2000). Offline, a mathematically linked mastoids reference was applied and the data were filtered using a 0.15-30 Hz band pass filter (phase shift-free Butterworth filters; 24 dB/octave slope). Data were segmented in epochs from 100 ms pre-stimulus onset until 1000 ms post-stimulus onset. Ocular artifact correction was done according to the Gratton and Coles algorithm (Gratton, Coles, & Donchin, 1983). The mean 100 ms pre-stimulus period was used for baseline correction. Artifact rejection criteria were minimum and maximum baseline-to-peak –75 to +75 µV, and a maximum allowed voltage skip (gradient) of 50 µV. Three participants with excessive EEG artifacts were excluded and replaced. Epochs with incorrect responses were discarded from the analysis. Epochs with correct responses were classified according to whether that picture was presented for the first or second time and by their valence, yielding six conditions (new-unpleasant, new-neutral, new-pleasant, old-unpleasant, old-neutral, old-pleasant). The mean number of valid epochs per condition ranged from 46.2 to 48.8.

Analyses

Hit rates (*H*, i.e. proportion 'old' responses to old stimuli) and false alarms rates (*FA*, i.e. proportion 'old' responses to new stimuli) were computed using the correction recommended by Snodgrass and Corwin (1988). Performance on the continuous recognition test was represented by the discrimination index $P_r = H - FA$, and by the response bias index $B_r = FA / (1 - P_r)$ (Snodgrass & Corwin, 1988). Only reaction times (RTs) of correct responses were analyzed. RT data from one older man were missing. In the free recall test, picture descriptions had to allow for sufficient identification of, and discrimination between pictures in order for the picture to be scored as remembered. The behavioral data, i.e. the valence and arousal ratings, RTs, memory performance and questionnaire scores, were tested with one-way or repeated measures ANOVAs with within-subject-factors valence (unpleasant, neutral, pleasant) and presentation (new, old), and the between-subject-factor age group (younger, older).

ERP activity at the different electrode sites was pooled into ERP activity at nine electrode clusters arranged in a three-by-three grid (left-anterior, midline-anterior, right-anterior, left-central, midline-central, right-central, left-posterior, midline-posterior, right-posterior), see Figure 1. The ERP waveforms were quantified by mean amplitude measures in three time windows: 200-400 ms, 400-700 ms and 700-900 ms. The selection of these time windows was based on previous research and visual inspection of the waveforms; the 200-400 ms time window covered the early frontal old/new effect, the 400-700 ms time window the parietal old/new effect, and the 700-900 ms time window encompassed the late frontal old/new effect. The mean amplitudes of each time window were subjected to repeated measures ANOVAs with valence (unpleasant, neutral, pleasant), presentation (new, old), caudality (anterior, central, posterior), laterality (left, midline, right) as within-subject-factors, and age group (younger, older) as between-subject-factor.

Given the present interest in age differences in emotional modulation of the ERP old/new effect, only the highest-order interactions involving at least age, old/new and valence are reported for each time window (Dien & Santuzzi, 2005). When applicable, degrees of freedom were corrected with the Greenhouse-Geisser correction. The *F* values, the uncorrected *df*s, the epsilon (ε) values and corrected probability levels are reported. A significance level of 5% (two-sided) was selected. Significant interactions were followed-up by Bonferroni-corrected post-hoc comparisons.

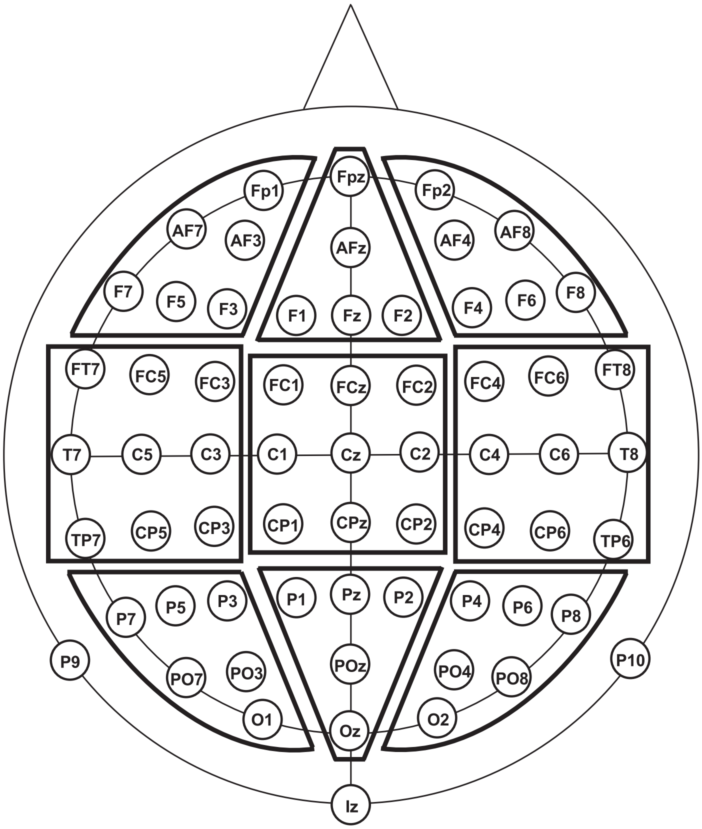

Figure 1. The nine electrode clusters (left-anterior, midline-anterior, right-anterior, left-central, midline-central, right-central, left-posterior, midline-posterior, right-posterior).

Results

Valence and arousal ratings

Table 2 displays the valence and arousal of the pictures as rated by the participants. For the valence ratings, a main effect of valence occurred, $F(2,76) = 211.8$, $\varepsilon = .56$, $p < .001$, with valence ratings being lowest for unpleasant pictures, intermediate for neutral pictures and highest for pleasant pictures, all *p*s < .001. For the arousal ratings, besides a significant effect of valence, a significant interaction of valence and age group occurred, $F(2,76) = 7.4$, $\varepsilon = .72$, $p = .004$. In the younger participants, arousal ratings were highest for unpleasant pictures, intermediate for pleasant pictures and lowest for neutral pictures, all *p*s < .001. In the older participants, in contrast, arousal ratings were similar for the unpleasant and pleasant pictures, $p = .22$, and lowest for the neutral pictures, both *p*s < .035.

Table 2. Mean valence and arousal ratings (standard deviations in brackets) of the pictures.

		Unpleasant	Neutral	Pleasant
Younger (n = 20)	**Valence**	3.3 (0.7)	5.2 (0.3)	6.6 (0.8)
	Arousal	4.8 (1.3)	3.1 (1.4)	4.1 (1.3)
Older (n = 20)	**Valence**	3.4 (0.9)	5.5 (0.8)	6.7 (0.9)
	Arousal	4.3 (1.3)	3.5 (1.6)	4.7 (1.7)

Note. Valence and arousal ratings ranged from 1 (extremely unpleasant or calm) to 9 (extremely pleasant or aroused) (Lang, 1980).

Recognition performance

See Table 3 for the hit and false alarm rates, as well as the discrimination and response bias indices.

Table 3. Mean (standard deviation in brackets) hit rate (*H*), false alarm rate (*FA*), discrimination index (P_r) and response bias index (B_r).

		H	*FA*	P_r	B_r
Younger (n = 20)	**Unpleasant**	.95 (.04)	.03 (.02)	.92 (.06)	.40 (.21)
	Neutral	.94 (.05)	.02 (.01)	.92 (.06)	.33 (.18)
	Pleasant	.94 (.04)	.03 (.02)	.91 (.05)	.36 (.22)
	Overall	.94 (.04)	.03 (.02)	.92 (.05)	.36 (.14)
Older (n = 20)	**Unpleasant**	.92 (.05)	.05 (.03)	.87 (.07)	.38 (.18)
	Neutral	.88 (.09)	.03 (.02)	.85 (.08)	.22 (.18)
	Pleasant	.89 (.06)	.04 (.03)	.86 (.07)	.27 (.17)
	Overall	.90 (.06)	.04 (.02)	.86 (.06)	.29 (.11)
Total (n = 40)	**Unpleasant**	.94 (.05)	.04 (.03)	.90 (.07)	.39 (.19)
	Neutral	.91 (.08)	.02 (.02)	.89 (.08)	.28 (.18)
	Pleasant	.92 (.05)	.03 (.02)	.88 (.07)	.31 (.20)

Note. A greater discrimination index indicates better recognition accuracy. A response bias larger than 0.5 indicates a liberal response bias, whereas a response bias smaller than 0.5 indicates a conservative response bias (Snodgrass & Corwin, 1988).

Hits and false alarms. With respect to hit rates, a main effect of valence occurred, $F(2,76) = 6.0$, $\varepsilon = .89$, $p = .005$. Hit rates were highest for unpleasant pictures, both *p*s < .007. Further, a significant main effect of age group, $F(1,38) = 9.5$, $p = .004$, indicated that the older adults had lower hit rates than the younger adults. For false alarm rates, a main effect of valence was observed, $F(2,76) = 5.0$, $\varepsilon = .98$, $p = .010$. False alarm rates were higher for emotional than for neutral pictures, both *p*s < .046.

Discrimination and response bias. Concerning the discrimination index, a main effect of age group occurred, $F(1,38) = 9.6$, $p = .004$, indicating that the older participants had poorer discrimination than the younger participants. For the response bias index, a main effect of valence was found, $F(2,76) = 4.5$, $\varepsilon = .95$, $p = .016$. Response bias was less conservative for unpleasant than for neutral pictures, $p = .010$.

Reaction times. The mean RTs for correct responses are displayed in Table 4. Besides significant main effects of valence and age group, a significant interaction of valence and age group occurred, $F(2,74) = 4.0$, $\varepsilon = .95$, $p = .024$. Responses were slowest to unpleasant pictures, all *p*s < .025, and this was more so in the older (mean $\Delta = 24$ ms, compared to neutral and pleasant pictures together) than in the younger adults (mean $\Delta = 10$ ms). In addition, the interaction of valence and presentation was significant, $F(2,74) = 33.0$, $\varepsilon = .85$, $p < .001$. Responses were slower to new-unpleasant pictures than to old-unpleasant pictures, $p = .001$. Moreover, upon first presentation, responses were slowest to unpleasant pictures, intermediate to pleasant pictures and fastest to neutral pictures, all *p*s < .003. Upon second presentation, responses were slower to neutral compared to pleasant pictures, $p = .003$. In short, responses were particularly delayed to new-unpleasant pictures.

Summary. No cross-over interactions of valence and age group occurred, indicating that no age differences occurred in the emotional modulation of recognition performance. Instead, both younger and older adults demonstrated a more liberal response bias for unpleasant pictures as well as delayed responses to new-unpleasant pictures.

Table 4. Mean (standard deviation in brackets) reaction times for correct responses.

		New	Old	Overall
Younger (n = 20)	**Unpleasant**	685 (76)	665 (69)	675 (69)
	Neutral	658 (76)	671 (64)	665 (68)
	Pleasant	667 (78)	662 (61)	665 (67)
	Overall	670 (75)	666 (63)	668 (67)
Older (n = 19)	**Unpleasant**	830 (107)	787 (89)	808 (93)
	Neutral	780 (93)	790 (82)	784 (79)
	Pleasant	793 (97)	773 (87)	783 (84)
	Overall	801 (99)	783 (84)	792 (85)
Total (n = 39)	**Unpleasant**	755 (117)	724 (100)	740 (105)
	Neutral	717 (104)	729 (94)	723 (95)
	Pleasant	728 (108)	716 (92)	722 (96)

Note. RTs are presented in milliseconds. RT data from one older man were missing.

Free recall performance

Figure 2 displays the number of remembered pictures per valence. On average, the younger participants remembered 31.5 pictures (range 15-63) and the older participants 22.9 (range 8-55), and this was significantly different, $F(1,38) = 5.0$, $p = .031$. A main effect of valence occurred, in combination with a significant interaction of valence and age group, $F(2,76) = 7.1$, $\varepsilon = .95$, $p = .002$. The younger participants demonstrated a memory benefit for emotional compared to neutral pictures, both *p*s < .001, but recalled similar numbers of unpleasant and pleasant pictures, $p = .76$. The older participants recalled more pleasant than neutral pictures, $p = .047$, both other *p*s > .12.

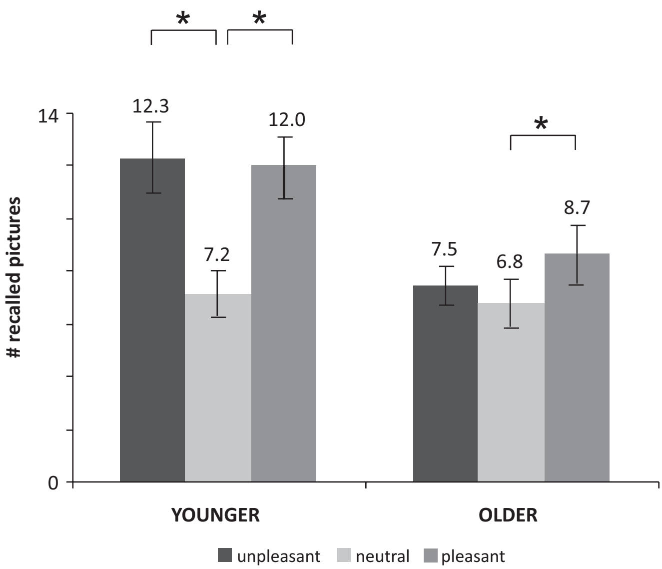

Figure 2. Number of pictures of each valence recalled in the free recall test, separately for the younger and older adults, error bars depict standard errors of the means, * significant difference, all *ps* < .048.

Old/new effects

Figure 3 depicts the grand average ERPs for new and old pictures and Figure 4 shows the scalp topographies of the old/new effects per valence. In each time window several of the main effects and two-, three- and four-way interactions were significant. In addition, in all time windows, the five-way interactions of valence, presentation, caudality, laterality and age group were significant as well, making lower level effects less relevant (Dien & Santuzzi, 2005); for the 200-400 ms time window, $F(8,304) = 2.4$, $\varepsilon = .72$, $p = .030$, for the 400-700 ms

4

time window, $F(8,304) = 3.6$, $\varepsilon = .75$, $p = .002$, and for the 700-900 ms time window, $F(8,304) = 3.1$, $\varepsilon = .70$, $p = .007$. To examine whether the emotional modulation of old/new effects differed between the younger and the older adults, the occurrence of old/new effects was determined by comparing the waveforms for old and new pictures separately per electrode cluster, valence and age group. The asterisks in Figure 4 indicate the clusters in which old/new effects were present according to post-hoc comparisons, all ps < .050 (Bonferroni-corrected).

200-400 ms. The younger adults exhibited an extensive early frontal old/new effect that was not modulated by emotion. In the older adults, the frontal old/new effect was smaller and more spatially confined than in the younger adults. Notably, it occurred for the emotional pictures only (see the left column of Figure 4).

400-700 ms. The younger adults demonstrated a widespread parietal old/new effect for all valences, although it was somewhat smaller and less widespread for the neutral pictures. The older adults did not show a significant parietal old/new effect at all (see the middle column of Figure 4).

700-900 ms. The younger adults exhibited a bilateral late frontal old/new effect for emotional pictures. In addition, the posterior part of the old/new effect for pleasant pictures appears to be an extension of the earlier parietal old/new effect (see the right column of Figure 4). Inspection of the data revealed that, in younger adults, the absence of an extended parietal old/new effect for unpleasant pictures was due to an increased positivity in the 700-900 ms time window in response to new-unpleasant pictures, and not to a decreased positivity in response to old-unpleasant pictures, see Figure 5. The older adults demonstrated a left frontal inverse old/new effect that was not modulated by emotion (see the right column of Figure 4).

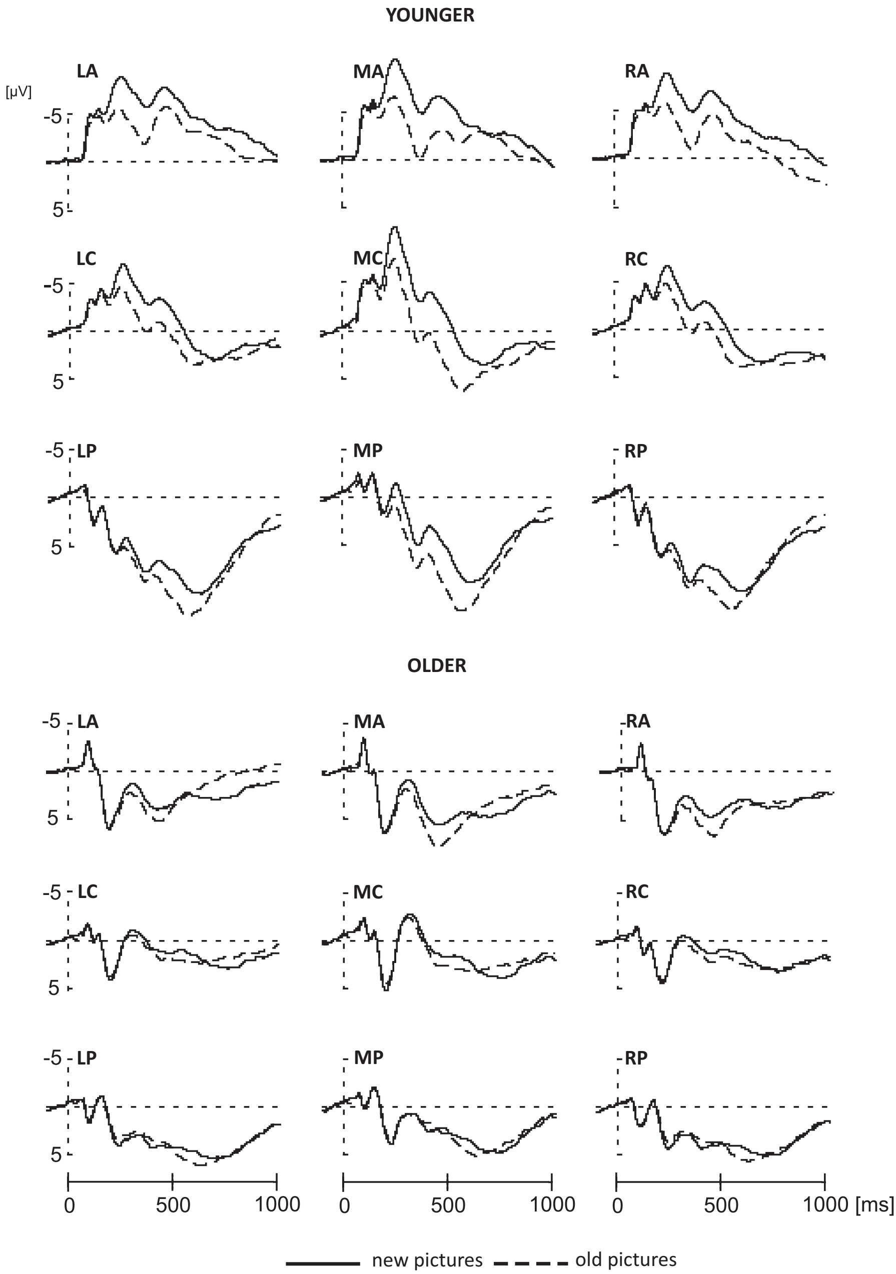

Figure 3. Grand average ERPs for new and old pictures collapsed across valences, at each of the electrode clusters (LA = left anterior, MA = midline anterior, RA = right anterior, LC = left central, MC = midline central, RC = right central, LP = left posterior, MP = midline posterior, RP = right posterior), separately for the younger and older adults, positive down.

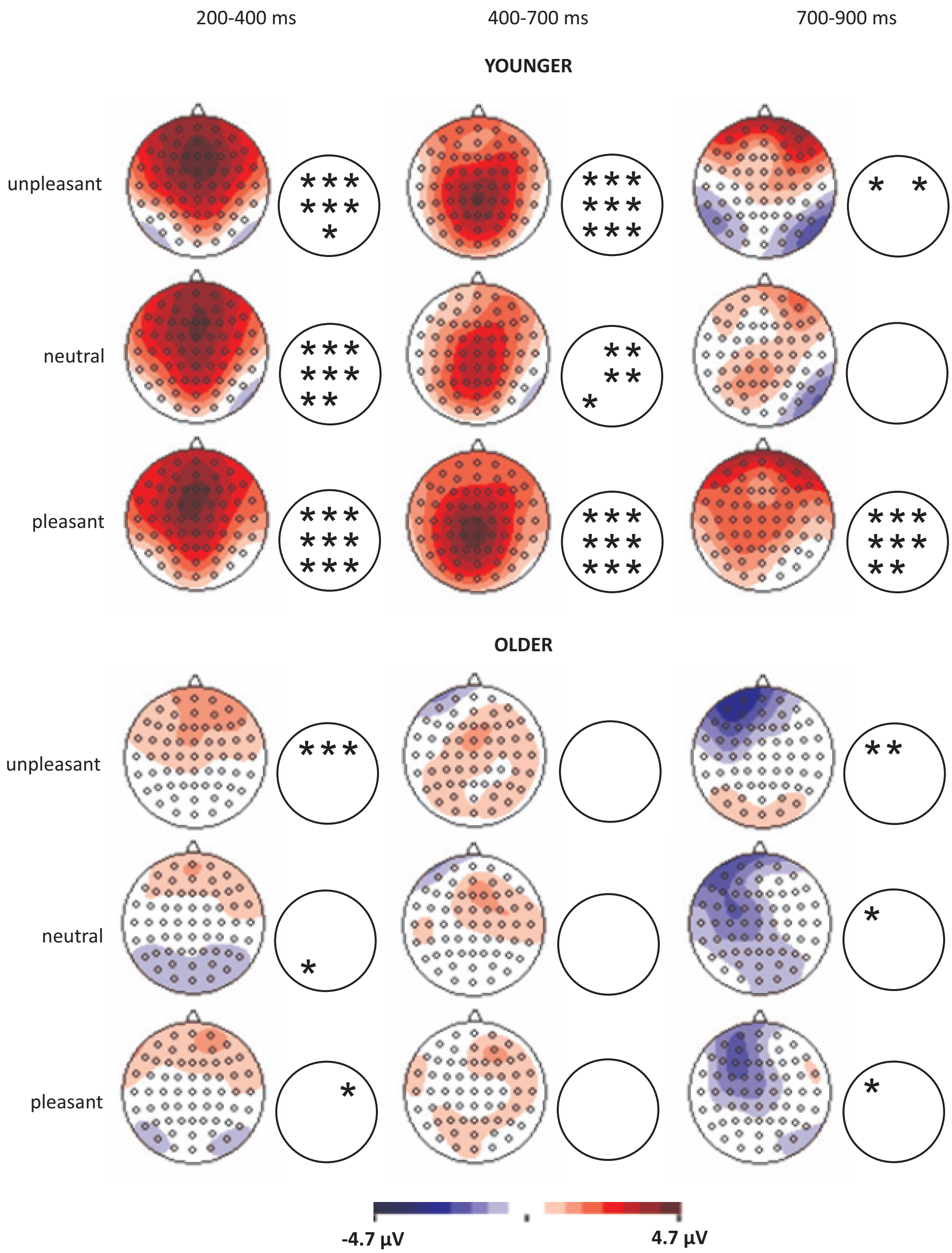

Figure 4. Voltage scalp distributions of the old/new effects (i.e. old - new) for unpleasant, neutral and pleasant pictures, separately for the younger and older adults and the selected time windows. Asterisks indicate the clusters in which the old/new effects were significant, all *ps* < .050 (Bonferroni-corrected).

