AGE-RELATED DIFFERENCES IN SELECTIVE ATTENTION TO EMOTIONAL MATERIAL: DOES TASK-RELEVANCE MATTER?

A Dissertation
Presented to
The Academic Faculty

by

Didem Pehlivanoglu

In Partial Fulfillment
of the Requirements for the Degree
Doctor of Philosophy in the
School of Psychology

Georgia Institute of Technology
December 2018

AGE-RELATED DIFFERENCES IN SELECTIVE ATTENTION TO EMOTIONAL MATERIAL: DOES TASK-RELEVANCE MATTER?

Approved by:

Dr. Paul Verhaeghen, Advisor
School of Psychology
Georgia Institute of Technology

Dr. Mark Wheeler
School of Psychology
Georgia Institute of Technology

Dr. Audrey Duarte
School of Psychology
Georgia Institute of Technology

Dr. Derek Isaacowitz
Department of Psychology
Northeastern University

Dr. Christopher Hertzog
School of Psychology
Georgia Institute of Technology

Date Approved: August 13, 2018

To Can, who is an almost lifelong friend, the funniest and greatest guy to be with.

ACKNOWLEDGEMENTS

First and foremost, I would like to thank my advisor and mentor Dr. Paul Verhaeghen for his support during whole grad school life at Georgia Tech. He is not only one of the most awesome, patient, and understanding advisors that I have known in the world of academia but also one of the nicest and kindest people that I have met in the planet. I am feeling so lucky and privileged to work with him. I am looking forward to our future work and I believe I still have a lot to learn from him.

I would also like to thank to my dissertation committee of Drs. Audrey Duarte, Christopher Hertzog, Mark Wheeler, and Derek Isaacowitz for their invaluable suggestions and feedback that contributed to my research idea, methodology, analysis, and interpretation of these data. Additionally, I would like to thank all my research assistants, Lindsey Drummond, Amelia Tan, and Carrie Brooks, and study participants without whom it would not be possible to complete this dissertation. I would also like to acknowledge that this dissertation was partially supported by an APA Dissertation Award.

Before I come to Georgia Tech, I had a chance to work with Dr. Hakan Cetinkaya during my bachelor's degree and Dr. Aysecan Boduroglu during my master's degree in Turkey. I am so happy that I got the opportunity to work with them and I would like to thank them for providing emotional and intellectual support that I needed in the beginning of my academic journey. My interactions with them made the rest of my academic journey possible.

Since I have come to Georgia Tech, I had a chance to meet with a really nice group of friends from different parts of the world and I am so happy to get to know them. I am especially feeling grateful for those with whom we have some special bond, connection, and memories that I want to keep for the rest of my life. A big thank you to my family members, especially to my mom, for letting me find my own way in life, for their unconditional love and support through my ups and downs, and for their understanding and respect about the choices I have made so far.

Last but not least, special thanks to my beloved Can, for providing unconditional love and support since 2005 (and maybe even before that :D) and for bearing with me when I was writing my dissertation. I feel so lucky to have him in my life and I am looking forward to many more adventures to come!

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

SUMMARY

According to the inhibitory deficit hypothesis, older adults have difficulties in preventing task-irrelevant materials from gaining access to working memory (Lustig, Hasher, & Zacks, 2007). Some neuroscientific evidence, however, show that the age-related inhibitory deficit disappears when task difficulty is equated. Thus, it is still not clear whether findings regarding the age-related inhibitory deficit are confounded by task-related factors or not. Additionally, although previous studies showed that event-related potentials (ERPs) to emotional material change as a function of task relevancy in the young, it is still an open question whether there are age-related differences on this issue. Combining these questions, the goal of this dissertation was to examine the effect of age on ERP correlates of inhibitory functioning by employing a selective attention task which required younger and older adults to selectively attend to either pictures (emotional or non-emotional) or to flanking line bars, concurrently presented on the screen. In the picture task, participants decided whether the picture was presented in black and white or color; in the bar task, they indicated whether the orientation of the bars matched or not. Prior to the experiment, I individually calibrated the difficulty of the non-emotional bar task such that accuracy was 75% correct. The behavioral data showed no interference from emotional material in the bar task. Accuracy in the picture task was higher for emotional relative to neutral pictures in the picture task, regardless of age. ERPs provided evidence for both emotion-based and more differentiated valence-based effect for the younger adult group in the picture task. In the bar task, there was evidence for enlarged ERPs for task-irrelevant emotional relative to task-irrelevant neutral pictures during the time windows (250-300 ms and 350-450 ms) associated with the negative ERP components, but task-irrelevant emotional material was suppressed at a later stage of processing (500-700 ms). ERP results for the older adult group provided evidence for an emotional positivity effect and an emotional negativity effect in the picture task. In the bar task, although interference from positive images occurred at early stage of processing, ERPs to task-irrelevant emotional and neutral pictures were similar during later ERP components. These findings are discussed in light of theories of cognitive aging and different accounts of emotional processing in aging.

CHAPTER 1

INTRODUCTION

The two basic aspects of selective attention are inhibition and activation. Inhibition reflects the suppression of task-irrelevant information, preventing it from gaining access to working memory; activation reflects the enhancement of task-relevant information. According to the inhibitory deficit hypothesis, activation-related processes are mostly preserved in older age, whereas inhibitory functioning declines with age (e.g., Hasher & Zacks, 1988; Lustig, Hasher, & Zacks, 2007). Both behavioral and neural data provide evidence for the position that older adults have difficulty in suppressing distractors. For example, in a series of studies by Gazzaley and colleagues (2005, 2008) participants were presented with an array of four cue stimuli including two faces and two scenes, presented in random order. The task required participants to either remember faces and ignore scenes or remember scenes and ignore faces; the control condition consisted of passively viewing the stimuli. After a brief delay, a memory probe was presented, and participants were required to report whether the stimulus matched one of the previously presented stimuli. Older adults showed the same amount of enhancement (i.e., an increase in neural activity relative to a passive viewing condition) as younger adults when processing to-be-remembered images (i.e., faces/scenes). In contrast, an age-related suppression deficit appeared; that is, relative to younger adults, older adults showed similar event-related potentials (ERPs) for to-be-ignored items and for items presented under the passive view condition in early visual processing (reflected by an attenuation and a delay in the P1 and N1 components in the older compared to the younger).

Importantly, these studies (e.g., Gazzaley et al., 2005; 2008) consistently reported that the age-related suppression deficiency in the early processing stream reflected by ERPs disappeared once older adults' working memory performance was matched with that of younger adults. Similarly, in her review of the literature, Fabiani (2012) notes that many of the neuroscientific findings about age differences in neural activity associated with inhibition functioning disappear when task difficulty is equated. Thus, one potential problem associated with the studies that reported age-related inhibitory deficits is that the observed age-related differences in neural data and behavioral performance may not result from the aging process per se, but from group differences in mean difficulty levels.

In the current study, I investigated the effect of age on ERP correlates of inhibitory functioning by employing a selective attention task which required younger and older adults to selectively attend to either pictures (emotional or non-emotional) or to flanking line bars, concurrently presented on the screen, by asking them to perform a task that focused either on the pictures or about the bars. The main interest was in comparing age-related differences in the extent to which emotional pictures were still being processed at the neural level when they were distractors (i.e., in the task where the line bars were the focus) versus when they were the focus of the task. In order to circumvent the task difficulty confound mentioned above, I calibrated task difficulty individually so that all subjects performed at identical levels in the non-emotional bar task.

I was inspired by several studies with younger adults that examined the degree to which emotion can capture attention by requiring participants to perform a cognitive task in the context of task-irrelevant, emotional pictures. The assumption is that if the emotional pictures are perceived as such, even when attention is directed toward another task, there would be a performance decrement in the cognitive task and/or enhanced ERPs for task-irrelevant emotional relative to task-irrelevant neutral pictures. This is typically what is found. For example, in a behavioral study by Erthal et al. (2005) participants were presented with central picture (neutral or unpleasant) and two peripheral bars and asked to decide whether the bars were in the same or a different orientation while ignoring the central picture. They found that response times in the bar orientation task were slower in the presence of task-irrelevant negative relative to neutral pictures, suggesting that irrelevant emotional images interfered with the main bar-orientation task by slowing response times.

Most ERP studies that examined the extent to which irrelevant emotional material is processed have specifically focused on three ERP components. The first and less often studied component is an early-onset positivity which has also been referred to as P2 (Carretie´, Martin-Loeches, Hinojosa, & Mercado, 2001a; Delplanque, Lavoie, Hot, Silvert, & Sequeira, 2004) or Selection Positivity (Daffner et al., 2012). This component appears around 200 ms at fronto-central electrode sites and it has been shown to be modulated by the valence content of stimulus during early attentional processing (e.g., Delplanque et al., 2004; Olofsson & Polich, 2007). Specifically, this component is associated with an emotional negativity bias (i.e., larger ERPs for unpleasant stimuli than for neutral and pleasant stimuli) in younger adults (Carretie´ et al., 2001a) whereas it is associated with positivity bias (i.e., larger ERPs for pleasant than neutral stimuli and unpleasant stimuli) in older adults (Newsome, Dulas, & Duarte, 2012).

The second component is an early-onset negativity that starts around 200 ms after stimulus onset at temporo-occipital electrode sites. This component has been referred to as

Early Posterior Negativity (EPN) (Schupp, Flaisch, Stockburger, & Junghofer, 2006; Schupp, Junghofer, Weike, & Hamm, 2003, 2004), N2 (Carretié, Hinojosa, Martín-Loeches, Mercado, & Tapia, 2004), or Selection Negativity (Daffner et al., 2012) and it has been linked to the early selective attention to emotional stimuli. This component is sensitive to arousing compared to non-arousing material in both younger (Schupp et al., 2007a) and older (Wieser, Mühlberger, Kenntner-Mabiala, & Pauli, 2006) adults.

The third emotional ERP component is a late-onset positivity that is most apparent around 400-600 ms post stimulus onset at central and centro-parietal electrode sites. This ERP effect is taken as a neural index of sustained attention (Cuthbert, Schupp, Bradley, Birbaumer, & Lang, 2000; Schupp et al., 2000; Schupp et al., 2006; Schupp et al., 2004) and has been referred to as Late Positive Potential (LPP) (Ito, Larsen, Smith, & Cacioppo, 1998; Schupp et al., 2004; Weinberg & Hajcak, 2011). This late-onset component has been shown to increase in response to motivationally-salient stimuli, defined either through content or task relevance. Some studies showed that it is larger for emotional compared to neutral content (Cuthbert et al., 2000; Foti, Hajcak, & Dien, 2009; Weinberg & Hajcak, 2010). There is also some evidence that, like early-onset positivity, this late-onset positivity is particularly sensitive to valence, more particularly a bias towards negative emotional content in younger adults (e.g. Huang & Luo, 2006; Ito et al., 1998), and a bias towards positive emotional content in older adults (Kisley, Wood, & Burrows, 2007; Mathieu et al., 2014)[1].

[1] The early-onset positivity has been shown to correlate with activity in the anterior cingulate (Carretie´ et al., 2004); the early-onset negativity with the amygdala and anterior cingulate; the late-onset ERP effect with activity in extrastriate occipital, posterior parietal, and inferotemporal visual cortex, as well as in amygdala, nucleus accumbens, anterior cingulate, and anterior insula (Sabatinelli, Keil, Frank, & Lang, 2013).

Among these ERP components, both early onset positivity and negativity are thought to reflect selective attention to emotional material (Olofsson et al., et al., 2008). They have been associated with the perceptual encoding of emotional material to assure that emotional stimuli have priority for working memory consolidation and conscious recognition at the later stage of processing (Schupp et al., 2006). Late-onset positivity reflects conscious representation of emotional material and has been associated with more elaborated and sustained attentive processing of motivationally-salient emotional stimuli up to the level of semantic meaning is achieved (e.g., Hajcak, Dunning, & Foti, 2009; Schupp et al., 2006)

Empirical results from ERP studies on this issue are mixed. Some studies show that participants showed similar ERPs to emotional and neutral images when they are required to perform a cognitive task in the context of task-irrelevant emotional pictures, suggesting that they did not engage with emotional pictures more than with neutral pictures when pictures were unattended. For instance, in a study by De Cesarei, Codispoti, and Schupp (2009), in one condition a small square box was presented at the center of the screen while either pleasant, unpleasant, or neutral pictures were presented in the periphery. The box was either closed or contained a gap and the task was to indicate the presence or absence of this gap. In the other condition, pleasant, unpleasant, or neutral pictures were presented at the center and the task was to view the pictures passively. ERPs (both early-onset negativity and late-onset positivity) were larger for emotional pictures (regardless of valence) compared to neutral pictures when the pictures were passively viewed, but ERP responses to emotional pictures were eliminated in the gap-detection task.

Other ERP studies, however, found evidence for larger ERPs to emotional relative to neutral material when pictures are supposed to be ignored during a non-emotional task. For example, in a series of experiments (e.g., Sand & Wiens, 2011; Wiens, Sand, Norberg, & Andersson, 2011a) participants were presented with negative and neutral IAPS pictures, presented a fixation, surrounded by six letters. In the picture task, participants indicated whether the pictures were shown in black and white or color; in the letter task, participants were instructed to ignore the pictures and to press a button only if the target letter N or X was among the letters shown. In the picture task, there was an evidence of larger early-onset negativity and late-onset positivity to negative versus neutral IAPS pictures. Interestingly, in the letter task, ERPs were reduced but still significantly larger for emotional than neutral IAPS pictures (Wiens et al., 2011a).

There could be two explanations for the mixed findings. First, different from the first group of studies (e.g., De Cesarei et al., 2009), Wiens et al. (2011a) presented their task-irrelevant emotional pictures at fixation, not in the periphery. It could thus be the case that ignoring task-irrelevant emotional material becomes harder when it is presented at fixation. A counter-argument to this interpretation is that study presented at fixation sometimes do fail to elicit an emotion-related ERP response (Holmes, Kiss, & Eimer, 2006). The study by Holmes et al. illustrates the second possibility, which I will capitalize on here, namely that what is crucial is the difficulty associated with the non-emotional foreground task. In the Wiens et al. (2011a) study, participants performed near ceiling in the letter task (89% correct), regardless of valence of the picture presented at fixation. Thus, it is worth considering that the emotional distractors might have been processed by attention simply because the non-emotional task was not particularly perceptually demanding. In Holmes et al., participants were shown neutral or fearful faces at fixation, flanked by slanted lines; they performed a 1-back task either on the face or on the set of lines (the latter task yielded 78% accuracy). The late-onset positivity that appeared in the face task was abolished in the line task, suggesting that when the cognitive task is demanding enough, emotional stimuli might fail to elicit the usual ERP response, even if the stimulus is presented at fixation. This finding seems to be consistent with perceptual load theory (Lavie, 1995), which argues that when perceptual load is larger, subjects prioritize task-relevant stimuli, resulting in effective rejection of task-irrelevant distractors.

This, then, in turn suggests that perception of the background emotional stimuli depends on task demands associated with the foreground task requires in younger adults. However, it is still an open question whether there are age-related differences in how task relevancy modulates ERP signals of emotional material. To test whether older adults are as successful as younger adults in suppressing background emotional material, it is necessary (as explained above) to equate both groups on the difficulty level of the foreground task, and to set this difficulty clearly below ceiling. Of the tasks reviewed, Erthal et al.'s (2005) orientation matching task seems to lend itself most naturally to a manipulation that equates difficulty across subjects at a fixed level, namely by first and separately determining individual thresholds for line orientation, and using this threshold to construct the mismatch stimuli. As in Erthal et al., I presented arousing positive, negative, and neutral pictures at fixation, with two bars on the right and left side of the picture. Participants performed two tasks. In the picture task, they decided whether the picture was presented in black and white; in the bar task, they indicated whether the orientation of the bars matched or not. Prior to the experiment proper, I individually calibrated the difficulty of the non-emotional bar task such that accuracy was 75% correct (using the procedure outlined in Verhaeghen, Geigerman, & Yang, 2016).

The task design additionally allowed me to test two competing theories of emotion and aging. According to socioemotional selectivity theory (SST) (Carstensen, Isaacowitz, & Charles, 1999) motivational priorities change as a function of time left in life. When individuals perceive the future as expansive, they are more likely to focus on information-seeking goals such as acquiring new information and meeting new people. When individuals perceive the time left as limited, they are more likely to focus on emotional-regulation goals. Given that older adults are more likely to perceive their future as limited, they focus on emotional-regulation goals more than younger adults. To increase their well-being, their information processing is claimed to shift toward positive information instead of negative information. Consistent with this theory, many studies show that relative to younger adults, older adults attend to and remember positive information more than negative information (for a meta-analysis, see Reed, Chan, & Mikels, 2014). Because SST argues that older adults purposefully and motivationally focus on positive information, it predicts that the positivity effect would require cognitive control. In line with this prediction, Mather and Knight (2005) showed that older adults remembered significantly more positive pictures than younger adults under a full attention condition, but they showed poorer memory for positive material compared to younger adults when cognitive control was reduced at encoding by adding a divided attention task. In contrast to SST, the aging and brain model (ABM), which is a competing perspective for explaining the positivity effect in older adults, argues that age-related decline in the amygdala selectively diminishes emotional arousal in response to negative stimuli (but not positive stimuli) and, as a result, older adults fail to process negative stimuli and experience less negative affect (Cacioppo, Berntson, Bechara, Tranel, & Hawkley, 2011). This perspective thus claims that the positivity effect in older adults arises as an unintended consequence of brain aging. In line with this view, a meta-analysis by Murphy and Isaacowitz (2008) reported reduced negativity preference in older adults compared to younger adults whereas there was no age-related differences in positivity preference, suggesting that older adults' positivity effect results from decreased focus on negative material rather than increased focus on positive material[2]. Additionally, ERP studies show that aging is negatively correlated with ERPs as elicited by negative images, whereas the late-onset positivity effect elicited by positive images was relatively stable across age (Kisley et al., 2007). More critically, weaker cognitive abilities predicted reduced ERPs to negative information, suggesting that age-related changes in the brain lead to cognitive decline, which in turn results in reduced processing of negative material (Foster, Davis, & Kisley, 2013). Given these two views make opposing arguments about the source of the positivity effect in older age, examining patterns in emotional modulation as a function of task relevancy via ERPs across younger and older adults in the current study provides an ideal ground for better understanding of age-related differences in emotional processing.