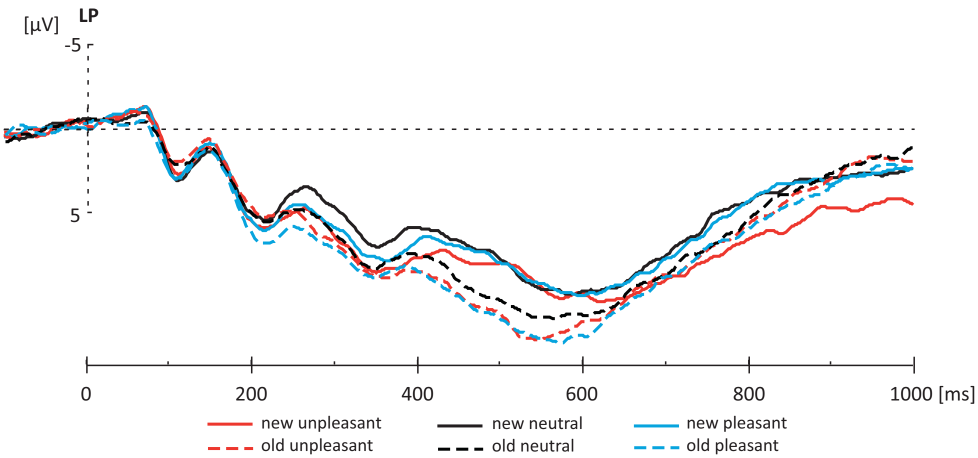

Figure 5. Grand average ERPs for the new and old pictures of each valence, at the left posterior (LP) cluster in the younger adults, positive down.

Discussion

The research question of this study was whether age differences would occur in the emotional modulation of the ERP old/new effects. While both the emotional modulation of old/new effects in younger adults as well as age differences in old/new effects for non-emotional stimuli have been investigated previously, the interrelationship between old/new effects, age and emotion has not received any attention yet. Furthermore, this study is to our knowledge the first to examine the effects of age on emotional recognition memory using the continuous recognition paradigm.

The behavioral results revealed no emotion enhancement of recognition discrimination in either of the age groups. Although the hit rate was increased for unpleasant pictures, this was cancelled out by an increased false alarm rate. This more liberal response bias for unpleasant pictures has been called the emotion-induced recognition bias (Budson et al., 2006; Windmann & Kutas, 2001) and reveals the tendency of both younger and older adults to classify unpleasant stimuli as old irrespective of their true new or old status (cf. Charles et al., 2003). In addition, new-unpleasant pictures were associated with delayed responses in both age groups, indicating that more processing time was required to decide whether these pictures were new or old. In short, besides the age-related decline of recognition memory in general, no age differences in emotional recognition memory were observed using the continuous recognition paradigm.

Age differences were, in contrast, observed in the emotional modulation of old/new effects, showing that the investigation of old/new effects has important additive value to behavioral measures when investigating age differences in emotional recognition memory. In the younger adults, the early old/new effect was not modulated by the emotional salience of the pictures (cf. Johansson et al., 2004; Maratos et al., 2000; Windmann & Kutas, 2001), while the parietal old/new effect was larger and more widespread for the emotional than for the neutral pictures (cf. Dietrich et al., 2001). Taking the early and parietal old/new effects as reflections of familiarity and recollection, respectively, these findings converge with the notion that the emotional salience of stimuli influences recollection more than familiarity (Comblain et al., 2004; Dewhurst & Parry, 2000; Ochsner, 2000). In the older adults, however, a different picture emerged. That is, the early old/new effect was present for the emotional but not for neutral pictures and the parietal old/new effect was absent altogether. Indeed, especially the recollection process is thought to weaken with aging (Light et al., 2000), and the current results suggest that it is the familiarity process that is enhanced for emotional stimuli in older adults instead.

Notably, the duration of the younger adults' parietal old/new effect appeared to be influenced by picture valence as it extended into the final time window (700-900 ms) for the pleasant, but not for the unpleasant or neutral pictures. However, this limited duration of the unpleasant old/new effect was actually caused by increased positivities for new-unpleasant pictures, and not by decreased positivities for old-unpleasant pictures (cf. Maratos et al., 2000). It has been hypothesized that these increased positivities in response to new-unpleasant pictures occur because these pictures elicit false memories, increased false alarm rates, and more liberal response biases (Maratos et al., 2000; McNeely, Dywan, & Segalowitz, 2004). In the current study however, a more liberal response bias for unpleasant pictures occurred in both age groups whereas the increased positivities for new-unpleasant pictures and the short-lived parietal old/new effect occurred in the younger adults only. So, interpreting the more positive waveform for new-unpleasant pictures as reflecting a more liberal response bias seems questionable, at least in the current study.

Age differences in emotional modulation were further observed in the late frontal old/new effect. In the younger adults, the late frontal old/new effect occurred for emotional, but not for neutral pictures, showing that post-retrieval operations such as source retrieval occurred for the emotional pictures only. In the older adults, no classic late frontal old/new effect was observed (cf. Trott et al., 1997; Trott et al., 1999; Wegesin et al., 2002). Instead an inverse old/new effect occurred at left frontal electrodes, which has been taken to represent the employment of age-specific compensatory memory strategies that are dependent on the left prefrontal cortex (cf. Swick & Knight, 1997; Swick et al., 2006). Importantly, this left frontal inverse old/new effect was not modulated by valence, so in contrast to the younger adults' strategies these older adults' memory strategies do not appear to be affected by the emotional salience of stimuli.

Age differences also occurred in emotional free recall as the younger adults recalled unpleasant and pleasant pictures equally well and better than neutral pictures, whereas the older adults recalled more pleasant than neutral pictures. The observed pattern of age differences in the effect of emotion on free recall is not a clear-cut positivity effect because the older adults did not recall significantly more pleasant than unpleasant pictures. Indeed, even though a positivity effect has previously been observed in free recall in some studies (Charles et al., 2003; Langeslag & Van Strien, 2009), it has not been observed in various other studies (Denburg et al., 2003; Grühn et al., 2005; Kensinger et al., 2002; Leigland et al., 2004). Adding to these latter findings, positivity effects neither occurred in the continuous recognition test or in the old/new effects in the present study. It has been shown that for a positivity effect to occur, the older adults have to deploy cognitive control (Mather & Knight, 2005). Although our older adults had completed less formal education than the younger adults, which is a nearly inevitable consequence of generational differences in educational possibilities, they were relatively well-educated and likely did not lack such control. Indeed, positivity effects did occur in the mood and arousal ratings. That is, the older adults reported more positive and less negative affect than the younger adults at time of testing (cf. Grühn et al., 2005; Mather & Knight, 2005; Mroczek & Kolarz, 1998) and the younger adults reported higher arousal for unpleasant than pleasant pictures, whereas the older adults reported equivalent arousal for unpleasant and pleasant pictures. So, age differences in emotional processing (with the positivity effect being a specific instance of such age differences) do not appear to occur consistently across different measures and tasks, and more research is needed to determine the origin of this variance.

To conclude, in contrast to emotional free recall, no age differences were observed in emotional continuous recognition performance. Nevertheless, the emotional modulation of ERP old/new effects did differ with age. The parietal and late frontal old/new effects were enhanced for emotional stimuli in the younger adults, while the early old/new effect was enhanced for emotional stimuli in the older adults. This suggests that while recollection and post-retrieval processes are augmented in emotional recognition memory in younger adults, familiarity is enhanced by emotional salience in older adults.

Chapter 5

Electrophysiological correlates of improved short-term memory for emotional faces

This chapter has been published as:
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This study has been presented as:
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Abstract

Long-term memory (LTM) is enhanced for emotional information, but the influence of stimulus emotionality on short-term memory (STM) is less clear. We examined the electrophysiological correlates of improved visual STM for emotional face identity, focusing on the P1, N170, P3b and N250r event-related potential (ERP) components. These correlates are taken to indicate which memory processing stages and cognitive processes contribute to the improved STM for emotional face identity. In the encoding phase, one or three angry, happy or neutral faces were presented for 2 s, resulting in a memory load of one or three. The subsequent 1-s retention phase was followed by a 2-s retrieval phase, in which participants indicated whether a probe face had been present or not during encoding. Memory performance was superior for angry and happy faces over neutral faces at load three. None of the ERP components during encoding were affected by facial expression. During retrieval, the early P3b was decreased for emotional compared to neutral faces, which presumably reflects greater resource allocation to the maintenance of the emotional faces. Furthermore, the N250r during retrieval was increased for emotional compared to neutral faces, reflecting an enhanced repetition effect for emotional faces. These findings suggest that enhanced visual STM for emotional faces arises from improved maintenance and from improved detection of face repetition at retrieval.

Introduction

In long-term memory (LTM), emotional stimuli are better encoded, consolidated, and retrieved than neutral stimuli, which results in an emotion enhancement effect on LTM (Hamann, 2001; Kensinger, 2004, 2007; LaBar & Cabeza, 2006; Phelps, 2004). The effect of stimulus emotionality on short-term memory (STM), however, is less well established. Recent research has shown better STM for the identity of angry faces compared to happy or neutral faces (Jackson, Wu, Linden, & Raymond, 2009). Functional magnetic resonance imaging (fMRI) revealed that the behavioural benefit for angry faces is supported by enhanced activation in the right superior temporal sulcus region, ventrolateral prefrontal cortex and basal ganglia (Jackson, Wolf, Johnston, Raymond, & Linden, 2008). Because of its temporal resolution, fMRI only provides limited information about the phase of the memory process at which the effect of facial expression on STM occurs.

Event-related potentials (ERPs) are a more useful measure for determining which stages of processing are influenced by a certain experimental manipulation (Linden, 2007; Luck, 2005) and ERP research on face processing and STM has yielded a number of components that index the different stages of face evaluation, encoding, and retrieval. In the current study, we measured ERPs during a task requiring STM for the identity of emotional faces (Jackson et al., 2008; Jackson et al., 2009). Examination of the electrophysiological markers may reveal during which memory phase (i.e. encoding, maintenance and/or retrieval) the emotion enhancement effect on STM occurs and may indicate the cognitive processes (such as structural face encoding, resource allocation etc.) involved. Because of the methodological problems of such reverse inferences (Henson, 2006) it is important to use neural signatures that are robustly and specifically associated with certain cognitive processes.

In a previous study (Morgan, Klein, Boehm, Shapiro, & Linden, 2008), the effect of memory load on the ERP was investigated using the same STM task as the above-mentioned studies, but with neutral faces only. The ERP waveform during the encoding and retrieval phases contained the P1, N170, P3b, and N250r components, with the latter three components being modulated by the number of faces that had to be remembered. In the current study, using the STM task with angry, happy, and neutral faces, we investigated whether the P1, N170, P3b and N250r are modulated by facial expression, to see if any of those components are an electrophysiological correlate of improved STM for emotional faces. We selected the P1 because it is a marker of the integrity of early visual processing and its amplitude has been associated with later STM retrieval success (Haenschel et al., 2007). The other components were selected because of their prominent and well-studied role in face perception (N170), memory (P3b) and face repetition (N250r).

The N170 is a negative component over inferior occipito-temporal electrodes that is thought to originate from posterior-lateral occipito-temporal cortex (Schweinberger, Pickering, Jentzsch, Burton, & Kaufmann, 2002). The N170 presumably reflects the structural encoding of face stimuli prior to face recognition and is usually unaffected by facial expression (e.g. Eimer & Holmes, 2002). Nevertheless, in some studies the N170, and even the earlier P1, have been found to be modulated by facial expression (e.g. Batty & Taylor, 2003; Sprengelmeyer & Jentzsch, 2006). However, because those modulations were not expression-specific, it has been suggested that they reflect non-specific configural and attention effects rather than emotion effects (Vuilleumier & Pourtois, 2007). In the current study it is therefore hypothesized that the P1 and N170 will not be electrophysiological correlates of the emotion enhancement effect on STM.

The P3b component is a positive deflection that occurs from about 300 ms after stimulus onset and is maximal at posterior electrodes. In general, the P3b is thought to reflect processing capacity or resource allocation (Kok, 2001; Polich, 2007). The P3b is normally increased for emotional compared to neutral stimuli (see Olofsson, Nordin, Sequeira, & Polich, 2008; Schupp, Flaish, Stockburger, & Junghöfer, 2006) and has shown an amplitude increase in response to fearful compared to neutral, and to threatening compared to friendly and neutral faces (Eimer & Holmes, 2002; Schupp, Öhman et al., 2004). The enhanced P3b for emotional stimuli is taken to reflect the capture of attention by stimuli that are emotionally significant (Kok, 2001; Langeslag, Franken, & Van Strien, 2008; Schupp, Cuthbert et al., 2004; Schupp et al., 2006).

During retrieval from STM, the P3b typically decreases with increasing memory load (Busch & Herrmann, 2003; Kok, 2001; Morgan et al., 2008), implying that fewer resources are allocated to the probe stimuli as more resources are allocated to maintenance processes (Kok, 2001). Interestingly, in a study in which spatial STM for non-emotional stimuli was tested following the induction of different emotional states, the P3b elicited by the probe stimulus was smaller during a negative than during a neutral state, indicating that the negative state diverted resources away from the probe (Li, Li, & Luo, 2006). Likewise, a smaller P3b occurred in response to acoustic startle probes that were preceded by emotional versus neutral sounds or pictures, and this P3b suppression was interpreted as the allocation of resources to processing the emotional stimulus preceding the probe at the expense of processing the probe stimulus itself (Keil et al., 2007; see also Schupp, Cuthbert et al., 2004). Thus, although the P3b is typically larger for emotional than neutral stimuli, it appears to be decreased for stimuli that have to compete for processing resources with preceding or ongoing emotional information. From the existing literature then, two contrasting hypotheses can be formulated for the current study. On the one hand, the P3b during encoding and/or retrieval could be larger for emotional compared to neutral faces. This would indicate that emotional faces are allocated increased processing resources, which could explain the emotion enhancement effect on STM. Alternatively, because an emotional probe face is preceded by the maintenance in STM of one or more emotional encoding faces, the P3b during retrieval may actually be decreased for emotional compared to neutral faces. In this scenario, more processing resources would be deployed for the maintenance of the emotional compared to neutral faces, which could account for the emotion enhancement effect as well.

In previous STM studies, the P3b consisted of an early and a late subcomponent, occurring between 300 and 400 ms and between 400 and 700 ms after stimulus onset respectively. In the context of STM retrieval, the early P3b might reflect stimulus evaluation whereas the late P3b may reflect memory search operations (Bledowski et al., 2006; Morgan et al., 2008). The P3b elicited by emotional stimuli has also been found to consist of two parts (e.g. Amrhein, Mühlberger, Pauli, & Wiedemann, 2004), where the early P3b has been taken to reflect resource allocation due to task-relevance or emotional salience and the late P3b (or slow wave) is associated with LTM formation and top-down control of emotional processing (Olofsson et al., 2008). Because the current study does not concern LTM or top-down control, it is expected that any emotional modulation of the P3b would occur in its early, and not in its late part.

The N250r or early repetition effect (ERE) is a relative negativity over inferior temporo-parietal electrodes and relative positivity over fronto-central electrodes for repeated compared to new faces around 300 ms after stimulus onset (see Schweinberger & Burton, 2003). The N250r only occurs for face repetitions across a short time period and is not observed for longer delays (Schweinberger, Pickering, Burton, & Kaufmann, 2002), suggesting that it is related to STM processes (see also Morgan et al., 2008). Because the N250r is larger for repeated familiar than unfamiliar faces, it is thought to reflect the activation of face recognition units (FRUs) (Herzmann, Schweinberger, Sommer, & Jentzsch, 2004; Schweinberger & Burton, 2003; Schweinberger, Pfütze, & Sommer, 1995). These FRUs match the products of the structural encoding process with stored structural codes that describe familiar faces, and this matching processes is supposed to be abstract and independent of image-specific details such as facial expressions (Bruce & Young, 1986; see also Haxby, Hoffman, & Gobbini, 2000). The N250r appears to originate from the fusiform gyrus (Schweinberger, Pickering, Jentzsch et al., 2002), where the fusiform face area (FFA) that is concerned with face identification (Haxby et al., 2000) is located. Indeed, a series of studies has suggested that the FFA codes face identity irrespective of facial expression, whereas the superior temporal sulcus processes facial expressions (Haxby et al., 2000; Schwaninger, Wallraven, Cunningham, & Chiller-Glaus, 2006; Schweinberger & Burton, 2003; Vuilleumier & Pourtois, 2007).

However, previous findings challenge the notion that FRUs are ignorant of changeable aspects of faces. The N250r was, for example, larger when a probe face was preceded by the same, as opposed to a different picture of the same individual (Schweinberger, Pickering, Jentzsch et al., 2002). Moreover, accumulating behavioural and neuroimaging evidence suggests that the processing of face identity and expression are not entirely separable (Calder & Young, 2005; Vuilleumier & Pourtois, 2007). That is, even though face identity appears to be processed independently of task-irrelevant facial expression, expression judgements are slowed by task-irrelevant variations in face identity (Schweinberger, Burton, & Kelly, 1999; Schweinberger & Soukup, 1998). Furthermore, familiar angry faces have been found to be recognized more slowly than familiar happy faces (Kaufmann & Schweinberger, 2004), and faces with a positive expression were judged as being more familiar and faces with a negative expression as less familiar compared to neutral faces (Baudouin, Gilibert, Sansone, & Tiberghien, 2000; Lander & Metcalfe, 2007). Also, FFA activity has been found to be affected by facial expression. Greater FFA activity has been reported for fearful versus neutral faces during a perceptual face matching task (Vuilleumier, Armony, Driver, & Dolan, 2001). In the fMRI study using the same STM task as the current study, the FFA was more activated by angry than by happy and neutral faces (Jackson et al., 2008). To our knowledge, it has not been investigated before whether the N250r is modulated by facial expression, but the above mentioned behavioural and fMRI findings suggest that this may actually be the case. Because the N250r reflects a repetition effect, any emotional modulation would be a sign of interacting STM and emotional processes. We therefore predict that the N250r may be an electrophysiological correlate for the emotion enhancement effect on STM, because it may be augmented for emotional versus neutral faces.

To summarize, in the current study we investigated whether the P1, N170, P3b and N250r components are an electrophysiological correlate of improved STM for emotional faces. Previous findings reported in the literature led to the hypotheses that especially the early P3b at retrieval and the N250r would be correlates of the emotion enhancement of visual STM.

Method

Participants

Twenty-nine students (15 men, mean age 19.7 years, age range 18-24 years) of the Erasmus University Rotterdam participated in return for course credit or monetary compensation. All participants were right-handed as determined by a hand preference questionnaire (Van Strien, 1992) and not depressed as assessed by the Beck Depression Inventory (Beck, Ward, Mendelson, Mock, & Erbaugh, 1961). Furthermore, all participants reported normal or corrected-to-normal vision, normal neurological and psychiatric health, and no use of drugs that are known to affect the central nervous system. The study was approved by the local ethics committee for psychological research and the participants gave written informed consent prior to testing.

Stimuli and short-term memory task

The stimuli for the visual STM task were 18 gray-scaled male faces from the Ekman and Friesen (1976) series: six individuals each displaying angry, happy and neutral facial expressions. Each stimulus subtended a visual angle of 1.5° vertically and 1.3° horizontally and was presented against a white background. A trial consisted of the following displays, see Figure 1. First, a red fixation cross was presented for 1000 ms to indicated that the trial was about to start. Next, during the encoding phase an array of faces was presented for 2000 ms. This encoding array consisted of either one to-be-remembered face and three scrambled faces or of three to-be-remembered faces and one scrambled face, resulting in a memory load of one or three respectively. The faces were arranged in a two by two grid around a black fixation cross (0.2°) in the centre of the screen with the centre of each stimulus 1° away from the fixation cross. A 1000 ms retention display followed, consisting of a black fixation cross. During the retrieval phase a probe face appeared in the centre of the screen for 2000 ms. Participants had to decide whether or not the probe face matched one of the faces in the preceding encoding array (50% match trials). Finally, during the inter-trial-interval a black fixation cross was presented with a varying duration between 2000 and 4000 ms.

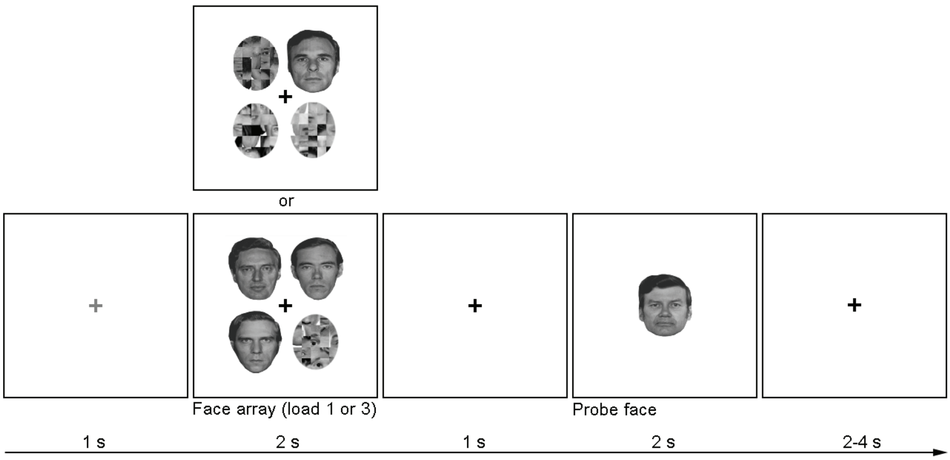

Figure 1. Trial overview.