1.1 Hypotheses

[2] It is important to note that reduced negativity in older adults relative to younger adults in the meta-analysis was limited to recognition memory measure within memory tasks; there was no age-related effects in emotion salience across attention and other types of memory tasks, suggesting that the effect is far from absolute.

Summary of hypotheses concerning age-related differences in ERP components in the picture task and the bar task are presented in Table 1.

1.1.1 Picture Task

In the picture task, I expected that emotional modulation would change based on ERP components and age. Previous ERP studies showed that ERPs reflecting early-onset positivity are sensitive to age-related biases in emotion processing and ERPs reflecting late-onset positivity are sensitive to motivationally-salient stimuli (e.g., Carretie´ et al., 2001a; Ito et al., 1998; Kisley et al., 2007; Newsome, et al., 2012). Thus, I expected the positivity bias in older adults and the negativity bias in younger adults would be captured by these early and late-onset positive deflections. ERPs associated with early-onset negativity, on the other hand, might be more informative about arousal rather than valence, given that previous studies have shown that early-onset negativity tends to be larger for arousing rather than non-arousing stimuli (e.g., Schupp et al., 2007a; Wieser et al., 2006). That is, ERPs associated with early-onset negativity might be larger for both positive and negative pictures than neutral pictures regardless of age.

Regarding the source of the positivity bias in older adults, I expected that if the age-related positivity bias results from an increased focus on positive material as suggested by SST (Carstensen et al., 1999), relative to younger adults, older adults would show larger ERPs for positive pictures compared to neutral and negative images. Additionally, given that SST argues that older adults purposefully focus on positive information, I would expect that this ERP pattern would be more evident during the time window associated with the late-onset positivity rather than early-onset positivity as the late-onset positivity is thought to reflect conscious representation and semantic elaboration of motivationally salient emotional material whereas early-onset positivity reflects relatively automatic and perceptual processing of positive material in older adults (Newsome et al., 2012). If, however, the positivity bias is driven by reduced negativity bias in older adults as suggested by ABM (Cacioppo et al., 2011), I expected that relative to younger adults, older adults would show reduced ERPs for negative images compared to positive and neutral images, with no age-related differences in the ERP amplitudes between positive and neutral images. Given that ABM predicts that processing of positive material is less effortful than negative material, I expected that this ERP pattern would be evident regardless of type of cognitive operations involved in ERP components. That is, the ERP pattern reflecting reduced ERPs for negative images in older adults relative to younger adults with no age-related differences in the ERP amplitudes between positive and neutral images would be evident during both early and late-onset positivity component.

1.1.2 Bar Task

In the bar task, I investigated how emotional modulation of ERPs would change based on age when pictures are unattended. Under the hypothesis that age-related inhibitory deficits are an artifact of task difficulty, there would be no age-related effects in ERPs for task-irrelevant material at all, given that the calibration procedure sets the load for the cognitive task to be identical across age groups. This finding would be consistent with perceptual load theory (Lavie, 1995). If, however, older adults show deficits in inhibitory functioning (Hasher & Zacks, 1988), the bar task should yield age-related differences in the emotional ERP components even after performance is equated, because task demand associated with the bar task may prevent older adults to exert suppression of task-irrelevant material. Thus, based the on inhibitory deficit hypothesis, I expected that older adults would show larger ERPs for task-irrelevant emotional material relative to neutral material during the bar task while ERPs for emotional and neutral pictures would be similar for younger adults. Additionally, if older adults show a deficit in inhibition of task-irrelevant emotional material in the bar task, the specific ERP pattern associated with this deficit would provide some insight about the source of the positivity bias in aging. Specifically, if older adults show an ERP pattern reflecting either a negativity bias (larger ERPs to task-irrelevant negative relative to positive and neutral images) or overall emotional processing (larger ERPs to task-irrelevant emotional relative to neutral images) with no positivity bias in the bar task especially during the time window associated with late-onset positivity, this would be consistent with SST, because SST predicts that the positivity bias requires involvement of cognitive control (Mather & Knight, 2005). If older adults, however, show an ERP pattern reflecting positivity bias (larger ERPs to task-irrelevant positive relative to negative and neutral images) in the bar task, this would be inconsistent with the SST.

Table 1 – Summary of hypotheses concerning age-related differences in ERP components in the picture task and the bar task.

	ERP component		
	Early-onset positivity	**Early-onset negativity**	**Late-onset positivity**
		Picture task	
Socio-emotional selectivity theory	OA: Possibly larger ERPs for positive pictures than negative and neutral pictures	OA: Possibly larger ERPs for positive and negative pictures than neutral pictures	OA: Definitely larger ERPs for positive pictures than negative and neutral pictures
	YA: Possibly larger ERPs for negative pictures than positive and neutral pictures	YA: Possibly larger ERPs for positive and negative pictures than neutral pictures	YA: Possibly larger ERP for negative pictures than positive and neutral pictures
Aging and brain model	No age differences in ERPs for positive and neutral pictures; OA reduced ERPs for negative pictures compared to YA	Possibly larger ERPs for positive and negative pictures than neutral pictures in both YA and OA	No age differences in ERPs for positive and neutral pictures; OA reduced ERPs for negative pictures compared to YA
		Bar task	
Inhibition view	Larger ERPs for task-irrelevant emotional pictures than neutral pictures for OA but not YA	Larger ERPs for task-irrelevant emotional pictures than neutral pictures for OA but not YA	Larger ERPs for task-irrelevant emotional pictures than neutral pictures for OA but not YA
Perceptual load theory	Similar ERPs for task-irrelevant material (positive = negative = neutral) in both YA and OA	Similar ERPs for task-irrelevant material (positive = negative = neutral) in both YA and OA	Similar ERPs for task-irrelevant material (positive = negative = neutral) in both YA and OA

Note. OA refers to older adults; YA refers to younger adults.

CHAPTER 2

METHOD

2.1 Participants

Thirty-four younger and 35 older adults participated in the experiment. Older participants were recruited from the community; they received cash payment ($10/hour) as compensation for participation. Younger adults were students at the Georgia Institute of Technology and participated in the study in return for course credit. Data from 2 younger and 3 older participants were excluded from further analysis due to slowing in responding (response times 2 standard deviations above the group mean) and/or more than 50% trials with ERP artifacts (e.g. alpha, eye movements, blinks, muscle tension). The mean age of the (remaining 32) younger adults (16 females) was 19.97 (SD = 1.58); mean age of the (remaining 32) older adults (18 females) was 70.59 (SD = 4.1). All participants were right-handed, with normal or corrected to normal vision, with no reports of psychiatric or neurological disorders, vascular disease, or color blindness. None of the participants were taking CNS-active medications. Older adults had completed more years of education (M = 16.97, SD = 2.96) than younger adults (M = 13.83, SD = 1.6) [$t(62) = 5.29$, $p < 0.001$]. Younger adults (M = 60.69, SD = 11.5) performed significantly better than older adults (M = 46.66, SD = 7.16) on a symbol-digit test (Smith, 1973) [$t(62) = 5.86$, $p < 0.001$]. Older adults' performance (M = 36.28, SD = 2.8) on the Shipley Vocabulary test (Shipley, 1946) was significantly higher than performance of younger adults (M = 31.06, SD = 3.17) [$t(62) = 6.98$, $p < 0.001$].

2.2 Stimuli

Given that older adults, relative to younger adults, tend to rate emotional pictures as more extreme for both valence and arousal (Grühn & Scheibe, 2008), it is important to select stimuli for which subjective ratings are matched between age groups. To this end, I conducted a picture rating study prior to the experiment in which I asked independent groups of younger and older adults to rate valence and arousal level of emotional stimuli. For the picture rating experiment, a total of 720 images, divided evenly between valence categories as determined by the experimenters, were selected from the International Affective Picture Set (IAPS) (Lang, Bradley, & Cuthbert, 1995), the Nencki Affective Picture System (NAPS) (Marchewka, Żurawski, Jednoróg, & Grabowska, 2014), the Open Affective Standardized Image Set (OASIS) (Kurdi, Lozano, & Banaji, 2016), The Geneva affective picture database (GAPED) (Dan-Glauser & Scherer, 2011), and Google (using search terms such as puppy, baby, wounded people, mutilation etc.). Because previous research showed that there are age-related differences in perception pictures with radical/exciting sports and erotic content (Backs, da Silva, & Han, 2005), pictures from these semantic categories were excluded. Additionally, an effort was made to select images with similar visual complexity (indexed by jpeg size; Donderi, 2006; Marchewka et al., 2014) since a previous study by Wiens, Sand, and Olofsson (2011b) showed that picture composition (i.e., figure vs scene) confounds ERP amplitudes.

The picture rating study was an online survey and participants were recruited through Amazon's Mechanical Turk (MTurk). During the picture rating experiment, younger and older adults were asked to rate the presented picture in terms of valence (on a 1-9 point scale, where 1 was extremely pleasant and 9 was extremely unpleasant) and arousal (on a 1-9 point scale, where 1 was extremely aroused and 9 was extremely calm).

Details about procedure of the picture rating experiment can be found in Appendix. As a result of the rating experiment, I ended up selecting a total of 462 pictures that had been rated as positive and arousing (N = 140; valence less than 4.25 and arousal less than 6.4), negative and arousing (N = 140; valence greater than 5.75, arousal less than 6), and neutral and non-arousing (N = 182; valence between 4.5 and 5.5, arousal greater than 6) for the current study. Of the 182 neutral pictures, 42 were used in the calibration experiment that participants performed prior to the experiment proper. Complexity of pictures selected for the experiment (indexed by JPEG size) did not differ between valence categories. The mean valence and arousal ratings for each picture category and age group for the stimuli included in the study are presented in Table 2 and Table 3.

Table 2 – Mean valence, minimum, and maximum ratings for the stimuli.

Image Type	Younger	Min - Max	Older	Min - Max
Negative	7.15 (0.64)	5.76 - 8.61	6.88 (0.50)	5.83 - 7.92
Positive	2.65 (0.55)	1.38 - 4.14	3.43 (0.47)	2.10 - 4.24
Neutral (Actual Exp.)	5.03 (0.21)	4.57 - 5.48	5.03 (0.20)	4.50 - 5.50
Neutral (Calibration Exp.)	5.03 (0.27)	4.52 - 5.43	5.03 (0.23)	4.52 - 5.43

Note. Standard deviations in parentheses. Min refers to minimum and max refers to maximum.

Table 3 – Mean arousal, minimum, and maximum ratings for the stimuli.

Image Type	Younger	Min - Max	Older	Min - Max
Negative	4.50 (0.69)	3.33 - 5.96	4.50 (0.61)	2.95 - 5.86
Positive	5.55 (0.82)	3.74 - 6.60	5.53 (0.59)	4.00 - 6.38
Neutral (Actual Exp.)	6.97 (0.54)	6.00 - 8.44	6.97 (0.38)	6.04 - 7.77
Neutral (Calibration Exp.)	6.97 (0.60)	4.42 - 5.43	6.98 (0.41)	4.52 - 5.43

Note. Standard deviations in parentheses. Min refers to minimum and max refers to maximum.

2.3 Procedure

Before starting the session, each participant signed a consent form, filled out the

Shipley Vocabulary test and symbol-digit test measuring verbal ability and processing speed, respectively. Next, they completed the calibration experiment which was followed by the actual experiment. EEG data were only recorded during the actual experiment. In both experiments, the subjects sat approximately 57 cm from the display. Both experiments were run on a 17-inch CRT monitor (1024 x 768 pixel resolution; 75 Hz refresh rate) using MATLAB (The MathWorks, Natick, MA) and the Psychophysics Toolbox (Brainard, 1997; Pelli, 1997).

2.3.1 Calibration Experiment

Trial structure for the calibration experiment is presented in Figure 1. Each trial started with the presentation of a fixation cross for 1,500 ms. Next, a central neutral picture (6.5º x 5.5º) and two bars (0.3 º x 2.75 º) positioned peripherally (2º to the right and left of the central picture) were shown briefly to reduce risks for saccades. Presentation duration of the stimuli was 200 ms for the younger participants and 250 ms for the older participants. Presentation duration for older adults was increased to allow for extra processing time due to age-related slowing. Only neutral pictures were used for the calibration experiment to avoid confounding image valence with task difficulty (see Padmala & Pessoa, 2014, for a similar calibration procedure). Following the stimulus presentation, the subjects were asked to withholder their response for 800 ms, during which a blank screen was presented. The blank screen was used to mimic the actual experiment in which the 800 ms delay and blank screen served to avoid contamination of the ERPs with movement artifacts associated with the key press (i.e., motor preparation). Immediately after the blank screen, the subjects were shown a question mark on the center of the screen and asked to indicate whether or not the orientations of the peripheral bars matched.

The goal of the calibration experiment was to find a perceptually demanding level of task difficulty for the bar task, in which each subject performs at 75% accuracy level[3]. To this end, I used the QUEST algorithm (Watson & Pelli, 1983), an adaptive staircase procedure to estimate thresholds. This algorithm selects stimulus values on the basis of the subject's performance in previous trials to determine the 75% discrimination threshold for the angular difference of the bars for each subject. The number of trials needed to estimate the 75% threshold was determined by the algorithm and the experiment stopped when the performance criterion was achieved for each participant[4]. A feedback about accuracy was given at the end. Discrimination thresholds obtained from the calibration experiment ranged from 3.29 to 22.58 (*M* = 10.34, *SD* = 4.11) for younger adults, from 3.55 to 31.56 (*M* = 15.3, *SD* = 6.79) for older adults. The calibration experiment took about 10 mins to complete.

[3] Previous studies (e.g., Gilbert, 1967) showed that when threshold is determined by presenting participants with a set of stimuli, some of which are above the threshold and some of which are below the threshold through the method of constant stimuli, the point of subjective equality deviates in the direction of the middle of the range of variables. To avoid this type of range effects, Poulton (1973) recommended to set the magnitude of threshold where the optimum lies. Based on this recommendation, I set task difficulty to 75% in the present study. Calibrating for lower performance criteria (i.e, 60%) in the bar task would have been difficult especially for older adults, given the range effects and age-related differences in subjective difficulty.

[4] In the calibration experiment, minimum number of trials for achieving the performance criteria was defined as 40; maximum number of trials for achieving the performance criteria was defined as 100. The average number of trials that subjects needed to reach the performance criterion was 74.13 trials for younger adults and 75.56 trials for older adults.

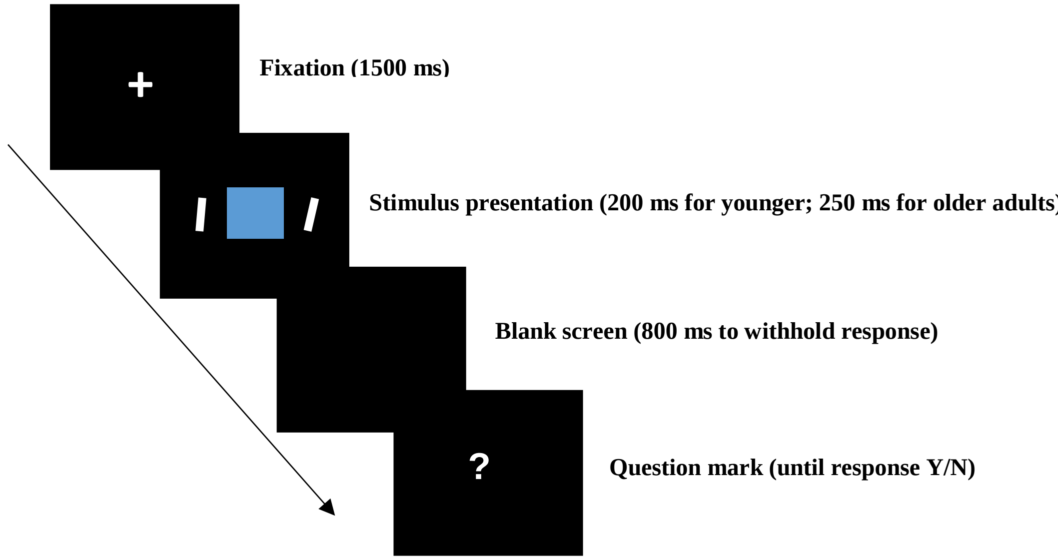

Figure 1 – Trial structure for the calibration experiment: Each trial started with presentation of a fixation cross was shown for 1,500 ms. After that, a neutral picture (represented by a blue square) flanked by two bars was shown briefly (200 ms for younger; 250 ms for older adults). This was followed by presentation of a blank screen for 800 ms during which the subjects were asked to withholder their responses. Immediately after, the subjects were shown a question mark and decided as quickly and accurately as possible as whether or not the orientations of the bars matched.