After some practice trials, the participants completed a total of 300 experimental trials (3 expressions x 2 loads x 2 match/mismatch x 25 trials per condition). The order of the trials was random with respect to memory load, facial expression, face identity, location occupied, and match/mismatch. The experimental trials were divided into five blocks interleaved with breaks. After the last STM block, the electrode cap was removed and the participants rated the valence and arousal of each face with a computerized version of the Self-Assessment Manikin (SAM) (Lang, 1980).

Electroencephalogram (EEG) recording and signal processing

The electroencephalogram (EEG) was recorded using a 64-channel amplifier and data acquisition software (ActiveTwo System, Biosemi, Amsterdam). The Ag-AgCl Active electrodes were placed upon the scalp by means of an elastic head cap (Biosemi, Amsterdam), according to the 10-10 International System (Fpz, Fp1/2, AFz, AF3/4, AF7/8, Fz, F1/2, F3/4, F5/6, F7/8, FCz, FC1/2, FC3/4, FC5/6, FT7/8, Cz, C1/2, C3/4, C5/6, T7/8, CPz, CP1/2, CP3/4, CP5/6, TP7/8, Pz, P1/2, P3/4, P6/7, P9/10, POz, PO3/4, PO7/8, Oz, O1/2, Iz) (American Clinical Neurophysiology Society, 2003). Vertical electro-oculogram and horizontal electro-oculogram were recorded by attaching additional electrodes (UltraFlat Active electrodes, BioSemi, Amsterdam) respectively above and below each eye, and at the outer canthi of both eyes. An active electrode (CMS – common mode sense) and a passive electrode (DRL – driven right leg) were used to comprise a feedback loop for amplifier reference. All signals were digitized with a sampling rate of 512 Hz, a 24-bit A/D conversion, and a low pass filter of 134 Hz.

One male participant was excluded because of excessive EEG artefacts and was replaced. In nine participants, one to three bad channels were corrected using spherical spline interpolation, in accordance with the guidelines by Picton et al. (2000). Offline, an average reference was applied and a phase shift-free Butterworth filter with a low cut-off of 0.5 Hz (12 dB/oct roll off) and a high cut-off of 20 Hz (48 dB/oct roll off) was applied. The EEG of trials with correct responses was segmented into epochs lasting from 200 ms before the onset of the encoding phase until the end of the retrieval phase. Ocular correction was applied using the Gratton and Coles algorithm (Gratton, Coles, & Donchin, 1983) and the 200 ms pre-encoding interval was used for baseline correction. Then, epochs were further segmented into separate encoding and retrieval epochs[1] that lasted from 200 ms pre-stimulus onset until 800 ms post-stimulus onset. Epochs with baseline-to-peak exceeding -75 or +75 µV or a voltage skip (gradient) exceeding 50 µV were rejected. Encoding and retrieval epochs were classified

1 The signal during the retention phase was not analysed because no ERP-eliciting stimulus (except for a fixation cross) was presented. In addition, any slow potentials (see Drew, McCollough, & Vogel, 2006) occurring in the retention phase could not be analyzed because of the high low cut-off of the filter, which was applied precisely to reduce such slow potentials so that a pre-encoding baseline could be used for the retrieval phase waveform.

according to facial expression, memory load and match/mismatch (retrieval epochs only). For the encoding phase, a mean number of 43.3 (*SD* = 5.6) out of 50 epochs per condition were included in the analysis. For the retrieval phase, a mean number of 21.5 (*SD* = 3.5) out of 25 epochs per condition were included in the analysis.

Peaks were detected as local maxima and minima in certain time windows and at electrodes determined by visual inspection of the grand averages and scalp topographies, see Figures 3 to 5, and previous research. The P1 was detected between 80 and 140 ms and the N170 between 140 and 210 ms in channels PO7 and PO8. For the P1 and the N170, peak amplitudes and latencies per channel were entered into the analysis. The early and late P3b were detected between 290 and 400 ms and between 400 and 700 ms respectively, at electrodes PO7, PO8 and POz, and peak latencies and mean amplitudes of the 50 ms time window around the peak per channel were submitted to the analysis[2]. The N250r was obtained in difference waves (match – mismatch) at retrieval. Because this peak could not be identified in all waveforms of the individual participants, its latency was determined from the grand average waveform (approximately 305 ms) and the mean amplitudes from a 50 ms time window around this peak (280-330 ms) at electrodes P9, P10 and FCz were entered into the analyses.

Analyses

The hit rates (*H*, i.e. proportion correct 'match' responses) and false alarms rates (*FA*, i.e. proportion incorrect 'match' responses) were computed using the correction recommended by Snodgrass and Corwin (1988). Memory performance was represented by the discrimination index $Pr = H - FA$, where $Pr = 1$ reflects perfect performance and $Pr = 0$ reflects chance performance, and by the response bias index $Br = FA / (1 - Pr)$. The response bias index describes the tendency of participants to respond 'match' irrespective of the true match or mismatch status of the probe stimulus, where $Br > 0.5$ indicates a liberal response bias and $Br < 0.5$ indicates a conservative response bias (Snodgrass & Corwin, 1988).

The data were analyzed with repeated measures analysis of variance with several factors. The valence and arousal ratings were analyzed with the factor Expression (angry, happy,

[2] Because the P3b is conventionally analyzed at parietal electrodes, the current P3b amplitude analyses were additionally run on both parietal (P5, Pz, P6) and parieto-occipital (PO7, POz, PO8) electrodes with the additional factor Caudality. These analyses showed that the P3b amplitudes and observed effects were either largest at parieto-occipital electrodes or equivalent at parietal and parieto-occipital electrodes, thereby justifying our reported analyses on parieto-occipital electrodes only. More specifically, during encoding the early P3b amplitude and the observed load effect were larger at parieto-occipital than at parietal electrodes, both Fs > 10.8, both ps < .004, whereas the late P3b amplitude and the observed electrode, load and electrode x load effects did not significantly differ between parietal and parieto-occipital electrodes, all Fs < 4.1, all ps > .052. During retrieval, the early P3b amplitude and the observed expression and match/mismatch effects were largest at parieto-occipital electrodes, all Fs > 5.0, all ps < .032, as was the match/mismatch effect on the late P3b, $F(1,28) = 7.5$, $p = .001$.

neutral). The memory performance measures *Pr* and *Br*[3] were analyzed with factors Expression and Load (1, 3). The median reaction times (RTs) for correct responses were analyzed with factors Expression, Load and Match/Mismatch. During encoding, the P1 and N170 amplitude and latency were analyzed with factors Hemisphere, Expression and Load. The early and late P3b amplitudes and latencies were analyzed with factors Electrode (PO7, POz, PO8), Expression and Load. During retrieval, the same P1, N170, early P3b and late P3b analyses with the additional factor Match/Mismatch were run. The N250r amplitude at P9 and P10 was analyzed with factors Hemisphere, Expression and Load, and the N250r amplitude at FCz with factors Expression and Load.

When applicable, degrees of freedom were corrected with the Greenhouse-Geisser correction. The *F* values, the uncorrected *df*s, the epsilon (ε) values and corrected probability levels are reported. A significance level of 5% (two-sided) was selected and only the significant ANOVA effects are presented. If necessary, significant effects were followed up by paired samples *t*-tests.

Results

Behavioural data

Valence and arousal ratings

The participants' mean valence and arousal ratings of the faces are displayed in Table 1. For the valence ratings the effect of Expression was significant, $F(2,56) = 153.7$, $\varepsilon = .68$, $p < .001$. Angry faces were associated with lowest valence, neutral faces with intermediate valence, and happy faces with highest valence, all *p*s < .001. Also for the arousal ratings the effect of Expression was significant, $F(2,56) = 51.2$, $\varepsilon = .97$, $p < .001$. Neutral faces were associated with lowest arousal, both *p*s < .001, whereas angry and happy faces did not differ in arousal, $p = .88$.

Table 1. Mean valence and arousal ratings (standard deviation in brackets) of the faces.

	Angry	Happy	Neutral
Valence	3.3 (1.1)	7.3 (0.8)	4.8 (0.6)
Arousal	5.8 (1.4)	5.7 (1.3)	3.3 (1.2)

Note. Valence and arousal ratings ranged from 1 (extremely unpleasant or calm) to 9 (extremely pleasant or aroused).

[3] When analyzing *d'* and *C*, as discrimination and bias indices respectively, the same pattern of results was obtained.

Memory performance

See Figure 2 for a graphical depiction of the mean discrimination index per condition. A main effect of Load was observed, $F(1,28) = 177.9$, $p < .001$, indicating that discrimination was better in load 1 than in load 3. Further, a main effect of Expression occurred, $F(2,56) = 14.7$, $\varepsilon = .97$, $p < .001$. Discrimination was poorer for neutral compared to angry and happy faces, both *p*s < .001, but was equivalent for angry and happy faces, $p = .98$. This main effect was modulated by a significant Expression x Load interaction, $F(2,56) = 6.6$, $\varepsilon = 1.00$, $p = .003$, wherein the benefit for emotional faces occurred in load 3 only, both *p*s < .001, all other *p*s > .12.

For the response bias *Br*, a main effect of Load was present, $F(1,28) = 6.5$, $p = .017$, indicating that response bias was more conservative in load 3 ($M = .39$, $SD = .19$) than in load 1 ($M = .47$, $SD = .15$). This means that when participants were uncertain, they were more inclined to respond 'match' in load 1 compared to load 3.

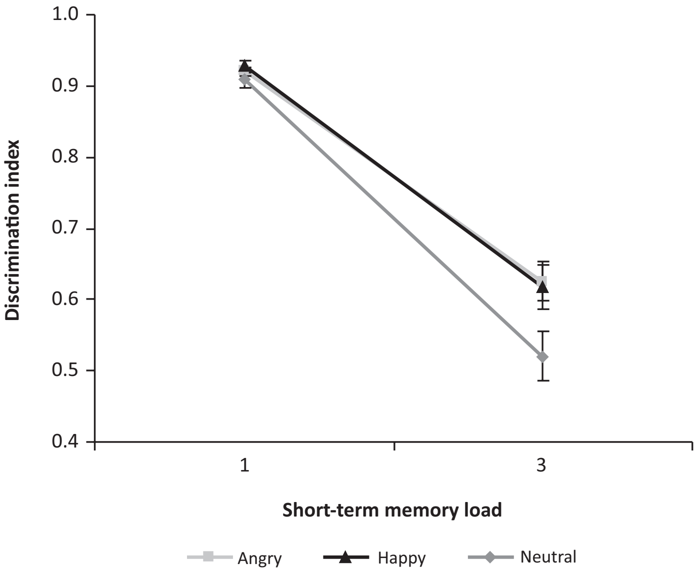

Figure 2. Performance as reflected by the discrimination index for angry, happy and neutral faces at memory loads 1 and 3.

Reaction times

See Table 2 for the median RTs for correct responses. A main effect of Load occurred, $F(1,28) = 195.7$, $p < .001$, indicating that RTs were longer for load 3 than 1. Further, a significant

Expression x Match/Mismatch interaction occurred, *F*(2,56) = 5.0, ε = .98, *p* = .011: responses to happy faces on match trials (*M* = 755 ms) were faster than responses to happy faces on mismatch trials (*M* = 797 ms), *p* = .005, both other *p*s > .88 (cf. Werheid, Alpay, Jentzsch, & Sommer, 2005).

Table 2. Median RTs (standard deviation in brackets) for correct responses in milliseconds.

		Angry	Happy	Neutral
Load 1	**Match**	650 (103)	641 (120)	678 (105)
	Mismatch	679 (111)	684 (101)	677 (106)
Load 3	**Match**	906 (194)	869 (143)	878 (130)
	Mismatch	879 (147)	911 (174)	883 (150)

Event-related potentials

Encoding

See Figure 3 for the P1, N170, early P3b and late P3b scalp topographies and the grand average waveforms at electrodes PO7, POz and PO8 during encoding.

P1. A main effect of Hemisphere on P1 latency occurred, *F*(1,28) = 6.9, *p* = .014, which indicated that the P1 occurred earlier at the right (*M* = 102 ms) than at the left hemisphere (*M* = 107 ms). None of the Load or Expression effects on P1 amplitude or latency were significant.

N170. A significant effect of Load, *F*(1,28) = 26.4, *p* < .001, showed that N170 amplitude was larger for load 3 than for load 1. With respect to N170 latency, the main effect of Load was significant, *F*(1,28) = 24.9, *p* < .001. The N170 occurred later for load 3 (*M* = 167 ms) than for load 1 (*M* = 164 ms). None of the Expression effects on N170 amplitude or latency were significant.

Early P3b. There was a main effect of Electrode, *F*(2,56) = 13.0, ε = .87, *p* < .001. The early P3b was largest at electrode PO8, both *p*s < .001. A significant effect of Load occurred as well, *F*(1,28) = 14.6, *p* = .001, showing that the early P3b amplitude was larger for load 1 than for load 3. Regarding the latency of the early P3b, there was a main effect of Load, *F*(1,28) = 9.6, *p* = .004, indicating that the early P3b occurred later for load 3 (*M* = 345 ms) than for load 1 (*M* = 338 ms). However, the Electrode x Load interaction was also significant, *F*(2,56) = 3.5, ε = .95, *p* =.041, showing that the load effect on early P3b latency occurred at lateral electrodes only, both *p*s < .026. None of the Expression effects on early P3b amplitude or latency reached significance.

Late P3b. A significant main effect of Electrode occurred, *F*(2,56) = 8.0, ε = .94, *p* = .001, with largest amplitude at electrode POz, both *p*s < .009. There was also a main effect of Load, *F*(1,28) = 5.6, *p* = .026, showing that the late P3b was larger for load 1 than for load 3. In addition, a significant Electrode x Load interaction was present, $F(2,56) = 3.3$, $\varepsilon = 1.00$, $p = .044$, as the load effect occurred at electrode PO8 only, $p = .001$. None of the Expression effects on late P3b amplitude or latency reached significance, nor did any of the Load effects on late P3b latency.

Summary. The N170 (structural face encoding) was larger with increasing load. In contrast, both the right-lateralized early P3b and the late P3b (processing capacity or resource allocation) were smaller with higher memory load. While the load effects on the N170 and the late P3b replicate previous findings (Morgan et al., 2008), the load effect on the early P3b does not. Nevertheless, these load effects during encoding cannot be interpreted unambiguously because they may simply reflect perceptual load differences in the encoding array: more faces and less scrambled faces with increasing load. Of more importance for the current research question, none of the investigated peaks showed modulation by facial expression.

Retrieval

See Figure 4 for the P1, N170, early P3b and late P3b scalp topographies and the grand average waveforms at electrodes P9, PO7, POz, PO8 and P10 during retrieval.

P1. There were no significant effects on P1 amplitude or latency.

N170. A significant main effect of Match/Mismatch on N170 latency occurred, $F(1,28) = 14.1$, $p = .001$, showing that the N170 at electrodes PO7 and PO8 occurred earlier for match ($M = 171$ ms) than mismatch probes ($M = 173$ ms). None of the effects on N170 amplitude at electrodes PO7 and PO8 were significant. Visual inspection of the N170 topography, however, revealed that at retrieval this component was maximal at electrode P9 and P10 and not at electrodes PO7 and PO8 as was the case at encoding. Therefore, the N170 amplitude and latency were also analyzed at electrodes P9 and P10. There was a main effect of Hemisphere, $F(1,28) = 5.3$, $p = .029$, indicating that the N170 was larger over the left than right hemisphere. A significant main effect of Load, $F(1,28) = 5.4$, $p = .028$, showed that the N170 was larger for load 1 than for load 3. Concerning N170 latency, a significant Hemisphere x Load interaction occurred, $F(1,28) = 5.9$, $p = .002$, but none of the post hoc comparisons reached significance, all ps > .08. None of the Expression or Match/Mismatch effects on N170 amplitude or latency reached significance.

Early P3b. The main effect of Electrode was significant, $F(2,56) = 15.1$, $\varepsilon = .96$, $p < .001$. The early P3b was larger at electrodes POz and PO8 than at electrode PO7, both ps < .001. The main effect of Expression was significant, $F(2,56) = 9.5$, $p < .001$. The early P3b was smaller for angry and happy than for neutral faces, both ps < .004, but similar for angry and happy faces, $p = .68$. The main effect of Load, $F(1,28) = 4.6$, $p = .040$, indicated that the early P3b was larger for load 1 than for load 3. The main effect of Match/Mismatch, $F(1,28) = 6.1$, $p = .020$, showed that the early P3b was larger for mismatch probes than for match probes. In addition, an Electrode x Match/Mismatch interaction occurred, $F(2,56) = 8.5$, ε = .92, $p = .001$. The match/mismatch effect was present at electrode PO7 only, $p < .001$. Concerning the latency of the early P3b, an effect of Load was observed, $F(1,28) = 9.0$, $p = .006$. The early P3b occurred earlier for load 3 (M = 336 ms) than for load 1 (M = 340 ms). Moreover, a significant Load x Match/Mismatch interaction was found, $F(1,28) = 13.3$, $p = .001$. The load effect on early P3b latency occurred on match trials only, $p = .021$.

Late P3b. The main effect of Electrode was significant, $F(2,56) = 20.6$, ε = .97, $p < .001$. The late P3b was largest at electrode POz, intermediate at PO8 and smallest at PO7, all *p*s < .009. The significant main effect of Load, $F(1,28) = 8.8$, $p = .006$, indicated that the late P3b was larger for load 1 than load 3. The main effect of Match/Mismatch, $F(1,28) = 7.7$, $p = .010$, revealed that the late P3b was larger for match probes than for mismatch probes. Regarding the latency of the late P3b, an effect of Electrode occurred, $F(2,56) = 6.7$, ε = .98, $p = .003$. The late P3b occurred earlier at electrode PO8 (M = 506 ms) than at electrodes POz (M = 531 ms) and PO7 (M = 534 ms), both *p*s < .006. In addition, the significant main effect of Match/Mismatch, $F(1,28) = 43.7$, $p < .001$, indicated that the late P3b occurred earlier on match trials (M = 510 ms) than on mismatch trials (M = 537 ms). Finally, a significant Electrode x Load interaction was found, $F(2,56) = 4.5$, ε = .95, $p = .017$. At electrode PO8, the late P3b occurred earlier for load 3 (M = 490 ms) than for load 1 (M = 522 ms). None of the Expression effects on late P3b amplitude or latency were significant.

N250r. See Figure 5 for the N250r scalp topography and the grand averages of the difference between match and mismatch trials at electrodes P9, P10 and FCz. At electrodes P9 and P10, a significant main effect of Load, $F(1,28) = 24.1$, $p < .001$, indicated that the N250r was larger for load 1 than for load 3. Nevertheless, the N250r was still present at load 3, as shown by a one-sample *t*-test, $t(28) = -3.5$, $p = .001$. The main effect of Expression was also significant, $F(2,56) = 3.9$, ε = 1.00, $p = .025$. The N250r was larger for angry than neutral faces, $p = .011$, with the N250r for happy faces non-significantly different in-between. At electrode FCz, the main effect of Load was significant, $F(1,28) = 31.5$, $p < .001$, showing that the frontal positivity associated with the N250r was larger for load 1 than for load 3. The frontal counterpart of the N250r was still present for load 3 as shown by a one-sample *t*-test, $t(28) = 3.7$, $p = .001$. Moreover, the main effect of Expression was significant, $F(2,56) = 4.4$, ε = .84, $p = .022$; the frontal counterpart of the N250r was larger for both angry and happy compared to neutral faces, both *p*s < .028, whereas it was similar for angry and happy faces, $p = .86$.

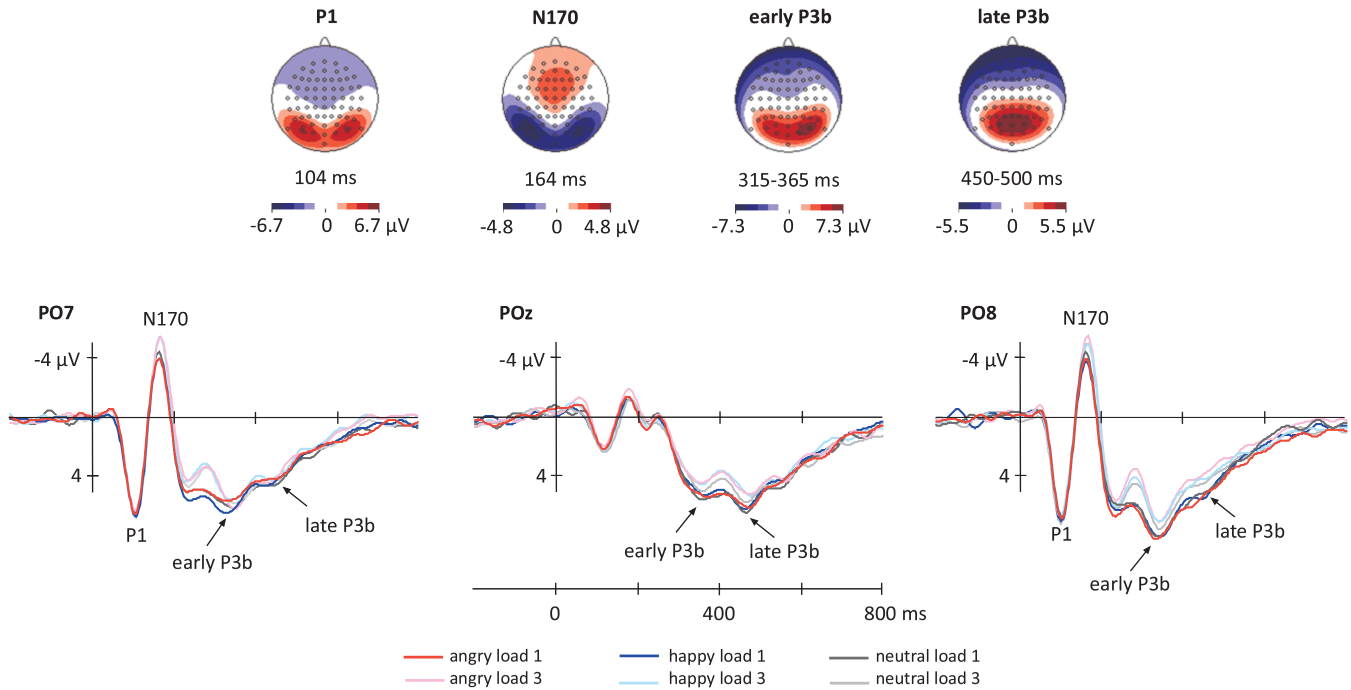

Figure 3. The P1, N170, early P3b and late P3b scalp topographies and the grand average waveforms at electrodes PO7, POz and PO8 during encoding.