2.3.2 Actual Experiment

Following the calibration experiment, EEG capping was done for the actual experiment. The trial structure in the actual experiment (Figure 2) was the same as the calibration experiment except that each trial started with the presentation of a small circle for 1,500 ms to signal for the subjects to blink (if necessary) and, thus, to avoid artifacts from eye blinks during the stimulus presentation. During stimulus presentation, the individual threshold obtained from the calibration experiment was used to set differences in angle of bar rotation on an individual basis in the actual experiment. There were 2 tasks in the actual experiment: In the bar task, subjects were instructed to ignore the task-irrelevant central images and to indicate whether or not the orientations of the peripheral bars match; they did this will maintaining fixation on the center of the screen, where the picture appeared. In the picture task, subjects were instructed to ignore the bars and to indicate whether or not the picture is presented in black and white[5]; likewise, they maintained fixation at the center of the screen, where the picture appeared.

Subjects performed the bar and picture tasks on separate blocks; task order was counterbalanced across participants. The picture and bar task in the current study were adopted from previous studies employing similar tasks (see Sand & Wiens, 2011; Wiens et al., 2011a, for the picture task; see Erthal et al., 2005; Padmala & Pessoa, 2014; Pessoa, Kastner, & Ungerleider, 2002; Verhaeghen et al., 2016, for the bar task). For both tasks, participants were instructed to keep their gaze on the center of the screen (i.e., at the position of the fixation cross). Each task consisted of 210 trials (a total of 420 trials) with 70 trials for negative, 70 for positive, and 70 for neutral pictures. In each task, there were 5 blocks of 42 trials and each block contained an equal number of neutral, positive, and negative images. The order of neutral and emotional images within a block was randomized. In each block, half of the pictures were black and white, the other half were colored pictures; the order of black and white and colored pictures was randomized. Picture color was counterbalanced across participants, that is, the pictures that were presented in black and white for one half of the participants were presented in color for the other half, and vice versa. The number of match/mismatch responses regarding the orientation of the bars was equal within the picture category in each block. That is to say, the angular

[5] One potential concern could be that using grayscale emotional pictures may diminish affective modulation associated with picture perception especially considering the fact that the stimuli will be presented very briefly in the study. Codispoti, De Cesarei, and Ferrari (2011) tested this possibility and they found that affective modulation does not depend on picture color; the ERPs were larger for emotional compared to neutral regardless of whether the pictures were colored or in grayscale, and were presented for long exposure duration (6 s) or very briefly (24 ms).

difference between the two bars was 0° (same) in half of the trials within each picture category in each block whereas in the other half, the angular difference between the two bars was created by rotating one of the bars either clockwise or counter clockwise one threshold value away from the original stimulus. The subjects were given feedback about accuracy at the end of each block (after 42 trials). The session, which consisted of the calibration and the actual experiment, lasted approximately 100 mins.

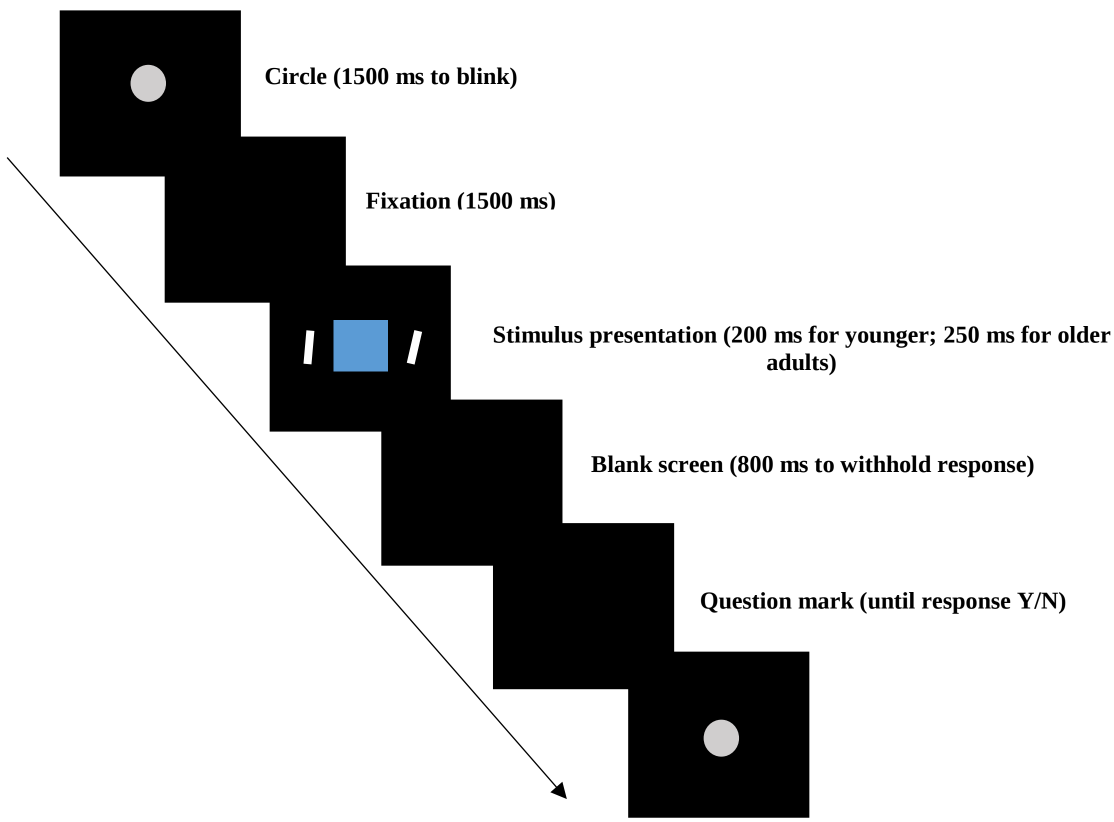

Figure 2 – Trial structure for the actual experiment: Each trial started with presentation of a circle for 1,500 ms to signal to the subjects to blink. Then, a fixation cross was shown for 1,500 ms. After that, a neutral, negative, or positive picture (represented by a blue square) flanked by two bars was shown briefly (200 ms for younger; 250 ms for older adults). This was followed by presentation of a blank screen for 800 ms during which the subjects were asked to withholder their responses. Immediately after, the subjects were shown a question mark and decided as quickly and accurately as possible as whether or not the orientations of the bars matched (bar task) or whether the picture was presented in black and white (picture task).

2.4 EEG Acquisition

Scalp-recorded EEG data was collected from 32 Ag-Ag/Cl electrodes using an ActiveTwo amplifier system (Biosemi, Amsterdam, Netherlands). Electrodes were positioned according to the extended 10–20 system (Nuwer et al., 1998). Electrodes were located at left/right hemisphere locations (FP1/FP2, AF3/AF4, F3/F4, F7/F8, FC1/FC2, FC5/FC6, C3/C4, T7/T8, CP1/CP2, CP5/CP6, P3/P4, P7/P8, PO3/PO4, O1/O2) as well as midline sites (Fz, Cz, Pz, Oz). Two additional electrodes placed on the left and right mastoid processes were used as off-line references. Four additional electrodes were placed above and below the left eye to record a vertical electrooculogram (VEOG) and on the outer canthi of the left and right eyes to record a horizontal electrooculogram (HEOG). EEG was recorded with 24 bit resolution and a sampling rate of 512 Hz. All data processing, including filtering and extracting epochs, was performed in MATLAB using ERPLAB (Lopez-Calderon & Luck, 2014) toolbox, except for artifact correction and rejection procedures which were performed in EEGLAB toolbox (Delorme & Makeig, 2004). For data processing, electrodes placed on the mastoids were used as off-line references and data were digitally band-pass filtered using a 2nd order infinite impulse response (IIR) Butterworth filter (half-amplitude cutoffs at 0.01 and 100 Hz, 12 dB/octave roll-off). Then, EEG segments were created from 200 ms pre-stimulus onset, time-locked to stimulus onset lasting until 1000 ms post stimulus onset. Artifacts were removed in 3 steps. First, manual artifact rejection procedure was applied to remove epochs containing non-ocular artifacts (e.g. large drift, electrode spikes, saturation). Second, independent component analysis was used to remove ocular artifacts components from the remaining epochs (Delorme & Makeig, 2004). Lastly, epochs containing uncorrected artifacts (±150 mV) were removed. Epochs were averaged separately for each participant, valence, electrode, and task. The averaged waveforms were digitally smoothed with a low-pass filter of 30 Hz. Only correct trials (i.e., hits and correct rejections) were included in the ERP analysis.

2.5 ERP Analysis

Visual inspection of ERP waveforms showed that older adults showed an early-onset positivity which was followed by a negative deflection and late-onset positivity. ERP waveforms from the younger group showed a widespread negative deflection (especially at frontal electrode sites), which was followed by late-onset positivity (only at central and centro-parietal electrode sites). There was no evidence for ERP pattern reflecting early-onset positivity in the young group. For this reason, the early-onset positivity was only examined in the older group. The early-onset negativity was examined in both age groups. In addition to the early-onset negativity, a non-hypothesized sustained negative deflection was observed, but only in the younger group, at frontal electrode sites. I labeled this component the late-onset negativity; I analyzed it in the younger group only. Following the negative deflection, a late-onset positivity appeared and was examined in both age groups.

I based my selection of electrodes and time windows for ERP analyses exclusively on the picture task, where the task likely led to modulation of ERPs by the emotional content (e.g., Sand & Wiens, 2011; Wiens et al., 2011a), as opposed to the bar task, where the contents of the pictures were supposed to be ignored by the participants. Once electrode sites were determined, the same set of electrode sites were used to examine modulation of ERPs by emotion in the bar task. This selection process started with examining the topographical difference maps. For each age group, the three topographical maps (one reflecting average emotional minus neutral, one for negative minus neutral, and one for positive minus neutral difference scores) associated with each component are presented in Figures 3 (early-onset positivity), 4 (early-onset negativity), 5 (late-onset negativity), and 6 (late-onset positivity). Based on the topographical difference maps, the early-onset positivity and negativity were examined at frontal and central electrode sites (F3, F4, FC1, FC2, C3, C4, CP1, CP2), the late-onset negativity was examined at frontal electrode sites (F3, F4, FC1, FC2), and the late-onset positivity was examined at central and centro-parietal electrode sites (C3, C4, CP1, CP2)[6].

To determine time windows associated with emotion related ERP components, mean ERP amplitudes from the picture task were divided into 50 ms temporal epochs and these data were subjected to Valence x Hemisphere x Location x Time ANOVAs separately for both age groups. The ANOVAs revealed a significant Valence x Time interaction for both younger [F(28,868 = 6.24, $p < 0.001$, $\eta^2_p = 0.17$] and older [F(28,868) = 5.17, $p < 0.001$, $\eta^2_p = 0.14$] adults. Follow-up analyses were conducted to determine temporal epochs during which a reliable Valence effect appeared. Time windows were created by collapsing

---

[6] It is important to note that the electrodes used to examine the early-onset positivity (F3/F4, FC1/FC2, C3/C4, CP1/CP2) and the late-onset positivity (C3/C4, CP1/CP2) in the present study are consistent with previous studies that have reported early-onset positivity (e.g., Carretie´ et al., 2001a; Newsome et al., 2012) at frontal and central electrode sites and late-onset positivity (e.g., Norberg, Peira, & Wiens, 2010; Sand & Wiens, 2011) at centro-parietal electrode sites. However, the electrode sites where the negative ERP component, especially the early-onset negativity, was observed in the present study are not typical -- previous studies showing similar negative deflection in response to emotional material have reported this component at occipito-temporal electrode sites. One potential explanation about why this component was not at posterior electrode sites could be about selection of reference electrode. That is, in the current study, the data was referenced to the mastoids whereas previous studies examining this negative deflection have specifically referenced their data to the grand average of all electrodes (e.g., Sand & Wiens, 2011; Schupp et al., 2007a). To examine this possibility, I referenced the data from 10 younger adults to the grand average. This, however, did not change negativity-related patterns in the ERP data.

across the temporal epochs reflecting consistent Valence effects for components of interest in each age group (data were corrected for multiple comparisons using Bonferroni correction). Once time windows for each component were defined for the picture task, corresponding time windows reflecting similar patterns (i.e., positive deflection, negative deflection) at similar time intervals were determined based on visual inspection of ERP waveforms from both age groups in the bar task. Based on these preliminary examinations of the ERP data, the early-onset positivity effect (observed only in the older adult group) was defined as the mean amplitude from 200 to 250 ms post probe onset in the picture task and 175 to 225 ms post probe onset in the bar task. The early-onset negativity effect was defined as the mean amplitude from 250 to 300 ms post probe onset in both tasks for both age groups. The late-onset negativity effect (observed only in the younger adult group) was defined as the mean amplitude from 350 to 450 ms post probe onset in both tasks. Lastly, the late-onset positivity was defined as the mean amplitude from 450 to 650 ms time window in both tasks for the older group. For the younger group, this component was defined as the mean amplitude from 550 to 750 ms time window in the picture task and from 500 to 700 ms time window in the bar task.

For all ERP analyses, mean amplitudes were measured separately for each participant, valence, and task at the electrode sites of interest during the time windows associated with each ERP effect. The resulting mean amplitudes were subjected to mixed ANOVAs including factors of Task, Valence, Location, Hemisphere and/or Group (when the effect is found in both age groups). Bonferroni correction for multiple comparisons was applied where appropriate.

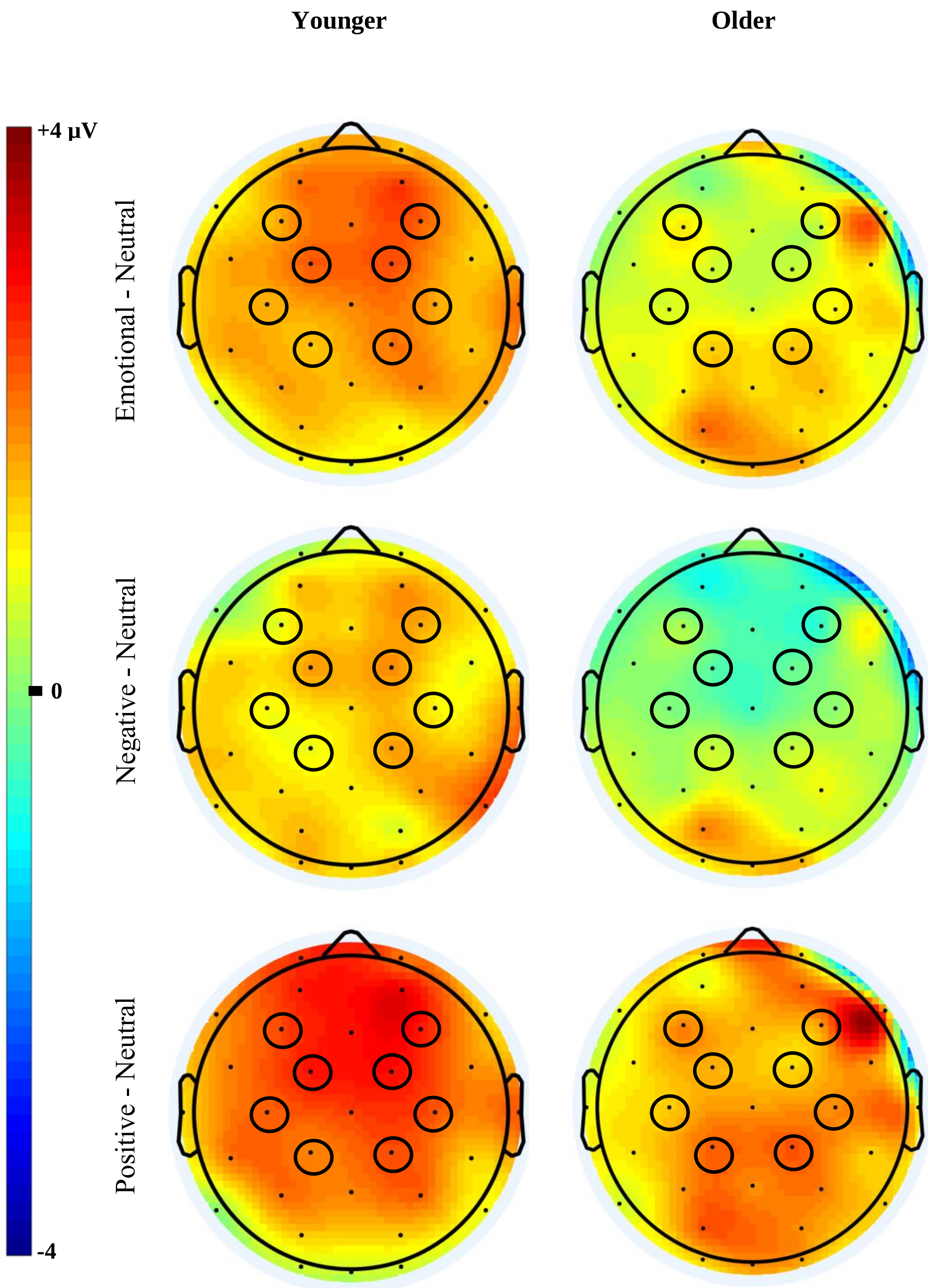

Figure 3 – Topographical maps reflecting average emotional minus neutral (top row), negative minus neutral (middle row), and positive minus neutral (bottom row) difference scores for the younger (left) and older adults (right) associated with early-onset positivity during 200-250 ms time window. Small circles represent electrode locations (F3/F4, FC1/FC2, C3/C4, CP1/CP2).