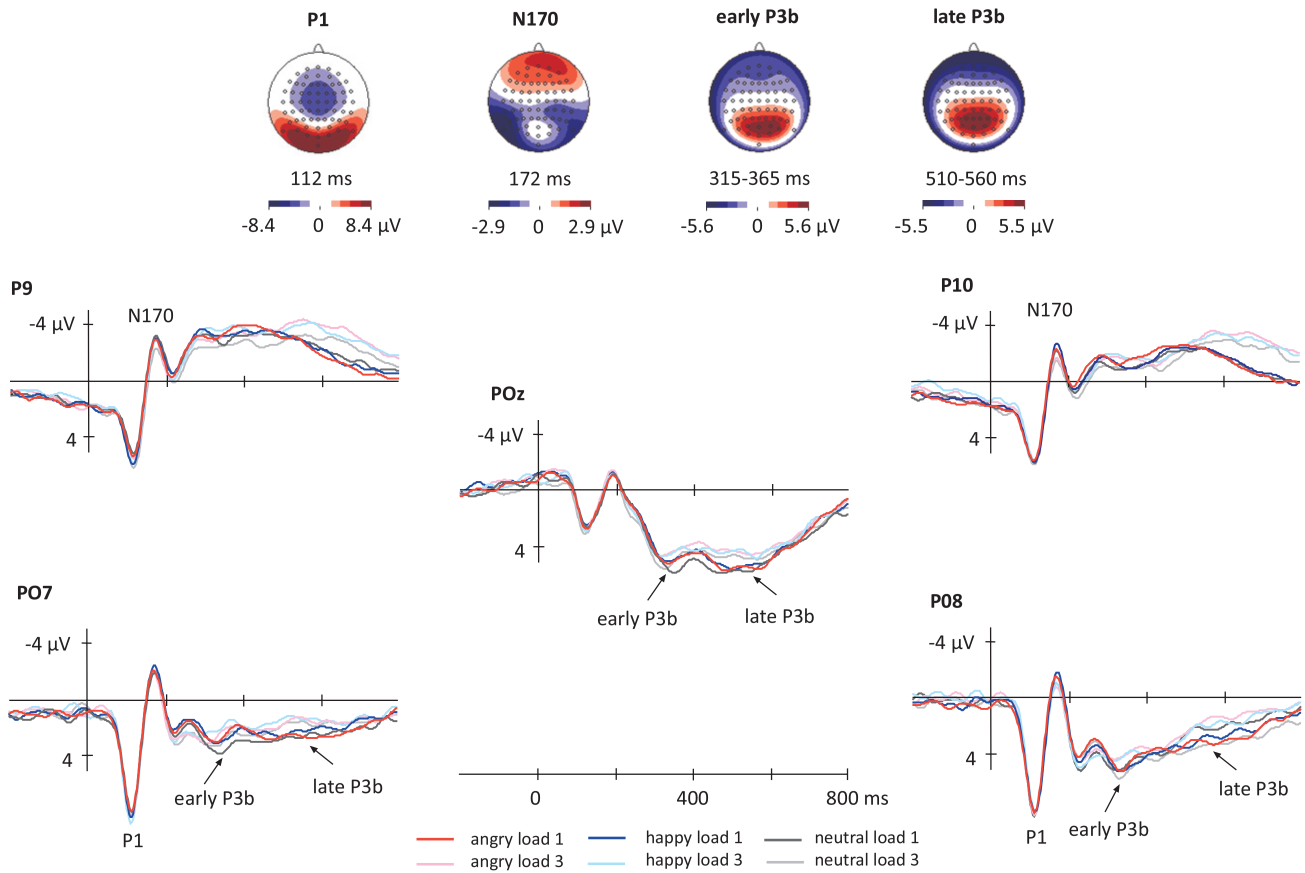

Figure 4. The P1, N170, early P3b and late P3b scalp topographies and the grand average waveforms at electrodes P9, PO7, POz, PO8 and P10 during retrieval. Note that a pre-encoding interval was used for baseline correction (see Methods).

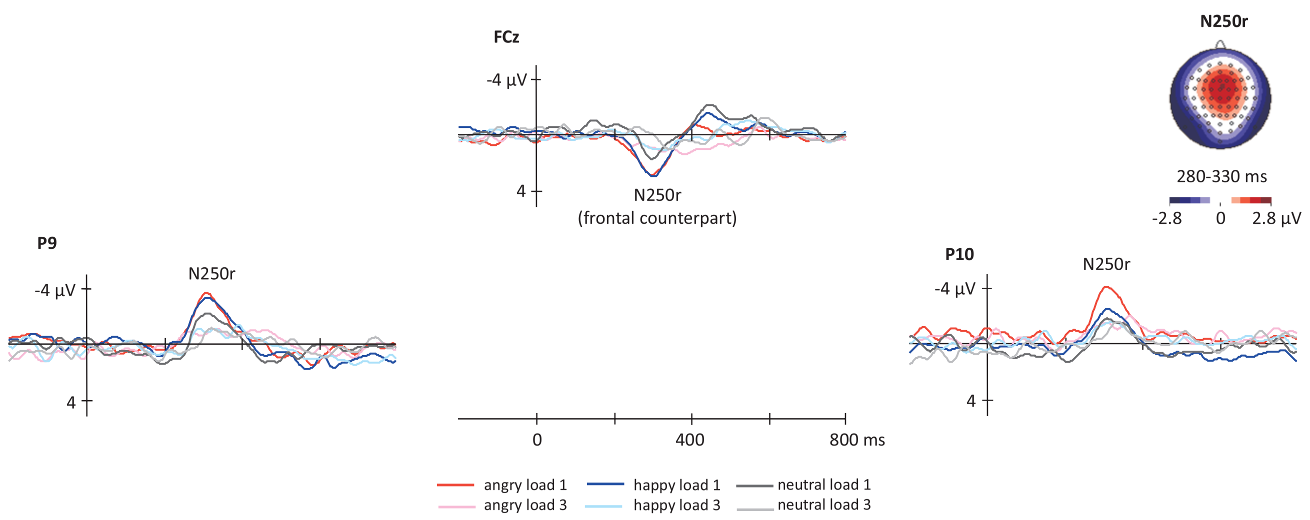

Figure 5. The scalp topography of the difference waves (match - mismatch) for load 1 between 280-330 ms after stimulus onset and the grand averages of the difference waves at electrodes P9, FCz and P10. Note that a pre-encoding interval was used for baseline correction (see Methods).

Summary. The N170 (structural face encoding), the right-lateralized early P3b, the late P3b (processing capacity or resource allocation) and the N250r (face repetition effect) showed suppression with increasing memory load. These load effects are a replication of Morgan et al. (2008) and the reader is referred to that article for an extensive discussion of these load effects. The absence of differences between match and mismatch trials on the P1 (early visual processing) and N170 amplitude is in agreement with studies that did not show a priming effect on these components (Schweinberger, Huddy, & Burton, 2004; Schweinberger, Pickering, Jentzsch et al., 2002). The topographical shift of the N170 from parieto-occipital electrodes at encoding to parietal electrodes at retrieval is interesting and deserves further investigation. The larger early P3b for mismatch than match trials indicates that mismatch probes require more stimulus evaluation than match probes. Moreover, the larger late P3b for match than mismatch trials presumably reflects the parietal old/new effect (see Rugg & Allan, 2000; Schweinberger, Pickering, Jentzsch et al., 2002). Of most importance for the present research question, however, both the early P3b and the N250r showed emotional modulation; the early P3b was decreased for emotional compared to neutral faces, whereas the N250r was increased for emotional compared to neutral faces.

Discussion

In this study, visual STM performance was improved for angry and happy compared to neutral faces when memory load was high. The goal of this study was to examine the electrophysiological correlates of this improved STM for emotional faces. These electrophysiological correlates could inform us whether the emotion enhancement effect on STM has its origin during encoding, maintenance and/or retrieval. Furthermore, they may illustrate what cognitive processes, which may or may not be specific to STM, are involved in the occurrence of this effect. The results showed that both the early P3b and the N250r during retrieval were modulated by facial expression.

The early P3b during retrieval was smaller for emotional compared to neutral faces. This stands in contrast to previous studies using faces or other stimuli, in which the P3b is usually larger for emotional compared to neutral stimuli because emotionally salient stimuli capture attention more than neutral stimuli (Eimer & Holmes, 2002; Olofsson et al., 2008; Schupp et al., 2006; Schupp, Öhman et al., 2004). But when viewing the emotion suppression of the P3b from a STM perspective, the current finding does make sense. The P3b is thought to be a sign of the event categorization process that determines whether a probe stimulus matches the to-be-remembered stimulus. When more stimuli have to be remembered, processing resources may already be depleted by the maintenance of the multiple to-be-remembered stimuli in STM storage, thus leaving less capacity for the evaluation of the probe stimuli (see Kok, 2001, for a review). Indeed, the early and late P3b during retrieval were suppressed with increasing memory load (cf. Bledowski et al., 2006; Morgan et al., 2008). The current observation of a reduced early P3b for emotional faces suggests that fewer resources were allocated to the evaluation of the emotional compared to neutral probes faces. As mentioned in the introduction, a smaller P3b has previously been observed in response to acoustic startle probes following emotional compared to neutral sounds or pictures, which was interpreted as the allocation of resources to the processing of the emotional stimuli at the expense of the processing of the probe stimulus itself (Keil et al., 2007; see also Schupp, Cuthbert et al., 2004). Also in the STM study of Li et al. (2006), the P3b elicited by a neutral probe stimulus was reduced during a negative compared to a neutral state. Even though behavioural performance was not affected, this was interpreted as increased emotion processing to the detriment of decreased probe processing. Similarly, the current observation of a reduced early P3b for, and thus decreased stimulus evaluation of, emotional probe faces suggests that more resources were allocated to the maintenance of angry and happy faces than to the maintenance of neutral faces in STM. Increased maintenance of emotional faces in STM storage may in turn explain the increased STM performance for these faces.

The N250r or early repetition effect was observed when comparing the retrieval waveforms for match and mismatch trials. The N250r was smaller, albeit still present, when three compared to one face had been presented during encoding, suggesting that the facilitated processing of repeated faces decreases as memory load increases (cf. Morgan et al., 2008). In concordance with the enhanced STM performance for the angry and happy faces the N250r was increased for the emotional faces, suggesting that these faces were more strongly perceived as repeated which may have resulted in a more accurate match between the probe faces and the faces maintained in STM. Thus, an increased repetition priming effect (Schweinberger et al., 1995) appears to bring about, at least in part, the improved visual STM for emotional stimuli.

It has been suggested that the N250r reflects activation of face recognition units (FRUs), which are abstract and invariant to facial expression (Bruce & Young, 1986; Schweinberger & Burton, 2003). However, as mentioned in the introduction, behavioural and imaging studies have shown that the perception of face identity and expression are not as mutually independent as has been proposed by classic cognitive models (Baudouin et al., 2000; Jackson et al., 2008; Kaufmann & Schweinberger, 2004; Lander & Metcalfe, 2007; Vuilleumier & Pourtois, 2007). The current first demonstration of emotional modulation of the N250r supports the view that the processing of face identity and facial expression is interactive (Calder & Young, 2005; Vuilleumier & Pourtois, 2007).

The observed early P3b decrease and N250r increase for emotional compared to neutral faces may seem contradictory. But the P3b and the N250r are markers of different cognitive processes, reflecting resource allocation and structural face processing respectively, and it is thus not unusual that they are differentially affected by facial expression. The observed decreased P3b suggests that more processing resources were deployed for the maintenance of emotional compared to neutral faces. In addition, or perhaps as a result, emotional faces were better detected as repeated, as evident from the increased N250r and the increased behavioural performance for emotional compared to neutral faces.

Even though the behavioural benefit of emotion occurred only when memory load was high, the increased N250r as well as the decreased early P3b for emotional faces occurred under both loads. Wilkinson and Halligan (2004) have argued that neural effects that are not accompanied by behavioural effects may actually yield important information. Here, the electrophysiological data suggest altered neural processing of emotional faces during a STM task even when ceiling effects prevent this from having an effect on performance. In line with the current findings, in the fMRI study (Jackson et al., 2008) using the same STM task, none of the activated brain areas showed an interaction between load and facial expression, suggesting that emotion enhancement of visual STM takes place by the additional recruitment of emotion processing networks as opposed to the increased recruitment of standard STM networks.

It may be that the observed effects of facial expression on memory performance and the ERP do not actually reflect an effect of stimulus emotionality. Because facial features are somewhat distorted in facial expressions, angry and happy faces may simply be less similar to each other than neutral faces. This increased discriminability of the emotional faces could have improved memory performance and increased the N250r. This explanation has been tested by Jackson et al. (2009). Two faces with the same expression and either the same or a different identity were presented simultaneously, and participants were required to make a speeded identity match judgment. Accuracy and RTs were not significantly different between any of the emotion conditions, suggesting that emotional faces are no more distinctive from one another than neutral faces. Moreover, the P1 and N170, reflecting early visual and structural face processing respectively, were not affected by facial expression, implying that the observed emotion effects on memory performance and later ERP components cannot be accounted for by low-level perceptual or structural differences between faces with different expressions.

Even though a few studies have observed an influence of facial expression on the P1 and N170, these modulations were not expression-specific and are taken to reflect non-specific configural or attentional effects rather than genuine emotion effects (Vuilleumier & Pourtois, 2007). Krombholz, Schaefer, and Boucsein (2007) indeed suggest that the N170 is modulated by facial expression only when participants are required to focus on it. In this study, participants were instructed that facial expressions were irrelevant and only face identity had to be kept in STM. Thus, facial expression influenced memory for face identity automatically (cf. D'Argembeau & Van der Linden, 2007). We believe that this identity memory task has high ecological relevance. That is, in real-life people would benefit from having an increased STM for the identities of people that show benevolence or malevolence through their emotional expressions, even in situations in which facial expression is not processed explicitly.

In prior studies STM performance was enhanced for angry, but not for happy faces (Jackson et al., 2008; Jackson et al., 2009). In contrast to those previous studies, the participants in this study were instructed to make speeded responses. It may be that when a rapid face identification judgment is required, any emotional information is taken into account, while when time pressure is absent, emotional information might be used more selectively resulting in an angry benefit only. Further, as the prior and current studies were conducted in different countries, the findings may differ because of cultural or individual differences such as affective disposition and personality (see e.g. Feldman Barrett, Tugade, & Engle, 2004; Hamann & Canli, 2004).

In analogy to LTM, the emotional enhancement of STM could result from boosted perception, encoding, maintenance and/or retrieval of emotional stimuli. In the current study, no effects of expression were observed during encoding. Thus, no neural evidence of boosted encoding of angry and happy faces was observed. Interestingly, in another study in which both the number of objects and the number of features (shape, texture and colour) that had to be remembered were varied, the P3b during encoding was influenced by object-load only, whereas the P3b during retrieval was sensitive to both object-load and feature-load (Busch & Herrmann, 2003). The current findings conform to those findings in the sense that the number of to-be-remembered objects influenced the P3b during both encoding and retrieval, whereas features such as emotional expression influenced the retrieval P3b only. Nevertheless, the possibility that emotional faces are better encoded into STM cannot be excluded yet and could be investigated using other neuro-imaging methods such as frequency spectrum analyses for example.

To conclude, the decreased early P3b during the retrieval of angry and happy faces suggests that improved maintenance of emotional faces contributes to the emotion enhancement effect on STM. In addition, the observed N250r increase for angry and happy faces implies that STM for emotional faces is enhanced because they are more strongly perceived as being repeated during retrieval.

Chapter 6

Aging and short-term memory for face identity of emotional faces

This chapter has been submitted for publication as:
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This study has been presented as:
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Abstract

Age differences have been observed in emotional modulation of long-term memory (LTM) but have not yet been investigated in short-term memory (STM) in a comparable manner. In this study, age differences in the effect of stimulus emotionality on STM for stimulus content were examined. Younger (18-29 years) and older (61-77 years) adults completed a STM task with angry, happy, and neutral faces. Memory for face identity was increased for angry and neutral compared to happy faces. The response bias was most conservative for angry, and most liberal for happy faces. No age differences were observed in this emotional modulation of STM. It is argued that this is not due to insufficient cognitive control in the older participants, but rather to the constraint nature of the task (probe-guided retrieval and short retention interval). The current findings suggest that emotional modulation of STM does not change across the life span.

Introduction

Many studies have examined age differences in emotional long-term memory (LTM), and age differences have been observed in several of these studies (see Mather & Carstensen, 2005, for a review). To our knowledge, only one study has investigated age differences in emotional short-term memory (STM). In that study, younger and older adults viewed unpleasant and pleasant pictures and were instructed to memorize the feeling that a picture elicited. Older adults showed superior memory for pleasant versus unpleasant feelings, while younger adults showed the opposite pattern (Mikels, Larkin, Reuter-Lorenz, & Carstensen, 2005). Findings in the LTM domain, however, typically concern memory for the emotional stimuli themselves, instead of memory for the elicited feelings. Although the study of Mikels et al. is methodologically sound, it does not provide knowledge of age differences in STM for the content of emotional stimuli.

The goal of the present study was to examine age differences in STM for emotional stimulus content. In previous studies, younger adults' STM has been found to be superior for pleasant pictures, intermediate for neutral pictures and inferior for unpleasant pictures (Perlstein, Elbert, & Stenger, 2002). In studies involving STM for face identity of emotional faces, younger adults had better memory for angry compared to happy and neutral faces (Jackson, Wolf, Johnston, Raymond, & Linden, 2008; Jackson, Wu, Linden, & Raymond, 2009). In younger and older adults' daily life, memory for the identity of faces is called upon in social interactions in which it would be important to remember the identity of those individuals that reveal their judgement, mood, or intentions through their facial expressions. In the current study, the emotional face STM paradigm of Jackson et al. (2008; 2009) was used to test age differences in STM for the content of the emotional stimuli (i.e. face identity), and not for the emotion conveyed (e.g. facial expression or feeling/emotion elicited).

In general it is assumed that people remember information that is emotionally salient better than non-emotional information (Kensinger, 2004). It has further been proposed that the age differences in emotional processing arise in the form of a so-called positivity effect, which is "a trend for adults to increasingly process positive information and/or decreasingly process negative information compared with other information with advancing age" (Langeslag & Van Strien, 2009, p. 376; Mather & Carstensen, 2005; but see Uttl & Graf, 2006). A positivity effect in memory for emotional faces has been observed in a previous LTM study. Younger adults recognized positive and negative faces equally well and older adults recognized positive faces better than negative faces (Mather & Carstensen, 2003). In another LTM study, however, a positivity effect was not observed. Younger adults recognized negative faces best, neutral faces intermediately and positive faces least, whereas older adults recognized neutral faces better than positive faces (Grady, Hongwanishkul, Keightley, Lee, & Hasher, 2007). In three more LTM studies, age differences in the effect of facial expression on recognition memory were absent all together (D'Argembeau & Van der Linden, 2004; Leigland, Schulz, & Janowsky, 2004; Spaniol, Voss, & Grady, 2008). It is unclear why the findings of these studies differ, but it may have to do with differences in the length of the delay between the study and test phases (which varied between 5 and 30 minutes), the specific facial expressions used, and the different recognition measures that were computed (discrimination indices or proportional scores (see also Uttl & Graf, 2006)).

The above mentioned findings concern the ability to distinguish faces that were or were not previously encountered, which can be called discrimination. Besides this measure, also the response bias can be a measure of interest in LTM and STM recognition tests. The response bias reflects the tendency to classify a certain stimulus as previously encountered, irrespective of its actual old or new status. Generally, people adopt a more liberal response bias for emotional than neutral stimuli (Ochsner, 2000; Windmann & Kutas, 2001). The response bias was not assessed in the above mentioned STM studies testing younger adults (Jackson et al., 2008; 2009), but it was assessed in one of the above mentioned LTM studies. In that study, it was modulated neither by the facial expression of the stimuli, nor by the age of the participant (D'Argembeau & Van der Linden, 2004). In multiple other LTM with emotional stimuli other than faces, no age differences were observed in the emotional modulation of the response bias either (Charles, Mather, & Carstensen, 2003; Comblain, D'Argembeau, Van der Linden, & Aldenhoff, 2004; Kapucu, Rotello, Ready, & Seidl, 2008; Spaniol et al., 2008)

The current study was conducted to examine age differences in the emotional modulation of STM. We used a well-established paradigm in younger adults that probes STM for the face identity of angry, happy and neutral faces. Based on previous studies (Jackson et al., 2008; Jackson et al., 2009), we expected to find increased discrimination for angry faces in younger adults. The hypothesis that a positivity effect occurs in discrimination, which would comprise that older adults would have relatively better memory for happy than angry faces compared to younger adults, was the particular hypothesis that was put to the test. In addition, on the basis of previous LTM studies, we expected that the response bias would be more liberal for emotional than neutral faces and that this effect of expression would not differ between younger and older adults. It should, however, be kept in mind that the results of the previous studies concerning age differences in emotional LTM for face identity were inconsistent and that it is unclear whether age differences in emotional modulation of STM will resemble the LTM domain.

Method

Participants

Participants were 20 younger (mean age 20.7 years; age range 18-29 years; 10 men) and 20 older (mean age 68.9 years; age range 61-77 years; 10 men) adults who volunteered to take part. Participants were not depressed[1], reported to be in good neurological and psychiatric health and did not use centrally-active drugs. The older adults were not demented, as they had a Mini Mental State Exam (MMSE) score of at least 27 (Derix et al., 2003; Folstein, Folstein, & McHugh, 1975). Participants' education was scored on a scale ranging from 1 (primary education) to 8 (master degree) (De Bie, 1987). The younger participants (M = 7.0, SD = 0.2) tended to have completed more formal education than the older participants (M = 6.2, SD = 1.7), $F(1,38) = 3.8$, $p = .058$. Visual acuity, if necessary corrected with glasses or contact lenses, was assessed using a Landolt-C card. Although the younger participants (M = 2.0, SD = 0.5) had higher visual acuity than the older participants (M = 1.3, SD = 0.4), $F(1,38) = 27.5$, $p < .001$, all participants had a visual acuity of at least 0.8 and asserted sufficient capability to view the faces. Participants were rewarded with course credit or money (at a rate of €7.50 per hour). The study was approved by the local ethics committee and the participants gave written informed consent prior to testing.