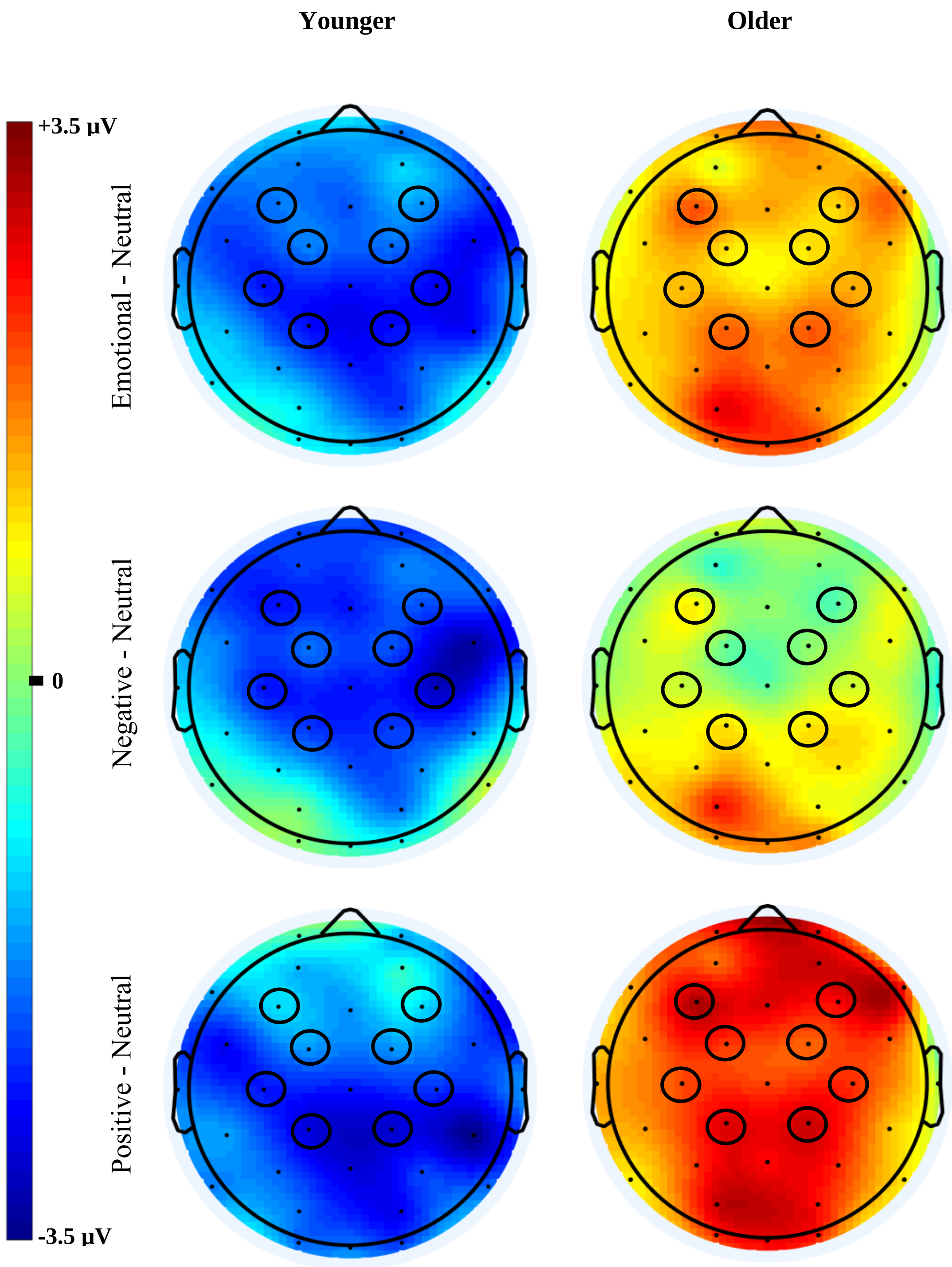

Figure 4 – Topographical maps reflecting average emotional minus neutral (top row), negative minus neutral (middle row), and positive minus neutral (bottom row) difference scores for the younger (left) and older adults (right) associated with early-onset negativity during 250-300 ms time window. Small circles represent electrode locations (F3/F4, FC1/FC2, C3/C4, CP1/CP2).

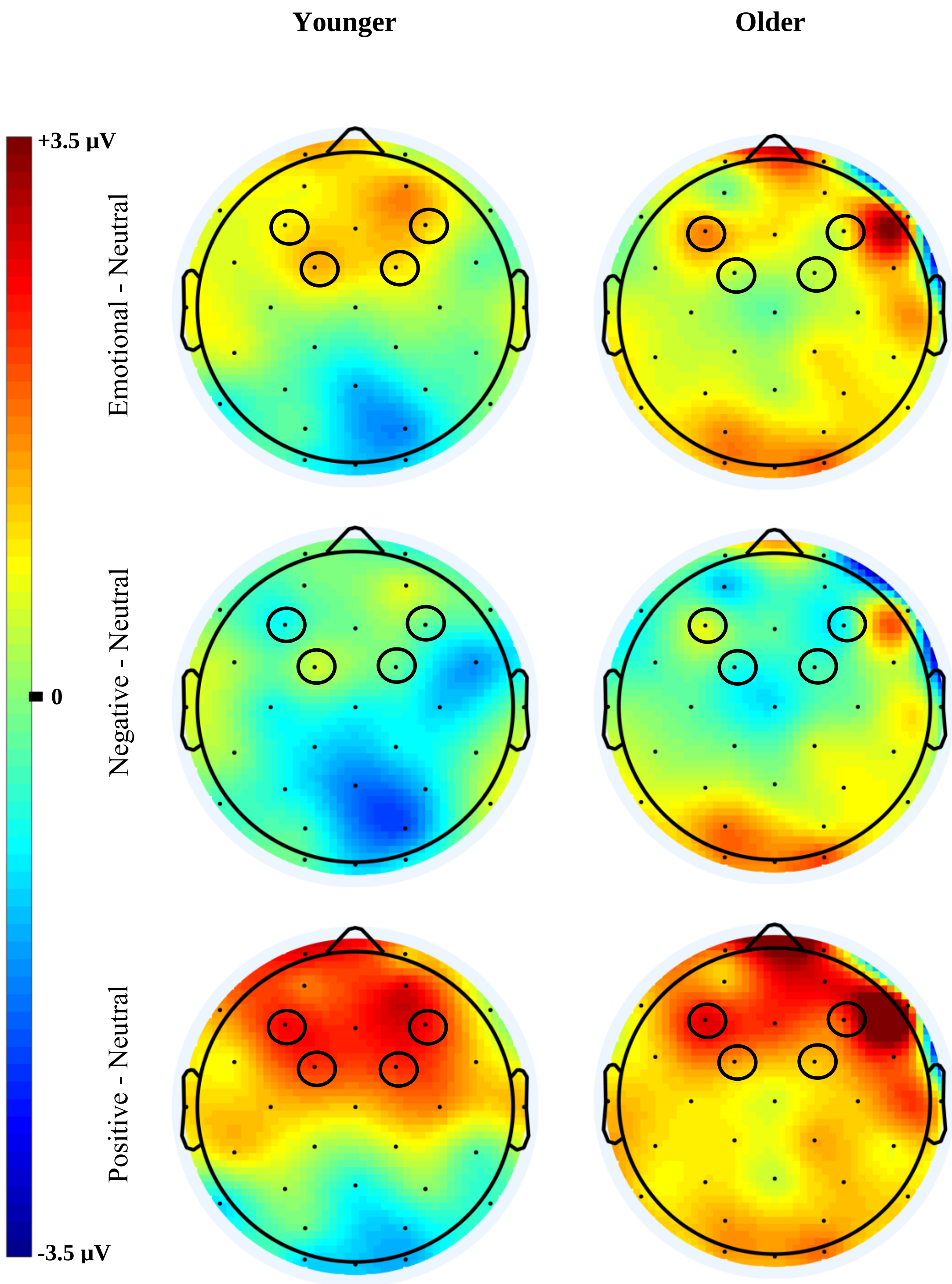

Figure 5 – Topographical maps reflecting average emotional minus neutral (top row), negative minus neutral (middle row), and positive minus neutral (bottom row) difference scores for the younger (left) and older adults (right) associated with late-onset negativity during 350-450 ms time windows. Small circles represent electrode locations (F3/F4, FC1/FC2).