Stimuli and memory task

The stimuli for the STM task were 18 gray-scaled faces from the Ekman and Friesen (1976) series: six men each displaying angry, happy and neutral facial expressions. The faces subtended a visual angle of 2.7° vertically and 2.4° horizontally and were presented against a white background. A trial consisted of the following displays, see Figure 1. First, a black fixation cross that increased and decreased in size indicated the start of a trial. During the encoding phase, an array of four stimuli was presented for two seconds. These stimuli were one to four faces, resulting in a memory load of one to four, with scrambled faces occupying the locations not filled by faces. The stimuli were arranged in a two by two grid around a black fixation cross (0.4°) in the centre of the screen with the centre of each stimulus 1.8° away from the fixation cross. During the retention phase, a fixation cross was presented for one second. During the retrieval phase, a probe face occurred in the centre of the screen. The participants had to decide whether or not the probe face matched one of the faces in the preceding encoding array (50% match trials). The response terminated the retrieval phase, and initiated the next trial.

6

[1] Younger participants were considered non-depressed if they scored less than 13 on the Beck Depression Inventory (BDI) (Beck, Ward, Mendelson, Mock, & Erbaugh, 1961; Lasa, Ayusi-Mateos, Vázquez-Barquero, Díez-Manrique, & Dowrick, 2000) and older adults if they scored less than 11 on the Geriatric Depression Scale (GDS) (Yesavage et al., 1983).

It is important to note that this STM task (Jackson et al., 2008; 2009) was an identity matching task, and not an emotion matching task. Because faces of only six individuals (each displaying all three expressions) were used, each face was repeated multiple times during the experiment. This actually ensured that the task tapped into STM and not into LTM, because participants had to decide whether a probe face, even though it may have been present in LTM storage because of its appearance on previous trials, matched any of the encoding faces in the current trial only. Furthermore, all of the faces within one trial displayed the same facial expression. This made facial expression uninformative for the task and prevented the occurrence of attentional biases towards or away from faces with certain expressions during encoding. This is important, because age differences in attentional biases for emotional faces have previously been observed (e.g. Isaacowitz, Wadlinger, Goren, & Wilson, 2006a, 2006b; Mather & Carstensen, 2003). The current design allowed the investigation of age differences in the influence of expression on STM without the potentially confounding influence of age differences in attentional biases during encoding.

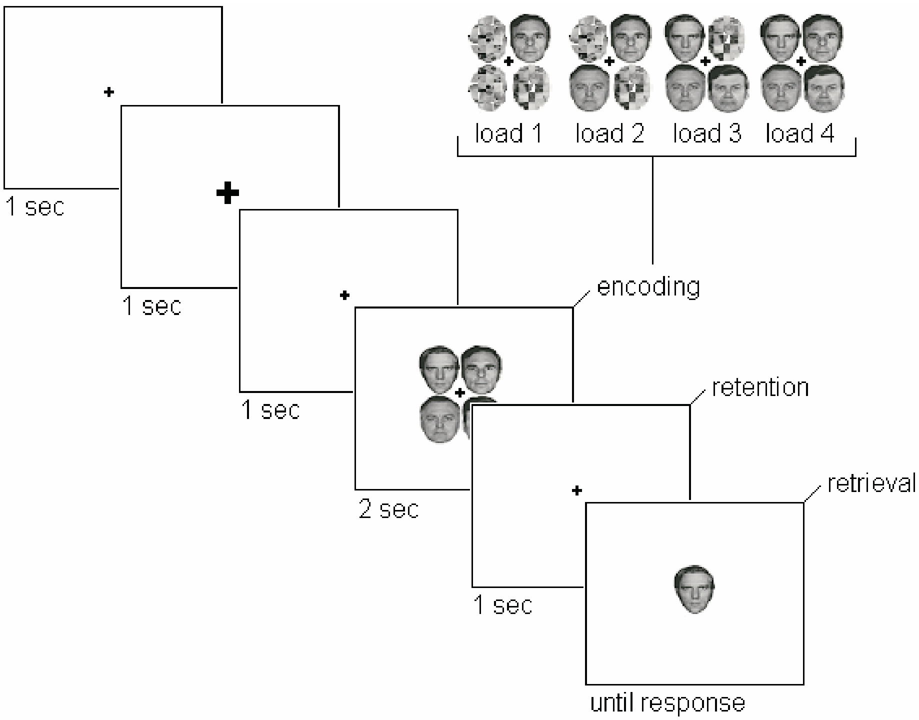

Figure 1. Trial overview.

Procedure

Upon arrival in the lab, the participants completed the above mentioned screening procedures. Following, the participants were introduced to the memory task and were told that the scrambled faces and the facial expressions could be ignored because those would not be useful for the task at hand. Participants were instructed to respond to the probe face by pressing the 'A' (match) or the 'L' (mismatch) keys on a keyboard, with their left and right index fingers respectively, as accurately as possible. Participants were asked to try to maintain fixation at the fixation crosses at all times.

After some practice trials, the participants completed a total of 192 experimental trials: 3 facial expressions x 4 loads x 2 match/mismatch x 8 trials per condition. The order of the trials was random with respect to memory load, facial expression, face identity, location occupied, and match/mismatch. The task was divided into four blocks interleaved with short breaks. After the final block, the participants rated the valence and arousal they experienced when viewing each face with a computerized version of the Self-Assessment Manikin (SAM) (Lang, 1980).

Analyses

The hit rates (*H*, i.e. proportion correct 'match' responses) and false alarms rates (*FA*, i.e. proportion incorrect 'match' responses) were computed using the correction recommended by Snodgrass and Corwin (1988). Memory performance was represented by the discrimination index $Pr = H - FA$, where $Pr = 1$ reflects perfect performance and $Pr = 0$ reflects chance performance, and by the response bias index $Br = FA / (1 - Pr)$. The response bias index describes the tendency of participants to respond 'match' irrespective of the true match or mismatch status of the probe stimulus, where $Br > 0.5$ indicates a liberal response bias and $Br < 0.5$ indicates a conservative response bias (Snodgrass & Corwin, 1988).

The data were analyzed with repeated measures analysis of variance (rmANOVA). Valence and arousal ratings were analyzed with the factors Expression (angry, happy, neutral), and Age group (younger, older). Memory performance measures *Pr* and *Br* were analyzed with factors Expression, Load (1, 2, 3, 4), and Age group. When applicable, degrees of freedom were corrected with the Greenhouse-Geisser correction. The *F* values, the uncorrected *df*s, the epsilon (ε) values and corrected probability levels are reported. A two-sided significance level of 5% was selected. Significant effects were followed-up by independent samples *t*-tests when testing age group effects and by paired samples *t*-tests when testing expression or load effects. In the case of load effects, consecutive loads were compared.

Results

Valence and arousal ratings

Valence

There were a significant effect of Expression, $F(2,76) = 189.1$, $\varepsilon = .74$, $p < .001$, and a significant Expression x Age group interaction, $F(2,76) = 4.3$, $\varepsilon = .74$, $p = .028$. Both the younger and older participants associated angry faces with lowest valence (younger: $M = 3.1$, $SD = 0.8$, older: $M = 3.5$, $SD = 1.3$), neutral faces with intermediate valence (younger: $M = 4.7$, $SD = 0.5$, older: $M = 4.7$, $SD = 0.9$), and happy faces with highest valence (younger: $M = 7.4$, $SD = 0.8$, older: $M = 6.7$, $SD = 1.0$), all *p*s < .001. Yet, the older participants rated happy faces as less pleasant than the younger participants did, $p = .015$. There was no significant main effect of Age group, $F < 1$, *ns*.

Arousal

A significant effect of Expression, $F(2,76) = 19.3$, $\varepsilon = .98$, $p < .001$, and a significant Expression x Age group interaction, $F(2,76) = 7.9$, $\varepsilon = .98$, $p = .001$, were observed. The younger participants rated angry ($M = 5.4$, $SD = 1.3$) and happy faces ($M = 5.8$, $SD = 1.4$) as more arousing than the neutral faces ($M = 3.8$, $SD = 1.3$), both *p*s < .001. The arousal ratings for angry and happy faces were not significantly different, $p = .29$. The older participants rated happy faces as most arousing ($M = 5.3$, $SD = 0.8$), both *p*s < .003, and angry ($M = 4.1$, $SD = 1.1$) and neutral faces ($M = 4.4$, $SD = 1.2$) as equally arousing, $p = .50$. This age difference occurred because the older participants rated angry faces as less arousing than the younger participants did, $p = .002$. The main effect of Age group was not significant, $F(1,38) = 2.4$, $p = .13$.

Memory performance

Discrimination index

There was an effect of Expression, $F(2,76) = 4.1$, $\varepsilon = .99$, $p = .016$, showing that discrimination was inferior for happy faces, both *p*s < .014, whereas discrimination was similar for angry and neutral faces, $p = .88$, see Figure 2a. This effect of Expression was not modulated by Age group or Load, all *F*s < 1.1, all *p*s > .40. The effect of Load, $F(3,114) = 200.2$, $\varepsilon = .92$, $p < .001$, showed that discrimination decreased with increasing load, all *p*s < .001. The effect of Age group, $F(1,38) = 16.6$, $p < .001$, showed that older participants had a lower discrimination index than younger participants. Moreover, the significant Load x Age group interaction, $F(3,114) = 6.9$, $\varepsilon = .92$, $p < .001$, indicated that significant age differences were present in loads 2 to 4, all *p*s < .020, but not in load 1, $p = .095$, see Figure 2c.

To control for the potentially confounding effect of the observed age differences in valence and arousal ratings, separate ANCOVAs for each expression were conducted with the covariates Valence rating and Arousal rating, and the factor Age group. For neither of the expressions, Valence rating and Arousal rating had a significant effect on the discrimination index, all *F*s < 2.1, all *p*s > .15. Moreover, the main effects of Age group, signifying decreased performance in the older compared to the younger adults, remained significant after controlling for age differences in valence and arousal ratings for all expressions, all *F*s > 5.6, all *p*s < .03.

Response bias index

The main effect of Expression, $F(2,76) = 12.8$, $\varepsilon = .96$, $p < .001$, revealed that the response bias was most conservative for angry faces, slightly liberal for neutral faces, and most liberal for happy faces, all *p*s < .023, see Figure 2b. This effect of Expression was not modulated by Age group or Load, all *F*s < 1.1, all *p*s > .33. Further, there was a significant effect of Load, $F(3,114) = 5.3$, $\varepsilon = .81$, $p = .004$. The response bias decreased from load 1 to 2, $p = .033$, was similar between loads 2 and 3, $p = .83$, and increased again between load 3 and 4, $p < .001$, see Figure 2d. Neither the main effect of Age group, nor the Load x Age group interaction was significant, both *F*s < 1.6, both *p*s > .21.

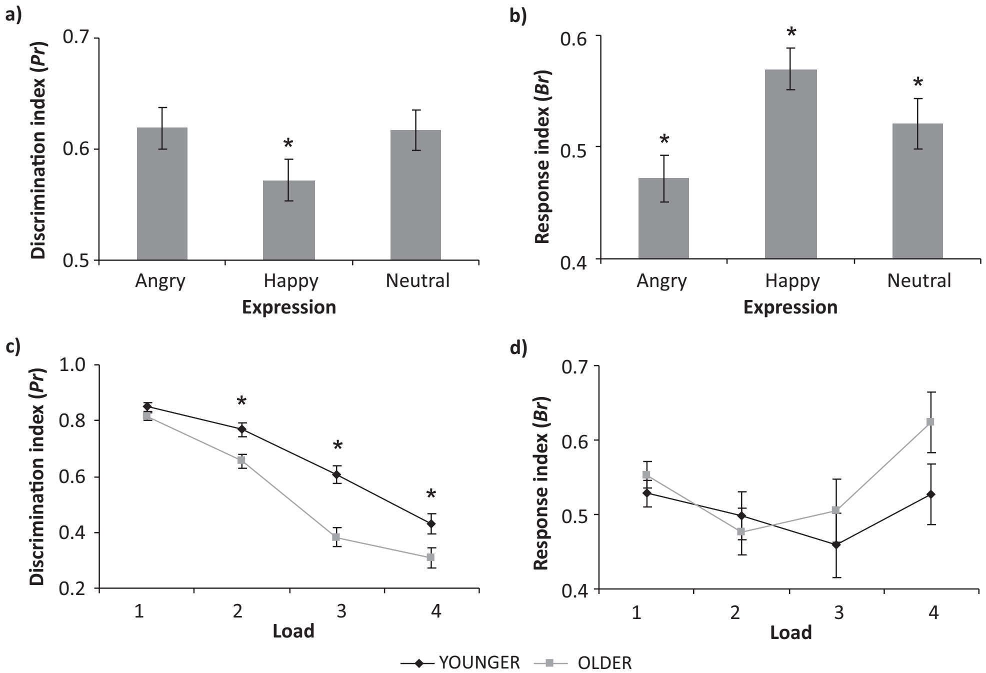

Figure 2 a) The discrimination index was lowest for happy faces, * both *p*s < .014 **b)** The response bias was most liberal for happy faces, intermediately liberal for neutral faces and least liberal for angry faces, * all *p*s < .023 **c)** Older adults had a lower discrimination index than younger adults in loads 2 to 4, * all *p*s < .020 **d)** No age differences occurred with respect to the response bias index.

To control for the potentially confounding effect of the observed age differences in valence and arousal ratings, additional ANCOVAs were conducted for each expression separately. For all expressions, the covariates Valence rating and Arousal rating, and the factor Age group together did not have a significant effect on the response bias index, all *F*s < 1.1, all *p*s > .37.

Discussion

The goal of the current study was to investigate the occurrence of age differences in STM performance for emotional stimulus content. The expression of the to-be-remembered faces influenced memory for face identity in two ways. First, discrimination between faces that were or were not presented previously was increased for angry and neutral compared to happy faces. Second, the response bias was most conservative for angry faces and most liberal for happy faces. Importantly, no interactions between facial expression and age group were observed on the discrimination and response bias indices.

The increased discrimination of angry over happy faces concurs with previous findings in younger adults only (Jackson et al., 2008; Jackson et al., 2009). The increased discrimination of neutral over happy faces, however, was an unexpected finding. Nevertheless, in a previous LTM study both younger and older adults had increased memory for neutral compared to happy faces as well (Grady et al., 2007). Furthermore, the response bias was most conservative for angry faces and most liberal for happy faces. Compared to neutral faces there was a decreased tendency to indicate that an angry probe face matched the content of memory storage, whereas there was an increased tendency to indicate that a happy probe face matched the content of memory storage. Similarly, in a prior LTM study, positive words were associated with a more liberal response bias than neutral words (Grider & Malmberg, 2008; see also Phaf & Rotteveel, 2005). In contrast to the more conservative bias for angry faces, the more liberal response bias for happy compared to neutral faces was in line with our hypothesis, and this liberal way of responding to happy faces appears to have substantially reduced discrimination of these faces. Most important for the current research question, no positivity effect or any other age differences were observed in the emotional modulation of both discrimination and response bias, even when we controlled for the observed age differences in valence and arousal ratings.

As one would expect, discrimination decreased with increasing memory load, as well as with aging. However, when only one face had to be remembered, older adults' performance was as good as the younger adults' performance, showing that the older adults were very well capable of performing the task according to the instructions. The older adults did have a poorer discrimination than younger adults when more than one face had to be remembered, which demonstrates that especially STM for multiple items deteriorates with aging.

Although we did observe effects of age on discrimination, the absence of an age effect on the emotional modulation of STM could have been due to a relative lack of power with only 20 participants per age group. However, even when increasing power by adopting a more lenient significance level (Stevens, 2002) of 10, 20, or even 30%, the interactions between expression and age group remain non-significant. In addition, age-independent effects of facial expression as discussed above were observed with the stringent significance level of 5%. Any modulating effects of age would probably be much smaller than the general effect of facial expression on STM.

Alternatively, because it has been suggested that sufficient availability of cognitive control is a prerequisite for age differences in emotional processing to occur (Mather, 2006; Mather & Knight, 2005), the current absence of age differences could have been the result of inadequate cognitive control or resource availability in the older adults. Although our older adults had completed less formal education than the younger adults, which is a nearly inevitable consequence of generational differences in educational possibilities, they were relatively well-educated and had intact cognitive functioning as assessed by the MMSE. It can therefore be assumed that our older participants' cognitive control was (above) average, thereby satisfying the prerequisite for the occurrence of age differences in emotional processing. The observed age differences in the valence and arousal ratings of the faces lend support for this notion. Furthermore, even though the condition with a memory load of one face was undemanding (as evident from the high and equivalent memory performance of younger and older adults), age differences in the effect of facial expression did not even occur under low memory load.

What factors could then explain the absence of age differences in emotional modulation of STM? The socio-emotional selectivity theory states that the older adults' limited remaining life time urges them to focus on emotion-related goals, while younger adults would focus more on knowledge-related goals (Carstensen, Isaacowitz, & Charles, 1999). But, the more externally constraint a task is, the less influence these emotion goals may have on task performance (Mather, 2006). Indeed, age differences in emotional memory are typically less pronounced in LTM recognition and cued recall tests than in free recall tests (e.g. Langeslag & Van Strien, 2008, 2009). The current STM task resembles LTM recognition tests in the sense that retrieval is guided by the presentation of a probe that requires a forced-choice decision. In addition, assuming that emotion-related goals influence only late stages of processing (Mather & Carstensen, 2005), the influence of these emotion-related goals may have been further reduced by the short time interval between encoding and retrieval phases of the STM task.

To conclude, we report here the first study in which age differences in emotional modulation of STM were investigated in a way that matched previous LTM studies. That is, age differences in the effect of stimulus emotionality on memory for stimulus content were examined. No age differences were observed in the effect of facial expression on STM for face identity. We argue that the current absence of age differences in the emotional modulation of STM is not due to insufficient statistical power or inadequate cognitive control in the older adults. Instead, it might be due to the restricted nature of the STM task. Of course more research is needed to examine whether, and under what circumstances, age differences in emotional STM occur. With the mean population age rising, research on the life span development of emotional processing, which includes emotional STM, becomes more and more important.

Chapter 7

Comparable modulation of the Late Positive Potential by emotion regulation in younger and older adults

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Abstract

It has been suggested that emotion regulation improves with aging. Here, we investigated age differences in emotion regulation by studying modulation of the Late Positive Potential (LPP) by emotion regulation instructions. The electroencephalogram (EEG) of younger (18-26 yrs) and older (60-77 yrs) adults was recorded while they viewed neutral, unpleasant, and pleasant pictures and while they were instructed to increase or decrease the feelings that the emotional pictures elicited. The LPP was enhanced when participants were instructed to increase their emotions. No age differences were observed in this emotion regulation effect, suggesting that emotion regulation abilities are unaffected by aging. This contradicts with studies that measured emotional regulation by self-report, yet accords with studies that measured emotional regulation by means of facial expressions or psychophysiological responses. More research is needed to resolve the apparent discrepancy between subjective self-report and objective psychophysiological measures.

Introduction

Older adults often report to experience higher levels of positive affect and/or lower levels of negative affect than younger adults (e.g. Gross et al., 1997; Langeslag & Van Strien, 2008; Mather & Knight, 2005). This improved affect in older adults has been taken to be the result of improved emotion regulation with aging (Mather & Carstensen, 2005), where emotion regulation is the use of behavioral or cognitive strategies to generate new emotions or to alter current emotions. An example of a behavioral strategy is emotion suppression, whereas attending to non-emotional aspects of a situation or reappraising a situation are examples of cognitive strategies (Ochsner & Gross, 2005). Processes underlying emotion regulation have been studied using neuroimaging methods such as Event-Related Potentials (ERPs) and functional Magnetic Resonance Imaging (fMRI), and almost exclusively in younger adults. Empirical data on age differences in emotion regulation are rather scarce.

Some previous studies on age differences in emotion regulation have relied on self-report measures. Following the question "Overall, how much control would you say you have over your emotions?" older adults reported greater emotional control than younger adults (Gross et al., 1997). On the one hand, improved emotion regulation with aging appears to comprise that the intensity of both negative and positive emotions is decreased, given that older compared to younger adults agreed more with questionnaire items such as "I try to avoid reacting emotionally, whether the emotion is positive or negative" (Lawton, Kleban, Rajagopal, & Dean, 1992) and have reported greater control over the inner experience of both negative and positive emotions. However, the increased control over negative emotions has been found to be associated with diminished negative feelings, whereas the increased control over positive emotions was associated with enhanced positive feelings (Gross et al., 1997). This suggests that improved emotion regulation actually involves decreasing the intensity of negative emotions and increasing the intensity of positive emotions. This hedonic emotion regulation mode would correspond to the above mentioned findings of improved affect with age. It would also be in line with the so-called positivity effect, which is "a trend for adults to increasingly process positive and/or decreasingly process negative information compared with other information with advancing age" (Langeslag & Van Strien, 2009, p. 376). Such a positivity effect has sometimes been observed in attention and memory tests (see Mather & Carstensen, 2005, for a review).

In some other studies concerning age differences in emotion regulation, objective measures of emotion regulation were collected besides self-report measures. In one study (Phillips, Henry, Hosie, & Milne, 2008), younger and older adults were instructed to regulate emotions that were elicited by emotional film clips, using behavioral suppression (i.e. not showing that you experience an emotion) or positive refocusing (i.e. thinking about an unrelated, positive memory). According to self-report, older but not younger adults were able to decrease their negative emotions by positive refocusing. According to objective ratings of facial expression by independent coders, younger adults were able to decrease their negative emotions by expressive suppression and older adults by both expressive suppression and positive refocusing. However, as negative emotions were more intense in the older than in the younger adults in the control condition in which no emotion regulation was applied, this relative absence of emotion regulation effects in the younger adults may just have been due to floor effects. In another study (Magai, Consedine, Krivoshekova, Kudadjie-Guamfi, & McPherson, 2006), younger and older adults recalled and recounted two recent events that made them feel sad and angry under behavioral suppression or control instructions. Older adults reported to experience less intense emotions following behavioral suppression compared to the control condition, whereas younger and middle-aged adults did not. In contrast, no age differences in emotion regulation occurred in the objective measures of coder-ratings of facial expression. Finally, in a study in which younger and older adults were instructed to behaviorally suppress and amplify their emotional responses to film clips (Kunzmann, Kupperbusch, & Levenson, 2005), no age differences were observed in the effect of emotion regulation on the objective measures of coder-rated facial expressions and physiological responses, such as skin conductance, heart beat, and blood pressure. In sum, although self-report measures do seem to suggest that emotion regulation improves with aging, objective measures such as facial expressions, skin conductance, heart beat, and blood pressure do not support this notion.

The absence of age differences in objective measures may be a consequence of the particular measures used. An objective measure that has not yet been employed to study age differences in emotion regulation but is very well suited for this purpose, is the ERP. In ERP studies, the Late Positive Potential (LPP) is a positive component starting about 400 ms after stimulus onset over the posterior scalp that is typically larger for emotional than neutral stimuli (see Schupp, Flaish, Stockburger, & Junghöfer, 2006, for a review). In younger adults, the LPP in response to emotional stimuli has been found to be modulated by emotion regulation instructions. The amplitude of the LPP is reduced when participants decrease their feelings in response to both unpleasant and pleasant stimuli, compared to when participants passively view these stimuli (Hajcak & Nieuwenhuis, 2006; Krompinger, Moser, & Simons, 2008; Moser, Hajcak, Bukay, & Simons, 2006; Moser, Krompinger, Dietz, & Simons, 2009). In line with the notion that the LPP is an index of stimulus arousal (Schupp et al., 2006), the reduction of the LPP amplitude due to decreasing emotions has been found to be correlated with the reduction in arousal ratings of the pictures following emotion regulation (Gootjes, Franken, & Van Strien, in preparation; Hajcak & Nieuwenhuis, 2006). In addition, increasing feelings elicited by emotional pictures has been found to enhance the LPP amplitude compared to passive viewing of these pictures (Moser et al., 2009). Modulation of the LPP amplitude can thus be conceived as an electrophysiological correlate of emotion regulation. Although formal comparisons have not been made in prior studies, this modulation appears to be independent of the regulation strategy used and the valence of the pictures. To our knowledge, age differences in emotion regulation have not been examined yet using objective neuroimaging measures such as ERP or fMRI. Three fMRI studies have measured brain activation of older adults while they performed an emotion regulation task (Urry, Van Reekum, Johnstone, & Davidson, in press; Urry et al., 2006; Van Reekum et al., 2007), but these studies did not include a group of younger adults.

The research question of the current study was whether age differences in emotion regulation abilities occur, using the LPP as an objective electrophysiological correlate of emotion regulation. We investigated the effects of increasing and decreasing unpleasant and pleasant emotions. To avoid continuous switching between the different tasks, which may be particularly difficult for older adults, we presented the various conditions in a blocked design (cf. Krompinger et al., 2008; Moser et al., 2006). Moreover, emotion regulation instructions were open-ended because we wanted to investigate age differences in emotion regulation abilities in general, not of one specific strategy (cf. Krompinger et al., 2008; Moser et al., 2006). As outlined above, the notion that emotion regulation improves with aging results in two competing hypotheses. First, if older adults are better in regulating their feelings than younger adults in general (non-hedonic mode), it can be expected that emotion regulation effects on the LPP would be larger in older than in younger adults. More specifically, older adults would show a more pronounced LPP suppression with decreasing feelings and a more pronounced LPP enhancement with increasing feeling compared to younger adults. Alternatively, it may be that older compared to younger adults are particularly good at decreasing negative emotions and increasing positive emotions (hedonic mode), in which case older adults would show a more pronounced LPP suppression when decreasing negative (but not positive) feelings and a more pronounced LPP enhancement when increasing positive (but not negative) feelings compared to younger adults. Because of the proposed link between emotion regulation and affect (Mather & Carstensen, 2005), we also probed trait and state affect of the participants. We expected that a non-hedonic mode of emotion regulation would not yield age differences in positive and negative affect, whereas a hedonic mode of emotion regulation in older adults would be accompanied by increased positive and/or decreased negative affect in older compared to younger adults (cf. Gross et al., 1997).

Methods

Participants

Nineteen younger (mean age 20.7 years, range 18-26 years, 9 men) and 20 older (mean age 68.1 years, age range 60-77 years, 10 men) participants provided usable data. The younger participants were undergraduate students and the older participants were recruited through an advertisement in a local newspaper and by word of mouth. All participants were right-handed as determined by a hand preference questionnaire (Van Strien, 1992) and not depressed[1]. The Mini Mental State Exam (MMSE) was used to screen for dementia, and all older participants had a score of at least 26 (Derix et al., 2003; Folstein, Folstein, & McHugh, 1975). The younger participants tended to have a slightly higher education level than the older participants, see Table 1. All participants reported to be in good neurological and psychiatric health, did not use centrally active drugs, had normal or corrected-to-normal vision, and asserted sufficient capability to view the pictures. Nevertheless, the older participants had a lower visual acuity than the younger as assessed by a Landolt-C card (if necessary corrected with glasses or contact lenses), see Table 1. Affect was assessed with the Positive and Negative Affect Schedule (PANAS) (Peeters et al., 1999; Watson, Clark, & Tellegen, 1988). Positive and negative affect during the past two weeks and negative affect immediately after the emotion regulation task did not differ between the age groups, all Fs(1,37) < 1.9, all ps > .17. Older compared to younger adults did, however, tended to report higher levels of positive affect immediately after the emotion regulation task, $F(1,37) = 3.1$, $p = .072$, see Table 1. Participants were rewarded with course credit or 20 Euros. The study was approved by the local ethics committee and the participants gave written informed consent prior to testing.

Stimuli

The stimuli were 40 neutral, 120 unpleasant, and 120 pleasant pictures from the International Affective Picture System (IAPS) (Lang, Bradley, & Cuthbert, 2005). These picture categories varied significantly in IAPS normative valence ratings, with lowest valence for unpleasant pictures ($M = 3.2$, $SD = 0.8$), intermediate valence for neutral pictures ($M = 5.1$, $SD = 0.3$) and highest valence for pleasant pictures ($M = 7.1$, $SD = 0.6$), all ps < .001. Unpleasant and pleasant pictures were matched in IAPS normative arousal ratings (both $M = 5.0$, $SD = 1.0$), and were more arousing than neutral pictures ($M = 3.5$, $SD = 0.7$), both ps < .001. The pictures

[1] Younger participants were considered non-depressed if they scored less than 13 on the Beck Depression Inventory (BDI) (Beck, Ward, Mendelson, Mock, & Erbaugh, 1961; Lasa, Ayusi-Mateos, Vázquez-Barquero, Díez-Manrique, & Dowrick, 2000) and older adults if they scored less than 11 on the Geriatric Depression Scale (GDS) (Yesavage et al., 1983).

were presented against a black background and subtended a maximal visual angle of 14° horizontally and 9° vertically.

Table 1. Education, visual acuity, and affect in each age group and the *p*-values associated with the differences between the age groups.

	Younger		Older		*p*-value
	Mean	Range	Mean	Range	
Education	7.0	7	6.5	3-8	.086
Visual acuity	1.7	1.0-2.0	1.1	0.5-2.0	< .001
Positive Affect (past two weeks)	33.5	20-46	35.3	28-48	.34
Negative Affect (past two weeks)	17.1	10-35	14.5	10-30	.18
Positive Affect (at this moment)	29.0	19-46	32.9	15-45	.072
Negative Affect (at this moment)	12.1	10-26	10.8	10-17	.21

Note. Education ranged from 1 (primary education) to 8 (master degree) (De Bie, 1987).

Procedure

Upon arrival in the lab, the participants completed the above-mentioned screening procedures and questionnaires. Next, they were seated in a comfortable chair in a dimly-lit, sound-attenuated room, and the electrode cap was attached. The task we used was based on previous studies (Krompinger et al., 2008; Moser et al., 2006), and was similar to these studies with respect to the emotion regulation instructions, stimulus duration, block order, number of stimuli per condition, etcetera. The current task consisted of five blocks. The first block always was the block in which participants were instructed to simply view neutral, unpleasant, and pleasant pictures (40 pictures of each valence). Picture valence was distributed pseudo-randomly with the constraint that no more than two pictures of the same valence succeeded each other. This view block was preceded by three practice trials with neutral pictures. The following four blocks were the emotion regulation blocks (40 pictures each). These blocks contained either unpleasant or pleasant stimuli and contained the instruction to either increase or decrease feelings that the pictures elicited, yielding four different blocks: increase-unpleasant, increase-pleasant, decrease-unpleasant, decrease-pleasant. Participants were instructed that they would be viewing either unpleasant or pleasant pictures and that they were supposed to try to increase or decrease the feeling that these pictures elicited. Participants could choose their own strategy, but they were given examples of how feelings could be increased or decreased. For example, participants could imagine themselves or a close person in the situation depicted in the picture in order to increase their feelings, or could think that the picture was staged to decrease their feelings. For all conditions, participants were instructed that they were not supposed to regulate their feelings by looking away from the pictures or by generating thoughts unrelated to the pictures. Instructions were as elaborate as necessary for the participants to understand their task. The order of the emotion regulation blocks was counterbalanced across participants. The distribution of individual pictures across the five blocks was random across participants, making any instruction effects unconfounded by picture content.

In all five blocks, each trial started with the presentation of an instruction word (either 'view', 'increase', or 'decrease', depending on the block) for 2000 ms to remind participants of their task. Then, a fixation cross with variable duration between 900 and 1100 ms was shown, which was followed by a picture that was presented for 1000 ms. Finally, a fixation cross occurred again for 1000 ms. Participants were encouraged to limit movements and to blink only during the presentation of the instruction word.

After the final block, the electrode cap was removed. Then, the participants completed a questionnaire to verify that they had followed the emotion regulation instructions (Krompinger et al., 2008).

Electroencephalogram recording and signal processing

The electroencephalogram (EEG) was recorded using a 64-channel amplifier and data acquisition software (ActiveTwo System, Biosemi, Amsterdam). The Ag-AgCl Active electrodes were placed upon the scalp by means of a head cap (Biosemi), according to the 10-10 International System (American Clinical Neurophysiology Society, 2003). Vertical and horizontal electro-oculogram were recorded by attaching additional electrodes (UltraFlat Active electrodes, BioSemi) respectively above and below the left eye, and at the outer canthi of both eyes. Additional electrodes were attached to the left and right mastoids. An active electrode (CMS – common mode sense) and a passive electrode (DRL – driven right leg) were used to comprise a feedback loop for amplifier reference. All signals were digitized with a sampling rate of 512 Hz, a 24-bit A/D conversion, and a low pass filter of 134 Hz.

A maximum of three bad channels per participant were corrected using spherical spline interpolation, which is in accordance with the guidelines of Picton et al. (2000). Offline, an averaged mastoids reference was applied and the data were filtered using a 0.15-30 Hz band pass filter (phase shift-free Butterworth filters; 24 dB/octave slope). Data were segmented in epochs from 200 ms pre-stimulus onset until 1000 ms post-stimulus onset. Ocular artifact correction was done according to the Gratton and Coles algorithm (Gratton, Coles, & Donchin, 1983) and the 200 ms pre-stimulus interval was used for baseline correction. Artifact rejection criteria were minimum and maximum baseline-to-peak –75 to +75 μV, and a maximum allowed voltage skip (gradient) of 50 μV. Two younger participants with excessive EEG artifacts were excluded and replaced, leaving the previously reported number of 39 participants. Epochs were classified according to their valence and the instruction that accompanied them, yielding seven conditions (view-neutral, view-unpleasant, view-pleasant, increase-unpleasant, increase-pleasant, decrease-unpleasant, decrease-pleasant). The mean number of valid epochs per condition ranged from 32.0 to 35.8.

Analyses

Because the LPP is maximal at the posterior scalp (Schupp et al., 2006) the analyses focused on posterior electrodes (cf. Hajcak & Nieuwenhuis, 2006; Krompinger et al., 2008; Moser et al., 2006; Moser et al., 2009). ERP activity was pooled to form activity in three electrode clusters covering the left-posterior, medial-posterior, and right-posterior scalp (Dien & Santuzzi, 2005), see Figure 1. The ERP waveforms were quantified by mean amplitude measures in two time windows. The 400-700 ms and 700-1000 ms time windows covered the early LPP and late LPP respectively (cf. Langeslag & Van Strien, 2009; Schupp, Cuthbert et al., 2004). The mean amplitudes of each time window were subjected to two different repeated measures ANOVAs. The first ANOVA was conducted as a manipulation check, to examine whether the pictures elicited the typical LPP emotion effects. This ANOVA concerned the view block only and tested the factors Valence (neutral, unpleasant, pleasant), Laterality (left, medial, right), and Age group (younger, older). The second ANOVA tested the effects of emotion regulation on the LPP, with the factors Instruction (view, increase, decrease), Valence (unpleasant, pleasant), Laterality, and Age group. Only effects involving Instruction and/or Valence are reported. To evaluate the degree of age differences in emotion regulation, effect sizes (Cohen's *d*) of the instruction effects were computed per age group separately as $(M_1 + M_2)/SD_{pooled}$, where $SD_{pooled} = \sqrt{((SD_1^2 + SD_2^2)/2)}$. Generally, $d = \pm0.2$ is considered to be a small effect, $d = \pm0.5$ to be a medium effect, and $d = \pm0.8$ to be a large effect (Cohen, 1992).

When applicable, degrees of freedom were corrected with the Greenhouse-Geisser correction. The *F* values, the uncorrected *df*s, the epsilon (ε) values and corrected probability levels are reported. A significance level of 5% (two-sided) was selected. Significant effects were followed-up by *t*-tests if necessary.

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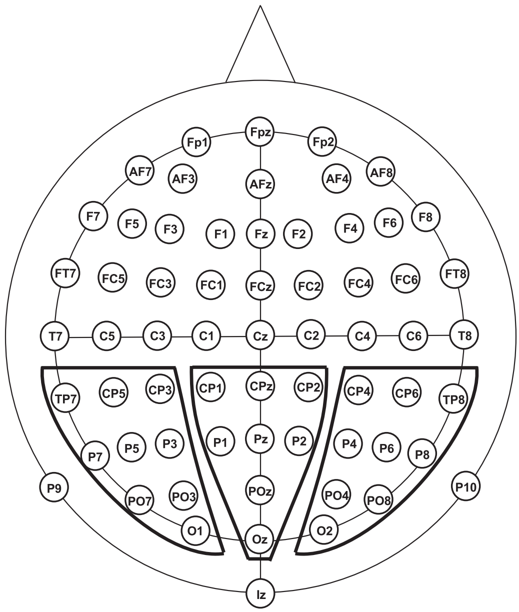

Figure 1. The three electrode clusters (left-posterior, medial-posterior, right-posterior) used in the analysis.

Results

Valence effects in view condition

The ERP waveforms at the medial-posterior cluster as a function of valence in the view condition are depicted in Figure 2a. See also Table 2 for mean voltages of the early and late LPP in each condition, time window and age group.

In the 400-700 ms time window, the effects involving Valence were not significant, all *F*s < 2.5, all *p*s > .10. In the 700-1000 ms time window, the main effect of Valence was significant, $F(2,74) = 7.8$, $\varepsilon = .87$, $p = .001$. The LPP was more positive for emotional than neutral pictures, both *p*s < .005, but not different for unpleasant and pleasant pictures, $p = .47$. Although this valence effect seems to be larger in the younger than the older adults, the interactions involving Valence and Age group, as well as any other interactions involving Valence, were not significant, all *F*s < 1.0, *ns*. In Figure 2b it can be seen that the valence effects have a posterior maximum in both age groups, corresponding to the scalp topography of the LPP. To conclude, the LPP in the view condition was larger for emotional compared to neutral pictures as is usually observed. This emotion effect occurred from 700 ms onward and did not differ between the age groups.

Table 2. Mean (standard deviation in parentheses) voltage (in μV) of the LPP at the medial-posterior cluster in all conditions, separately for each time window and age group.

	400-700 ms		700-1000 ms	
	Younger	**Older**	**Younger**	**Older**
increase-unpleasant	4.7 (4.0)	6.0 (3.6)	5.3 (3.1)	4.2 (3.4)
view-unpleasant	1.4 (3.2)	4.0 (3.2)	2.8 (2.5)	3.1 (3.2)
decrease-unpleasant	3.3 (4.8)	5.2 (2.2)	3.6 (3.5)	4.3 (2.9)
increase-pleasant	5.0 (4.5)	6.0 (3.1)	4.6 (4.0)	3.6 (2.9)
view-pleasant	1.4 (3.1)	3.9 (3.1)	2.6 (2.5)	2.8 (2.8)
decrease-pleasant	2.6 (4.8)	4.5 (2.8)	3.6 (3.7)	3.0 (2.9)
view-neutral	0.7 (2.9)	3.1 (2.7)	1.2 (2.0)	1.9 (3.2)

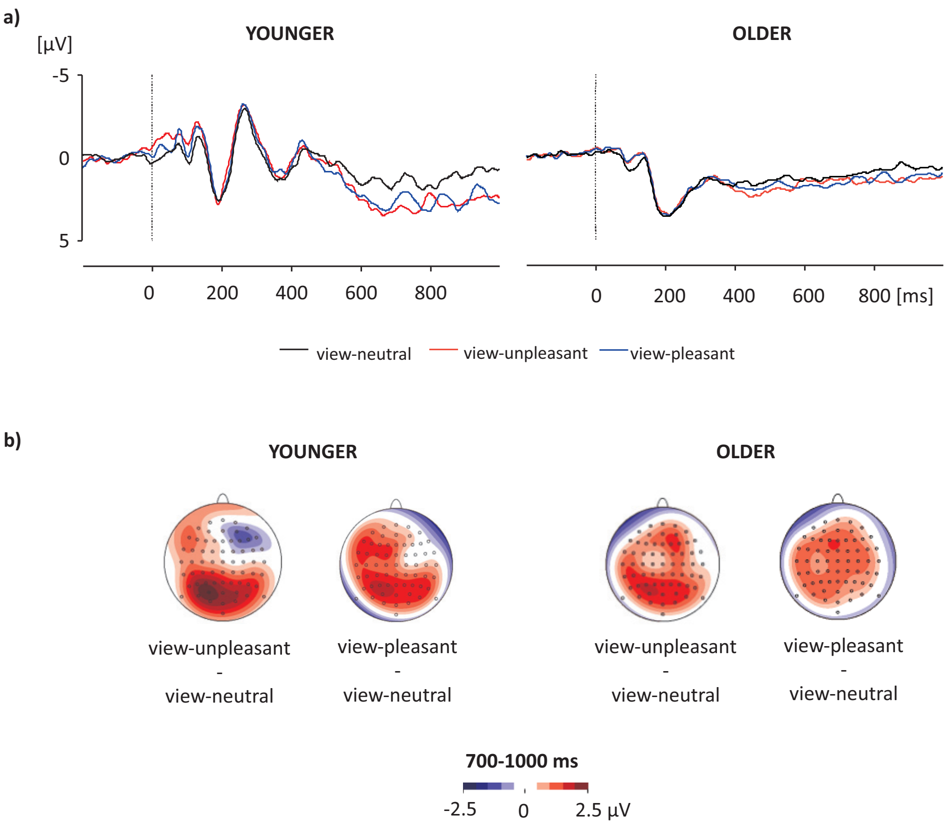

Figure 2 a) The ERP waveform at the medial-posterior cluster for the three valences in the view condition, separately for each age group **b)** Voltage scalp topographies of the valence effects in the view condition between 700-1000 ms after stimulus onset, separately for each age group.

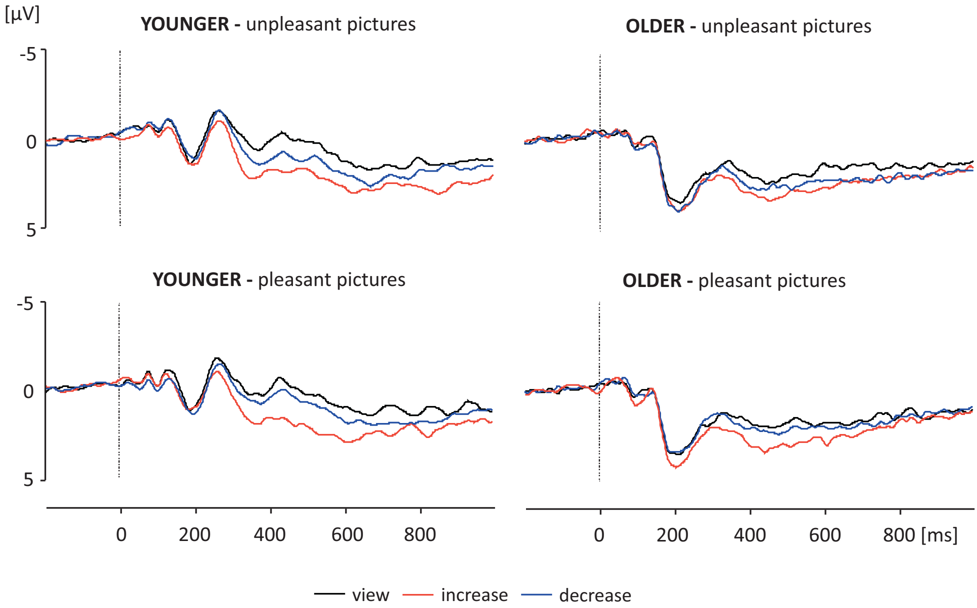

Figure 3. The ERP waveform at the medial-posterior cluster for the three instruction conditions for unpleasant and pleasant pictures, separately for each age group.

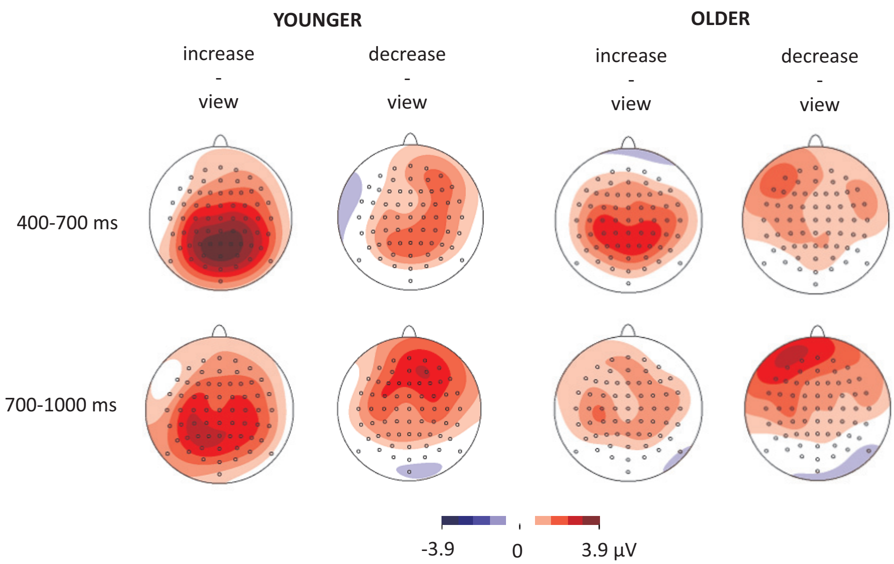

Figure 4. Voltage scalp topographies of the instruction effects, separately for each time window and age group.

Instruction and valence effects in view and emotion regulation conditions

Figure 3 shows the ERP waveforms at the medial-posterior cluster for the three instruction conditions and Figure 4 depicts the voltage scalp topographies of the instruction effects. See also Table 2 for mean voltages of the early and late LPP in each condition, time window and age group.

In the 400-700 ms time window, there was a significant main effect of Instruction, $F(2,74) = 15.8$, $\varepsilon = .90$, $p < .001$, with the LPP being more positive in the increase compared to the view and decrease condition, both *p*s < .002. The LPP in the decrease condition tended to be more positive than the LPP in the view condition, $p = .051$. The significant Instruction x Laterality interaction, $F(4,148) = 5.0$, $\varepsilon = .82$, $p = .002$, indicated that the difference between the view and the decrease condition was significant only at the medial-posterior cluster, $p = .025$, and not at the left- and right-posterior clusters, both *p*s > .076. The differences between increase and view, and increase and decrease conditions, in contrast, were significant in all three clusters, all *p*s < .004. The other effects involving Instruction or Valence, including interactions with Age group, were not significant, all *F*s < 2.8, all *p*s > .10. To examine possible age differences with greater power than the overall ANOVA, we performed independent samples *t*-tests on the increase and decrease effects for each valence. No age differences were observed, all *t*s(37) < ±1.4, all *p*s > .19. It can be seen in Table 3 that the effect sizes of the instruction effects were either similar in younger and older adults, or larger in the younger than the older adults.

In the 700-1000 ms time window, there was a significant main effect of Instruction, $F(2,74) = 5.1$, $\varepsilon = .88$, $p = .012$, with the LPP being more positive in the increase compared to the view and decrease conditions, both *p*s < .038. The LPPs in the view and decrease conditions did not differ, $p = .19$. In addition, the main effect of Valence was significant, $F(1,37) = 6.7$, $p = .014$. The LPP was more positive for unpleasant than pleasant pictures. The other effects involving Instruction or Valence, including interactions with Age group, were not significant, all *F*s < 2.1, all *p*s > .13. The independent samples *t*-tests concerning age differences in the increase and decrease effects for each valence did not reveal any age differences either, all *t*s(37) < ±1.3, all *p*s > .19. It can be seen in Table 3 that the effect sizes of the instruction effects were either rather similar in younger and older adults, or larger in the younger than the older adults.

To summarize, the LPP between 700 and 1000 ms was more positive for unpleasant than pleasant pictures in all three instruction conditions. Between 400 and 1000 ms, the LPP was more positive in the increase than in the view and decrease conditions. The LPP between 400 and 700 ms was more positive for the decrease compared to the view condition. This decrease effect (difference between the decrease and view conditions) was smaller than the increase effect (difference between the increase and view conditions), see Table 3. Most important for the current research question, all of the effects of picture valence and instruction were similar in younger and older adults.

Table 3. Effect sizes (Cohen's *d*) of the instruction effects at the medial-posterior cluster, separately for each time window and age group.

	400-700 ms		700-1000 ms	
	Younger	**Older**	**Younger**	**Older**
increase-unpleasant vs. view-unpleasant	0.89	0.58	0.89	0.32
decrease-unpleasant vs. view-unpleasant	0.44	0.43	0.29	0.37
increase-pleasant vs. view-pleasant	0.93	0.69	0.62	0.26
decrease-pleasant vs. view-pleasant	0.29	0.19	0.33	0.07

Note. Cohen's *d* is computed as $(M_1 + M_2)/SD_{pooled}$, where $SD_{pooled} = \sqrt{((SD_1^2 + SD_2^2)/2)}$. Generally, $d = \pm 0.2$ is considered to be a small effect, $d = \pm 0.5$ to be a medium effect, and $d = \pm 0.8$ to be a large effect (Cohen, 1992).

Discussion

Here we examined by means of an ERP study whether age differences in emotion regulation occur. Younger and older adults viewed neutral, unpleasant, and pleasant pictures and were instructed to increase or decrease the feelings that unpleasant and pleasant pictures elicited while the electroencephalogram was recorded. The typical emotion effect on the LPP was observed, as the 700-1000 ms LPP was larger for emotional than neutral pictures and for unpleasant than pleasant pictures (cf. Ito, Larsen, Smith, & Cacioppo, 1998; Schupp et al., 2006; Schupp, Öhman et al., 2004) in both younger and older adults. Because in prior studies the LPP has been shown to be a correlate of emotion regulation (Hajcak & Nieuwenhuis, 2006; Krompinger et al., 2008; Moser et al., 2006), we focused on this ERP component.

The results showed that the LPP was indeed affected by emotion regulation. The LPP amplitude was more pronounced when feelings were increased compared to decreased or not regulated (cf. Moser et al., 2009). The direction of this effect is in line with the typical emotion effect on the LPP, in the sense that more intense emotional stimuli elicit a larger LPP (Schupp et al., 2006). Importantly, no age differences in emotion regulation effects on the LPP were observed. Although we did observe effects of instruction on the LPP, the absence of modulation of instruction effects by age could have been due to a relative lack of power with sample sizes of 19 vs. 20 participants per age group. However, even when increasing power by performing simple comparisons no age differences were observed. Furthermore, the effect sizes suggested that, if anything, the instruction effects were larger in the younger than the older adults. Therefore, neither of the hypotheses, that older adults would be better in regulating their emotions in general or that older adults would be particularly good at decreasing negative emotions and increasing positive emotions (non-hedonic vs. hedonic modes respectively), could be confirmed.

The design of the current study did not include pre- and post-regulation valence and arousal ratings of the stimuli (cf. Krompinger et al., 2008; Moser et al., 2006). Nevertheless, rating differences following emotion regulation have previously been shown to correlate with the LPP amplitude difference following emotion regulation (Gootjes et al., in preparation; Hajcak & Nieuwenhuis, 2006), suggesting that these measures match. Therefore, the current data suggest that, when instructed to do so, younger and older adults are equally capable of increasing both negative and positive emotions. Nevertheless, the older adults tended to experience more positive affect after completion of the emotion regulation task than younger adults. Thus, although the electrophysiological indices of emotion regulation suggest that younger and older adults regulated their emotions to the same extent, the older adults did report improved affect after the emotion regulation task. Apparently, age differences in affect can occur in the absence of age differences in emotion regulation.

It is intriguing that aging does not alter objective indices of emotion regulation abilities in this and prior studies (Kunzmann et al., 2005; Magai et al., 2006) while subjective indices of emotional regulation in prior studies (Gross et al., 1997; Lawton et al., 1992; Magai et al., 2006; Phillips et al., 2008) indicate that emotion regulation does improve with aging. This age difference in sense of emotional control may be due to age differences in spontaneous emotion regulation. First, it has previously been shown that emotion regulation becomes less costly with aging (Scheibe & Blanchard-Fields, 2009). Older compared to younger adults might therefore apply emotion regulation more often in daily life, leading to more control over emotions in daily life. Second, older adults may apply emotion regulation at different time points in the emotion generation process. In this respect, antecedent-focused emotion regulation refers to altering or preventing the occurrence of an emotional response, whereas the response-focused emotion regulation refers to changing an ongoing emotional response (Gross, 2002). In this study, mainly antecedent-focused emotion regulation would have happened, as participants knew the valence of the picture and whether they were supposed to increase or decrease the accompanying feeling beforehand because of the block design. It has been suggested that older adults would apply more antecedent-focused emotion regulation whereas younger adults would apply more response-focused emotion regulation in daily life (Kensinger & Leclerc, 2009). Although this is an interesting hypothesis, there is to our knowledge no empirical data yet that could support or falsify it. Third, younger and older adults may use different emotion regulation strategies (e.g. suppression, reappraisal, distraction, selective inattention to emotional aspects (Ochsner & Gross, 2005)). Previous research has shown that the use of suppression decreases with age, whereas the use of reappraisal increases with age (John & Gross, 2004). Future research could further focus on possible age differences in spontaneous emotion regulation.

Two previous ERP studies (Krompinger et al., 2008; Moser et al., 2006) did not show an effect of increasing feelings on the LPP amplitude, but showed a reduction of the LPP with decreasing feelings instead. In the current study, which has a similar design as those previous studies with respect to the stimulus duration and the open-ended, blocked emotion regulation instructions, the instruction to decrease feelings generally had no effect on the LPP. An important difference that might explain this discrepancy is that the arousal level of the emotional pictures was lower in the current study. It may be difficult to increase emotional responses to high arousing pictures, accounting for the absence of an LPP enhancement by increasing feelings in the previous studies, as well as to decrease emotional responses to low arousing pictures, accounting for the absence of an LPP attenuation by decreasing feelings in the current study. Nevertheless, in the study by Moser et al. (2009) with highly arousing pictures, a trial-by-trial manipulation of emotion regulation instruction, and long stimulus presentation (4 sec), both an LPP attenuation by decreasing feelings and an LPP enhancement by increasing feelings were observed. Here we show that, when using low arousing pictures, increase effects can even be observed with blocked emotion regulation instructions and short stimulus presentations (1 sec). Nevertheless, in order to reach a definite conclusion on the notion that arousal levels might play a role in the extent to which emotions can be increased or decreased, future research should compare regulation of emotion elicited by both low and high arousing stimuli directly.

We did not observe an LPP attenuation by decreasing feelings, but instead the LPP between 400 and 700 ms was somewhat enlarged when decreasing feelings compared to passively viewing emotional pictures. The direction of this effect is contrary to the typical emotion effect on the LPP and it is difficult to determine whether it is a meaningful finding. This effect of decreasing feelings on the LPP was smaller than the effect of increasing feeling and was not present between 700 and 1000 ms, during which the effect of increasing feelings on the LPP remained present.

To conclude, we observed LPP enhancement by increasing emotions. Importantly, we did not observe any age differences in this emotion regulation effect on the LPP. This finding stands in contrast to self-report data obtained in previous studies that suggest that emotion regulation changes with age, but is in accordance with objective measures obtained in previous studies that did not show age differences in emotion regulation either. We thus could not corroborate the notion that emotion regulation abilities improve with aging. Clearly, more research is needed to investigate the potential age differences in the application of emotion regulation in every day life, because that may shed light on the apparent discrepancy between subjective and objective measures of emotion regulation in older adults.

Chapter 8

Conclusion

Emotion and cognition influence each other reciprocally. Although the general idea may be that emotion influences the ratio adversely, research has shown that emotion may actually improve several cognitive abilities. Emotional information is, for example, typically better remembered than equivalent neutral information (Kensinger, 2007). The other way around, we can deploy our cognitive abilities to regulate our emotions (Gross, 1998; Ochsner & Gross, 2005). It has been proposed that emotional processing would change when people age (Mather & Carstensen, 2005). With the mean population age rising, research on the life span development of emotional processing is highly relevant. The goal of the project that resulted in this thesis was to investigate the age differences in emotional processing in general, and emotional memory in particular. The main approach in the experimental chapters was to collect both behavioral and event-related potential (ERP) data in younger and older adults during various memory tests with emotional stimuli, in order to identify age differences in behavior and neural activation during emotional processing. In this chapter, the main findings are summarized and discussed, conclusions are drawn, and suggestions for future research are made.

Summary, discussion, and conclusions

The main findings of this thesis are discussed according to the eight research questions that were posed in Chapter 1.

1) How can the positivity effect be defined and assessed?

In Chapters 2 and 3, the positivity effect was defined as a trend for adults to increasingly process positive and/or decreasingly process negative information compared with other information with advancing age. In Chapter 2, it was argued that, because there are three possible patterns of biases that may underlie the positivity effect, it is essential to test the Valence x Age group interaction and within-subject valence comparisons in order to determine whether a positivity effect is present.

2) How consistently does the positivity effect occur in LTM and what are preconditions for the occurrence of a positivity effect?

The literature review of studies concerning age differences in emotional long-term memory (LTM) presented in Chapter 2 revealed that a positivity effect was not observed consistently across studies. Table 1 in the present chapter summarizes the behavioral findings of age differences in emotional memory in the studies described in this thesis (comparable to Table 1 in Chapter 2). In this thesis, a positivity effect in memory was present in the free recall test in Chapter 3. As participants were unaware that stimulus valence was a factor in this study, this shows that a positivity effect can occur in the absence of explicit consideration of stimulus emotionality. Further, a near-positivity effect was observed in the free recall test in Chapter 4, while positivity effects were absent in the continuous recognition test that preceded the free recall test in Chapter 4, in the short-term memory (STM) task in Chapter 6, and even in the cued recall test that the participants in the study of Chapter 3 completed after the free recall test that did yield a positivity effect, see Table 1. It has been suggested that the more externally restraint a task is, the less likely it is that a positivity effect will occur (Mather, 2006) and the current disparity between free recall and the other tests that are more restraint in the sense that they include probe-guided retrieval, supports this notion.

In the present studies, a double dissociation was observed in age differences in valence and arousal ratings, and age differences in behavioral performance and electrophysiological activity. In Chapter 4, older adults found unpleasant and pleasant pictures equally arousing (i.e. no bias), while younger adults found unpleasant pictures more arousing than pleasant pictures (i.e. negativity bias). In Chapter 6, older adults experienced happy faces as more arousing than angry faces (i.e. positivity bias), whereas younger adults found happy and angry faces equally arousing (i.e. no bias). These age differences can be considered to be positivity effects on their own. Nevertheless, in these studies no positivity effects were observed in performance on the continuous recognition test with unpleasant, pleasant, and neutral pictures, in the ERP old/new effects obtained during the continuous recognition test, or in performance on the STM task with faces. In the study of Chapter 3, in contrast, no age differences occurred in valence and arousal ratings, yet a positivity effect was present in free recall and in the Late Positive Potential (LPP). This suggests that age differences in experienced stimulus valence and arousal levels are unrelated to the occurrence of behavioral and neurophysiological positivity effects.

To summarize, from the literature review in Chapter 2 it was concluded that type of encoding (incidental, intentional) and stimulus class (words, pictures, faces) do not influence the occurrence of a positivity effect. On the basis of the studies of this thesis it can be concluded that a positivity effect can occur even when stimulus emotionality is not explicitly considered by the participants. Moreover, the positivity effect appeared to be unrelated to age differences in valence and arousal ratings. Previous studies have suggested that using stimuli low in personal relevance (Tomaszczyk, Fernandes, & MacLeod, 2008) and adequate cognitive control in the older adults (Knight, Seymour, Gaunt, Nesmith, & Mather, 2007) are preconditions for the positivity effect. The current studies further suggest that the positivity effect may occur more in tasks that are less externally constraint (see also Mather, 2006).

Table 1. Occurrence of positivity effects in the studies described in this thesis.

Chapter	Participants (n)	Stimuli	Encoding	Measure	Valence x Age group interaction	Post hoc comparisons	Negativity bias	Positivity bias	No bias	Positivity effect
3	Y (19): 19-26 yrs O (19): 65-82 yrs	pictures	intentional	free recall	significant, *p* = .027	Y: U > P > N O: U = P > N	Y		O	●
				cued recall	significant, *p* = .001	Y: U = P > N O: N > U (P ns.)			Y & O	
4	Y (20): 17-27 yrs O (20): 63-77 yrs	pictures	intentional	continuous recognition (discrimination)	not significant, *p* not reported	U = P = N			Y & O	
				continuous recognition (response bias)	not significant, *p* not reported	U > N (P ns.)			Y & O	
				free recall	significant, *p* = .002	Y: U = P > N O: P > N (U ns.)			Y & O	
6	Y (20): 18-29 yrs O (20): 61-77 yrs	faces	intentional	short-term memory (discrimination)	not significant, *p* > .40	U = N > P	Y & O			
				short-term memory (response bias)	not significant, *p* > .33	P > N > U		Y & O		

Note. Y = younger adults, O = older adults, higher discrimination signals better performance, higher bias signals more liberal response bias, U = negative, P = positive, N = neutral, ns. = non-significantly different in-between.

3) Do neurophysiological and behavioral positivity effects co-occur?

In Chapter 3 it was investigated whether behavioral and neurophysiological positivity effects co-occur, because these have been studied only separately in previous studies. A positivity effect was observed in the free recall test, see Table 1. A positivity effect was also found in the LPP that occurred during the encoding of the pictures, showing that neurophysiological and behavioral positivity effects do occur simultaneously. Because the LPP reflects motivated attention (Schupp, Flaish, Stockburger, & Junghöfer, 2006), the current and previous findings (Kisley, Wood, & Burrows, 2007; Wood & Kisley, 2006) of a positivity effect in the LPP suggest that there is a positivity effect in attention. This would imply that there is a trend for adults to increasingly attend to positive and/or decreasingly attend to negative information compared with other information with advancing age. As outlined in Chapter 1, measuring the differential amount of attention that is allocated to negative and positive stimuli is not straightforward using behavioral paradigms, and most of the prior behavioral studies did not find a positivity effect in attention. Although the finding of a positivity effect in the LPP was not replicated in the study in Chapter 7, the findings of the study described in Chapter 3 suggest that the LPP might be a fruitful measure of age differences in emotional attention. Moreover, because the amount of attention that is allocated to certain information is positively related to the probability that that information will be remembered (Hamann, 2001), the current co-occurring positivity effects suggest that the positivity effect in memory might, at least partly, result from a positivity effect in attention.

4) Does mood congruency play a role in the occurrence of a positivity effect?

Table 2 displays the findings of age differences in state and trait negative and positive mood, as assessed by questionnaires, in the studies described in this thesis. When comparing this table to Table 1 in Chapter 1, it can be seen that age differences in mood were observed less consistently in current than in previous studies. Nevertheless, the current studies reveal a double dissociation between the occurrence of a positivity effect and the occurrence of more positive and/or less negative mood with aging. More specifically, in Chapter 3, a positivity effect was observed in free recall and the LPP while there were no significant age differences in mood (if anything, the younger tended to experience more positive mood than the older adults), see Table 2. Conversely, in Chapter 4, older adults experienced more positive and less negative mood than the younger adults, see Table 2, yet a positivity effect was not observed in memory performance or the ERP old/new effects. It can thus be concluded that the positivity effect does not result from a mood congruency effect (see also Schlagman, Schulz, & Kvavilashvili, 2006), which entails that people preferably remember information that is congruent with their mood (Lewis & Critchley, 2003).

Table 2. Occurrence of age differences in positive and negative mood in the studies described in this thesis.

Chapter	Participants (n)	State or trait	Negative mood	Positive mood
3	Y (19): 19-26 yrs	state	Y = O	Y = O
	O (19): 65-82 yrs	trait	Y = O	Y > O (trend)
4	Y (20): 17-27 yrs	state	Y > O	Y < O
	O (20): 63-77 yrs	trait	Y > O	Y = O
7	Y (19): 18-26 yrs	state	Y = O	Y < O (trend)
	O (20): 60-77 yrs	trait	Y = O	Y = O

Note. Y = younger adults, O = older adults.

5) Do age differences occur in the emotional modulation of ERP old/new effects?

The study reported in Chapter 4 was conducted to investigate age differences in the emotional modulation of ERP old/new effects obtained during a continuous recognition test, because the emotional modulation of ERP old/new effects has previously been investigated in younger adults only. No age differences occurred in the emotional modulation of behavioral memory performance, see Table 1, but age differences were present in the emotional modulation of the ERP old/new effects. This discrepancy shows that neurophysiological effects can have important additive value to behavioral measures (see also Wilkinson & Halligan, 2004) when studying age differences in emotional processing. The electrophysiological data show that stimulus emotionality enhanced the parietal and late frontal old/new effects in younger adults, but the early old/new effect in older adults. Thus, although behavior was unaffected, recollection and post-retrieval processes appear to be augmented in emotional recognition memory in younger adults, whereas familiarity appears to be enhanced by emotional salience in older adults.

6) What cognitive processes at which memory stages play a role in the emotion modulation of STM?

Because the cognitive mechanisms behind emotional modulation of STM have hardly been examined before, the study described in Chapter 5 identified the electrophysiological correlates of emotional modulation of STM. The goal of the study was to determine which memory processing stages and cognitive processes contribute to the emotional enhancement effect on STM. In this study, young adults performed a STM task in which they remembered the face identity of faces with angry, happy, and neutral expressions while ERPs were obtained. Behaviorally, angry and happy faces were better remembered than neutral faces, yielding a classic emotion enhancement effect on STM. However, angry and neutral faces were better remembered than happy faces in the same task in the study described in Chapter 6, see Table 1. Moreover, in prior work, angry faces were remembered better than happy and neutral faces (M. C. Jackson, Wolf, Johnston, Raymond, & Linden, 2008; M. C. Jackson, Wu, Linden, & Raymond, 2009). Nevertheless, these latter two findings can be considered to reflect a negativity bias. Although all of these studies used the same STM paradigm, subtle differences existed in the timing of the task (such as speeded vs. unspeeded responses, limited vs. unlimited duration of the perceived response window) possibly leading to the discrepant findings. In any case, the study reported in Chapter 5 showed that emotional faces elicited a smaller P3b and a larger N250r component during retrieval. This suggest that emotional enhancement of STM occurs because emotional faces are better maintained during the retention interval and because emotional faces are better perceived as repeated during retrieval. In contrast to general findings in the LTM domain, no evidence for enhanced attention allocation to, or enhanced encoding of emotional faces was observed in this STM task.

7) Do age differences occur in the emotional modulation of STM?

Because age differences in the emotional modulation of STM for stimulus content had not been investigated previously, the study in Chapter 6 was conducted to identify age differences in behavioral performance on the above-mentioned emotional STM task with angry, happy, and neutral faces. Crucially, participants were instructed to remember the face identity (i.e. stimulus content), and not the facial expression (i.e. stimulus emotionality), making the STM task conceptually comparable to emotional LTM memory tests. No age differences were observed in the emotional modulation of STM, see Table 1. This absence of age differences was probably due to the restraint nature of the STM task, as well as to the automaticity (D'Argembeau & Van der Linden, 2007) of the influence of facial expression on memory for face identity. These findings in the STM domain are therefore in correspondence with the idea that bottom-up emotional processing does not change across the life span (Mather & Carstensen, 2005).

8) Do age differences occur in emotion regulation abilities?

Because positivity effects in memory, attention, and mood have been taken to result from improved emotion regulation in older adults (Kensinger & Leclerc, 2009; Mather & Carstensen, 2005), age differences in emotion regulation were examined in the current project as well. In Chapters 1 and 7, several problems with respect to the supposed age differences in emotion regulation were identified. The main issue is that age differences in emotion regulation are often only inferred from age differences in emotional reactivity or from self-report measures, instead of empirically observed using emotion regulation tasks. Moreover, it is unclear what improved emotion actually comprises and in what aspect of emotion regulation these age differences would occur. In the study described in Chapter 7, it was investigated whether age differences in emotion regulation abilities occur by instructing younger and older adults to increase and decrease the emotions that unpleasant and pleasant pictures elicited. Modulation of the LPP by these instructions was taken to be the electrophysiological correlate of emotion regulation abilities. No age differences were observed in the effect of emotion regulation on the LPP, which is in accordance with previous studies using other kinds of objective measures to study age differences in the success of emotion regulation (Kunzmann, Kupperbusch, & Levenson, 2005; Magai, Consedine, Krivoshekova, Kudadjie-Guamfi, & McPherson, 2006). Thus, these findings do not support the existence of age differences in emotion regulation abilities. Meanwhile, the older adults did tend to report more state positive affect than the younger adults, see Table 2, thereby casting some doubt on the suggested link between improved emotion regulation and improved mood in older adults.

Suggestions for future research

The work presented in this thesis of course has identified many issues that require additional examination, as well as some suggestions on how to conduct such future research. First of all, it would be important to explicitly define the topic under investigation. In this thesis an attempt was made to define the positivity effect. I hope that the present definition and the accompanying suggestions for data analysis will be taken into account in future research. Note that the current definition implies that statements such as "older adults showed a positivity effect" (e.g. Fernandes, Ross, Wiegand, & Schryer, 2008, p. 304; Mather & Knight, 2005, p. 567) are equivalent to stating that 'older adults showed an age difference', which obviously is peculiar. It would be more correct to state that 'younger and older adults were tested and that a positivity effect was observed', or something similar. In the case that the definition and suggestions for analysis would be considered unsatisfactory by other researchers in the field, they could at least serve as a starting point for the discussion on how to define and analyze the positivity effect in a way that does suffice.

In this thesis, it has been argued that the positivity effect is not a consistent finding. Future research could focus on identifying the preconditions for the occurrence of a positivity effect, and could further explore the relation between positivity effects in brain and behavior. In this thesis it was also argued that a positivity effect is not the only finding of interest in the field of age differences in emotional processing. Future research on aging and emotion should therefore not focus on this particular age effect solely.

Compared to our knowledge on emotional LTM, very little is known about the emotional modulation of STM. Only few studies have yet been conducted that studied the effect of stimulus emotionality on STM for stimulus content. This area could be further explored, both in younger adults alone and with respect to age differences herein, and by using stimuli other than emotional faces, such as emotional words or pictures.

The notion that emotion regulation improves with aging requires more research. This research should test whether this improvement with aging actually occurs, and if so, how it comes about. Conclusions on this issue can not be based on speculation or self-report measures only, but require empirical data. Future studies could employ emotion regulation tasks that have previously been used to study emotion regulation in younger adults in the lab (e.g. D. C. Jackson, Malmstadt, Larson, & Davidson, 2000; Krompinger, Moser, & Simons, 2008; Moser, Hajcak, Bukay, & Simons, 2006; Moser, Krompinger, Dietz, & Simons, 2009; Ochsner, Bunge, Gross, & Gabrieli, 2002). Additionally, given that younger and older adults might not differ in emotion regulation abilities but rather in spontaneous application of emotion regulation in everyday life, non-self report dependent ways of investigating emotion regulation in daily life might need to be devised in order to investigate this possibility.

It should be kept in mind that the impact of age on emotion may not be uniform but rather may depend on the particular aspect of emotion (Borod, 1993). The impact of age on emotion may, for example vary between the different discrete emotions, or between the experience, expression or perception of emotions. Moreover, also an absence of age differences in some kind of measure of emotional processing (either behaviorally or neurophysiologically) may yield interesting knowledge, even though null findings are of course difficult to interpret. After all, it can hardly be assumed that every aspect, see Figure 1 in Chapter 1, of emotion changes with aging.

Finally, the older participants of the studies described in this thesis belonged to the select population of healthy older adults. It would also be interesting to study whether and how emotional memory (and emotional processing in general) is affected by geriatric disorders, such as Parkinson's disease and different forms of dementia (e.g. Budson et al., 2006; Kensinger, Brierley, Medford, Growdon, & Corkin, 2002; Wright, Dickerson, Feczko, Negeira, & Williams, 2007).

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Samenvatting

Het onderwerp van dit proefschrift is de wisselwerking tussen emotie en cognitie. Hoewel het algemene idee bestaat dat emotie de ratio negatief beïnvloedt, heeft onderzoek aangetoond dat emotie een aantal cognitieve vaardigheden juist verbetert. Emotionele informatie wordt bijvoorbeeld vaak beter onthouden dan soortgelijke neutrale informatie. Bovendien kunnen we onze emoties reguleren door gebruik te maken van onze cognitieve vaardigheden. Het is gesuggereerd dat het verwerken van emotionele informatie zou veranderen als mensen ouder worden. Het doel van dit project was om leeftijdsverschillen in gedrag en hersenactiviteit tijdens het onthouden van emotionele informatie, en tijdens het reguleren van emoties te onderzoeken. De voornaamste benadering in de experimentele hoofdstukken was het verzamelen van gedragsdata en *event-related potential* (ERP)-data bij jong volwassenen en ouderen terwijl zij geheugen- en emotieregulatietaken uitvoerden.

In **Hoofdstuk 2** van dit proefschrift is het positiviteitseffect gedefinieerd als *een neiging van volwassen om naarmate men ouder wordt positieve vergeleken met negatieve informatie meer en/of negatieve vergeleken met positieve informatie minder te gaan verwerken*. Deze definitie beschrijft een leeftijdseffect en het positiviteitseffect moet dus niet verward worden met een positiviteitsbias. Dat is namelijk een versterkte verwerking van positieve ten opzichte van negatieve informatie binnen individuen of een leeftijdsgroep. Een negativiteitsbias beschrijft een versterkte verwerking van negatieve ten opzichte van positieve informatie. Er zijn drie mogelijke patronen van biasen die ten grondslag kunnen liggen aan een positiviteitseffect: 1) jong volwassen vertonen geen bias en ouderen vertonen een positiviteitsbias, 2) jong volwassen vertonen een negativiteitsbias en ouderen vertonen geen bias, en 3) jong volwassen vertonen een negativiteitsbias en ouderen vertonen een positiviteitsbias. Om te bepalen of er een positiviteitseffect is opgetreden is het daarom essentieel dat de interactie tussen de factoren Valentie (onplezierig, plezierig, neutraal) en Leeftijdsgroep (jongeren, ouderen), en de vergelijkingen tussen de valenties binnen iedere leeftijdsgroep getest worden. Uit het literatuuroverzicht in Hoofdstuk 2 van studies naar leeftijdsverschillen in emotioneel langetermijngeheugen bleek dat een positiviteitseffect geen consistente bevinding is.

Tot nu toe waren positiviteitseffecten in gedrag en in hersenactiviteit slechts apart van elkaar onderzocht. In **Hoofdstuk 3** werd daarom gekeken of ze ook tegelijkertijd optreden. Jong volwassen en ouderen probeerden onplezierige, plezierige en neutrale foto's te onthouden en rapporteerden die later in een vrije-herinneringstaak en een gestuurde-herinneringstaak. Er werd een positiviteitseffect gevonden in gedrag, namelijk in de vrije-herinneringstaak. Aangezien proefpersonen niet wisten dat de emotionele lading van de stimuli ertoe deed, blijkt een positiviteitseffect ook kunnen optreden als er niet gelet wordt op de emotionele lading van stimuli. Er trad ook een positiviteitseffect op in hersenactiviteit, namelijk in de Late Positieve Potentiaal (LPP) in het ERP. Hieruit blijkt dat positiviteitseffecten in gedrag en in hersenactiviteit elkaar vergezellen. Aangezien de LPP aandacht reflecteert, kan voorzichtig geconcludeerd worden dat het positiviteitseffect in geheugen meer veroorzaakt wordt door een positiviteitseffect in aandacht dan door *retrieval*-processen, die gereflecteerd worden in de oud/nieuw-effecten.

In **Hoofdstuk 4** werd onderzocht of er leeftijdsverschillen zijn in de invloed van emotie op ERP oud/nieuw-effecten, omdat de invloed van emotie op oud/nieuw-effecten eerder alleen nog maar bij jong volwassen was onderzocht. Jong volwassen en ouderen voerden daarvoor een continue herkenningstaak uit met onplezierige, plezierige en neutrale foto's. In de herkenningstaak werden foto's van alle valenties even goed onthouden door beide leeftijdsgroepen, terwijl er wel leeftijdsverschillen optraden in de daarop volgende vrije-herinneringstaak. Jong volwassen onthielden emotionele foto's beter dan neutrale foto's, terwijl ouderen vooral de plezierige foto's goed onthielden. Er waren ook leeftijdsverschillen in de invloed van emotie op oud/nieuw-effecten. Jong volwassen vertoonden grotere pariëtale en late, frontale oud/nieuw-effecten voor emotionele dan neutrale stimuli, terwijl bij ouderen het vroege oud/nieuw-effect groter was voor emotionele dan neutrale stimuli. Deze bevindingen tonen aan dat bij jong volwassen *recollection*- en *post-retrieval*-processen sterker optreden bij emotionele stimuli, terwijl bij ouderen het *familiarity*-proces versterkt wordt wanneer stimuli een emotionele lading hebben.

In **Hoofdstuk 5** is bij jong volwassen onderzocht welke cognitieve processen tijdens welke geheugenstadia bijdragen aan de invloed van emotie op het kortetermijngeheugen, aangezien dat nog volstrekt onbekend is. De proefpersonen voerden een taak uit waarbij ze de identiteit van gezichten met een boze, blije of neutrale gezichtsuitdrukking een korte tijd moesten onthouden. Het bleek dat boze en blije gezichten beter werden onthouden dan neutrale gezichten. Emotionele gezichten lokten een kleinere P3b en een grotere N250r uit dan neutrale gezichten. Hieruit blijkt dat het kortetermijngeheugen beter is voor emotionele dan neutrale gezichten omdat emotionele gezichten beter worden vastgehouden in het geheugen (*maintenance*) en omdat het bij emotionele gezichten beter opvalt als hetzelfde gezicht weer wordt aangeboden tijdens het ophalen van het gezicht uit het geheugen (*retrieval*). Er werden geen aanwijzingen gevonden dat de opslag (*encoding*) in het kortetermijngeheugen wordt beïnvloed door de emotionele lading van stimuli.

Het was nog niet eerder onderzocht of er leeftijdsverschillen zijn in de invloed van emotie op het kortetermijngeheugen voor de inhoud van de stimulus. De studie die wordt beschreven in **Hoofdstuk 6** onderzocht dit gedragsmatig, met behulp van dezelfde taak met boze, blije en neutrale gezichten die ook in Hoofdstuk 5 werd gebruikt. Jong volwassenen en ouderen werden geïnstrueerd om de identiteit van de gezichten (d.w.z. de inhoud van de stimulus) te onthouden, en niet de gezichtsuitdrukking (d.w.z. de emotionele lading van de stimulus), waardoor de taak vergelijkbaar is met taken die gebruikt zijn bij onderzoek naar leeftijdsverschillen in de invloed van emotie op het langetermijngeheugen. De blije gezichten werden minder goed onthouden dan de boze en neutrale gezichten, door zowel jong volwassenen als ouderen. Er waren dus geen leeftijdsverschillen in de manier waarop emotie het kortetermijngeheugen beïnvloedt. Omdat gezichtsuitdrukkingen het geheugen voor de identiteit van een gezicht automatisch beïnvloeden, zijn deze bevindingen in overeenstemming met het idee dat automatische, *bottom-up* processen niet veranderen tijdens het ouder worden.

Er is gesuggereerd dat positiviteitseffecten in geheugen, aandacht en stemming het gevolg zouden zijn van een verbetering van emotieregulatie tijdens de veroudering. In **Hoofdstuk 1** en **7** zijn een aantal problemen met deze bewering beschreven. Deze bewering is bijvoorbeeld hoofdzakelijk gebaseerd op bevindingen van leeftijdsverschillen in emotionele reactiviteit en op zelfrapportagematen, in plaats van op empirische bevindingen. Bovendien is het onduidelijk wat er precies wordt verstaan onder verbeterde emotieregulatie en welke aspecten van emotieregulatie precies verschillen tussen jongeren en ouderen. In **Hoofdstuk 7** is onderzocht of er leeftijdsverschillen zijn in emotieregulatie. Jongvolwassenen en ouderen werden geïnstrueerd om hun gevoelens bij onplezierige en plezierige foto's te versterken of te verminderen. Het effect van deze instructies op de LPP fungeerde daarbij als maat voor de vaardigheid in het reguleren van emoties. De LPP was groter in reactie op emotionele dan neutrale foto's in beide leeftijdsgroepen. Wanneer proefpersonen hun negatieve en positieve emoties versterkten was de LPP groter dan wanneer ze hun emoties niet probeerden te veranderen. Er werden geen leeftijdsverschillen gevonden in dit effect van emotieregulatie op de LPP. Dit is in overeenstemming is met eerdere studies die andere objectieve maten van de vaardigheid in het reguleren van emoties hebben gebruikt. De studie beschreven in Hoofdstuk 7 levert dus geen bewijs voor het idee dat emotieregulatie verbetert tijdens veroudering.

In **Hoofdstuk 8** ten slotte werden de bevindingen van de verschillende studies geïntegreerd. In overeenstemming met de conclusie uit het literatuuroverzicht in Hoofdstuk 2 dat het positiviteitseffect geen consistente bevinding is, trad het ook niet op in alle geheugentaken in de huidige studies. Het is eerder geopperd dat hoe dwingender een geheugentaak is, des te kleiner de kans is dat een positiviteitseffect optreedt. De huidige bevindingen steunen dit idee, aangezien er een positiviteitseffect optrad in de vrije-herinneringstaak (Hoofdstuk 3) maar niet in de gestuurde-herinneringstaak, de continue herkenningstaak en de kortetermijngeheugentaak (Hoofdstuk 3, 4 en 6) die dwingender waren in de zin dat *retrieval* werd geleid door het aanbieden van een stimulus. Daarnaast was er een dubbele dissociatie tussen het optreden van een minder negatieve en/of een meer positieve stemming van ouderen vergeleken met jong volwassen en het optreden van een positiviteitseffect in geheugenprestatie en hersenactiviteit. Hieruit kan geconcludeerd worden dat een positiviteitseffect niet het gevolg is van een stemmingcongruentie-effect, wat inhoudt dat mensen informatie beter onthouden wanneer die in overeenstemming is met hun stemming. Verder bleek er ook een dubbele dissociatie te zijn tussen het optreden van een positiviteitseffect in de *arousal* die proefpersonen ervoeren bij de stimuli en het optreden van een positiviteitseffect in geheugenprestatie en hersenactiviteit. Concluderend kan gesteld worden dat taakeigenschappen het optreden van een positiviteitseffect meer lijken te beïnvloeden dan proefpersooneigenschappen (zoals stemming).

In **Hoofdstuk 8** werden ook suggesties gedaan voor toekomstig onderzoek. Ik hoop dat er gebruik zal worden gemaakt van de definitie van het positiviteitseffect en van de suggesties voor de analyse daarvan zoals die in dit proefschrift zijn gegeven, of dat deze tenminste als startpunt zullen dienen voor een discussie met als doel overeenstemming te bereiken over hoe het positiviteitseffect gedefinieerd en geanalyseerd zou moeten worden. Aangezien het positiviteitseffect niet consistent lijkt op te treden, zou er meer onderzoek gedaan kunnen worden naar de voorwaarden voor het optreden van dit effect. Er zou ook meer onderzoek gedaan kunnen worden naar de relatie tussen het positiviteitseffect in gedrag en hersenactiviteit. Toekomstig onderzoek naar leeftijdsverschillen in het verwerken van emotionele stimuli zou zich echter niet alleen maar op het positiviteitseffect moeten concentreren, aangezien andersoortige leeftijdsverschillen ook interessant kunnen zijn. Verder is er meer empirisch onderzoek nodig naar het bestaan en de aard van leeftijdsverschillen in emotieregulatie, en naar het optreden van leeftijdsverschillen in de invloed van emotie op het kortetermijngeheugen. Het zou ook interessant zijn om te onderzoeken hoe het emotionele geheugen (en emotionele verwerking in het algemeen) verandert als gevolg van ouderdomsaandoeningen zoals de ziekte van Parkinson en verschillende soorten dementie.

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Curriculum Vitae

Sandra Juliëtte Elisabeth Langeslag was born on July 21st 1982 in Wageningen, The Netherlands. She obtained the diploma gymnasium-B at the Fioretti College in Lisse in 2000. In 2001 she started studying psychology at Maastricht University. Her research apprenticeship, which concerned electrophysiological measurements of love, took place at the Erasmus University Rotterdam during the first half of 2005. In the summer of 2005 she graduated cum laude in Biological Psychology. Subsequently, she spent the second half of 2005 as a visiting researcher at the University of Wales, Bangor, UK. In 2006 she started as a PhD-student at the Institute of Psychology at the Erasmus University Rotterdam, studying the topic of emotional memory. During her PhD she participated in the educational program of the Graduate Research Institute EPOS. Besides her PhD-project she developed her own line of research on the neurocognition of romantic love. She further developed and taught a third year course on the neurobiology of emotions and participated in several other psychology courses as a tutor, prakticum assistant, or lecturer. In 2008, she was awarded the Dr. W.H. Posthumus-van der Goot stipend. She has recently obtained a position as an assistant professor at the Institute of Psychology at the Erasmus University Rotterdam.

Publications

Journal articles & book chapters

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Langeslag, S. J. E., & Van Strien, J. W. (under review). Aging and short-term memory for face identity of emotional faces.

Abstracts

Langeslag, S. J. E., Morgan, H. M., Jackson, M. C., Linden, D. E. J., & Van Strien, J. W. (2008). Electrophysiological correlates of improved working memory for emotional faces. *International Journal of Psychophysiology, 69,* 198.

Jackson, M. C., Wu, C.-Y., Langeslag, S. J. E., Linden, D. E. J., & Raymond, J. E. (2006). Enhanced visual working memory for angry faces. *Journal of Vision*, *6*(6), 361a, http://journalofvision.org/6/6/361/, doi:10.1167/6.6.361.

Invited presentations

Liefde [Love]. (2009). Stanislascollege, Delft, The Netherlands.

Emotional faces: Romantic love and Short-term memory. (2009). Cognitive Science Seminar, Birkbeck, University of London, UK.

The Late Positive Potential: Romantic love and Age differences. (2008). Cognitive Neuroscience Colloquium, University of Wales, Bangor, UK.

Verliefdheid en de hersenen [Romantic love and the brain]. (2008). Science café Rotterdam, The Netherlands.

Liefde [Love]. (2007). Erasmus University Rotterdam, 5th anniversary of the Institute of Psychology, The Netherlands.

Conference presentations

Langeslag, S. J. E., Franken, I. H. A., & Van Strien, J. W. (2009). *Romantic love and attention*. NVP Winter Conference 2009, Egmond aan Zee, The Netherlands.

Langeslag, S. J. E., Morgan, H. M., Jackson, M. C., Linden, D. E. J., & Van Strien, J. W. (2008). *Electrophysiological correlates of improved working memory for emotional faces*. EPOS workshop "Neurocognitive approaches to control and working memory", Leiden, The Netherlands.

Langeslag, S. J. E., Morgan, H. M., Jackson, M. C., Linden, D. E. J., & Van Strien, J. W. (2008). *Electrophysiological correlates of improved working memory for emotional faces*. 14th World Congress of Psychophysiology, St. Petersburg, Russia.

Posters

Langeslag, S. J. E., & Van Strien J. W. (2009). *Aging and emotion regulation: An ERP study*. Conference on Changing Emotions, Brussels, Belgium.

Langeslag, S. J. E., & Van Strien J. W. (2009). *Aging and emotion regulation: An ERP study*. 3rd Annual meeting of the Social and Affective Neuroscience Society, New York, US.

Van Strien, J. W., Gootjes, L., Langeslag, S. J. E., & Franken, I. H. A. (2009). *Facial fear attenuates the ERP old/new effect*. 3rd Annual meeting of the Social and Affective Neuroscience Society, New York, US.

Langeslag, S. J. E., & Van Strien J. W. (2009). *Aging and short-term memory for emotional faces*. International Society for Research on Emotion 2009 Conference, Leuven, Belgium.

Langeslag, S. J. E., & Van Strien J. W. (2009). *Aging and emotion regulation: An ERP study*. EPOS workshop "Methods and challenges in developmental neuroimaging", Amsterdam, The Netherlands.

Langeslag, S. J. E., & Van Strien J. W. (2007). *Attention, rather than retrieval, contributes to age differences in emotional memory: an Event-Related Potential (ERP) study*. NVP Winter Conference 2007, Egmond aan Zee, The Netherlands.

Langeslag, S. J. E., & Van Strien, J. W. (2006). *Do we get more pleasant memories as we grow older? An event-related potential (ERP) study investigating the subsequent memory effect for emotional pictures in young and older adults*. NWO Autumn School "Active Memory", Doorwerth, The Netherlands.

Jackson, M. C., Wu, C.-Y., Langeslag, S. J. E., Linden, D. E. J., & Raymond, J. E. (2006). Enhanced visual working memory for angry faces. Vision Sciences Society 6th Annual Meeting, Sarasota, US.

Popular media

Roze wolk, blikseminslag, vlinders in je buik? Gewoon een kwestie van dopamine, serotonine en noradrenaline [Pink cloud, stroke of lightning, butterflies in your stomach? Just a matter of dopamine, serotonin, and noradrenaline] (2009). *Margriet, 45,* 58-59.

De chemische kant van de liefde [The chemical aspect of romantic love] (2008/2009). *Mind Magazine, Dec 2008/Jan 2009,* 125.

Verliefdheid en de hersenen [Romantic love and the brain] (2008). *Nederland-e.*

Love is in the brain (2008). *NOS Headlines.*

Hoe weet je of je echt verliefd bent? [How do you know whether you are truly in love?] (2008). *Willem Wever.*

Het moment dat je wist: Hij is het [The moment you knew: He is the one] (2006). *Viva, 47*, 14.