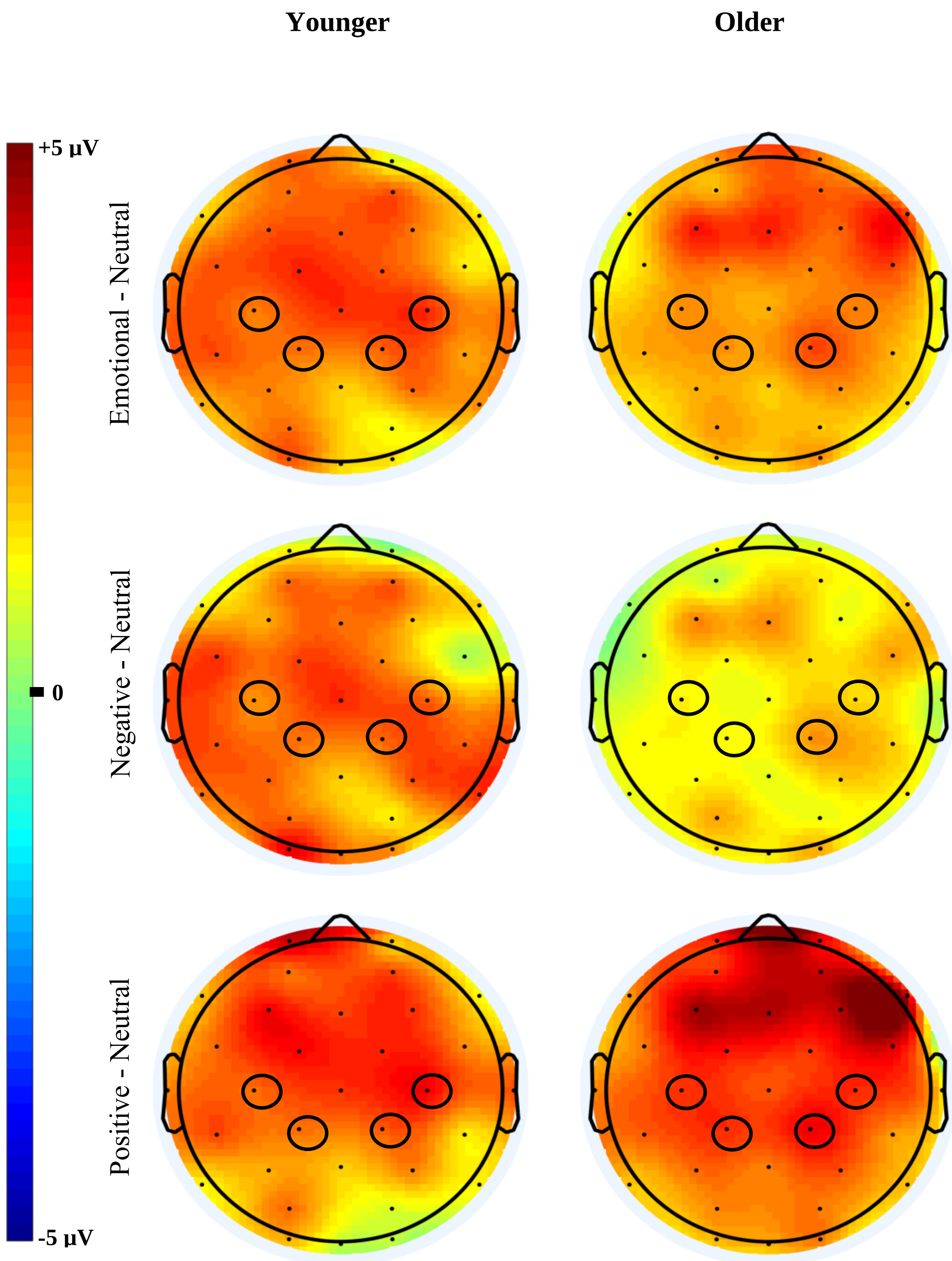

Figure 6 – Topographical maps reflecting average emotional minus neutral (top row), negative minus neutral (middle row), and positive minus neutral (bottom row) difference scores for the younger (left) and older adults (right) associated with late-onset positivity during 550-750 ms (younger) and 450-650 ms (older) time windows. Small circles represent electrode locations (C3/C4, CP1/CP2).

CHAPTER 3

RESULTS

3.1 Calibration Experiment Results

Bar task performance of younger adults (M = .75, SD = 0.04) in the calibration experiment was similar to that of the older adults (M = .76, SD = 0.06) [$t(62) = 0.33$, $p = 0.75$], also indicating that the desired level of accuracy (75%) was indeed achieved. Younger adults (M = 10.34, SD = 4.11) had lower thresholds for angular disparity than older adults (M = 15.3, SD = 6.79), [$t(62) = 3.53$, $p = 0.001$].

3.2 Actual Experiment: Behavioral Results

I conducted a Group (Younger, Older) x Task (Bar, Picture) x Valence (Positive, Negative, Neutral) ANOVA on correct responses and corresponding reaction times. Proportions of correct and corresponding response times for negative, positive, and neutral valences in each task are presented in Table 4. With regard to accuracy, the ANOVA revealed a main effect of Task [$F(1,62) = 294.11$, $p < 0.001$, $\eta^2_p = 0.83$] and a significant Task x Valence interaction [$F(2,124) = 5.10$, $p = 0.007$, $\eta^2_p = 0.08$]. The Task x Valence interaction reflects that accuracy for both negative and positive images was larger than accuracy for neutral images in the picture task [all ts > 1.91, ps < 0.001], while there was no effect of valence on accuracy in the bar task [all ts < 0.64, ps > 0.5] [7]. Additionally,

[7] I also calculated corrected recognition rates (proportion of hit rates minus false alarm rates) in the bar task for each participant. A Group (Young, Older) x Valence (Positive, Negative, Neutral) ANOVA on corrected recognition rates in the bar task revealed no significant main effects or interactions [all Fs < .58, ps > 0.26]. Calculating corrected recognition rates for the picture task was not possible as there is no way to assess false alarm rates.

accuracy was higher in the picture task than in the bar task regardless of image valence [all *t*s > 13.76, *p*s < 0.001]. Note that the picture task clearly shows a ceiling effect, potentially masking true emotion effects. Neither a main effect of valence nor interaction effects involving age group was significant (all *F*s < 2.6, *p*s > 0.1). With regard to response times, the ANOVA revealed a main effect group [$F(1,62) = 6.71$, $p = 0.01$, $\eta^2_p = 0.9$], indicating that older adults responded slower than younger adults. Neither main effects of Task and Valence nor other interaction effects involving Age Group, Task and/or Valence factors was significant [all *F*s < 0.7, *p*s > 0.1][8].

Table 4 – Proportion correct and corresponding reactions times in the picture and bar task for younger and older adults.

		Younger		Older	
Picture Task					
	Negative	.98 (.01)	455 (116)	.97 (.04)	540 (207)
	Neutral	.97 (.02)	452 (118)	.95 (.06)	525 (179)
	Positive	.99 (.02)	434 (110)	.98 (.02)	514 (157)
Bar Task					
	Negative	.72 (.09)	448 (162)	.75 (.13)	516 (142)
	Neutral	.72 (.10)	428 (189)	.76 (.12)	514 (164)
	Positive	.73 (.10)	428 (136)	.75 (.12)	553 (155)

Note. Standard deviations in parentheses.

3.3 Actual Experiment: ERP Results

Figures 7 and 8 display the average ERP waveforms elicited by negative, neutral, and positive images obtained from correct trials in the picture and bar tasks for the younger

[8] I also tested for interference from emotional material in the bar task by analyzing the data only from incorrect responses from the bar task. A set of Group (Young, Older) x Valence (Positive, Negative, Neutral) ANOVAs on overall proportion of incorrect and false alarm rates in the bar task showed no effect of Valence, nor any Valence x Group interactions (all *F*s < 0.37, *p*s > 0.7). Similarly, another set of analyses on response times for overall proportion of incorrect responses and false alarms did not yield any significant main effects of Valence, nor any Valence x Group interactions (all *F*s < 1.25, *p*s > 0.29).

adults. Figures 9 and 10 display the corresponding results for the older adults. Additionally, summary of ERP data containing the time windows, relevant electrodes, and the nature of the effect associated with each component in the picture and bar tasks for younger and older adults are presented in Tables 5 and 6.

3.3.1 Early-onset Positivity

A Task x Valence x Location x Hemisphere ANOVA in the older group revealed a main effect of Valence [$F(2,62) = 14.69$, $p < 0.001$, $\eta^2_p = 0.32$]. As can be seen in Figures 9 and 10, ERPs were larger for positive images ($M = 3.75$ μV, $SD = 6.47$) than negative ($M = 1.79$ μV, $SD = 7.14$) and neutral images ($M = 1.47$ μV, $SD = 6.94$) in both tasks [all ts > 4.02, ps < 0.001]. The difference between negative and neutral images was not significant [$t(31) = 0.62$, $p = 0.54$]. Additionally, Task x Hemisphere [$F(1,31) = 17.03$, $p < 0.001$, $\eta^2_p = 0.35$] and Task x Location [$F(1,31) = 37.76$, $p < 0.001$, $\eta^2_p = 0.55$] interactions were significant. Follow-up analyses regarding Task x Location interaction showed that within the picture task ERPs were larger at central (C3/C4) ($M = 3.04$ μV, $SD = 6.75$) and centro-parietal (CP1/CP2) ($M = 3.77$ μV, $SD = 7.14$) electrode sites than frontal (F3/F4) ($M = 3.38$ μV, $SD = 6.29$) and fronto-central (FC1/FC2) ($M = 2.88$ μV, $SD = 7.06$) electrode sites [all ts > 2.56, ps < 0.02] whereas in the bar task, ERPs were larger at frontal ($M = 3.38$ μV, $SD = 6.29$) and fronto-central ($M = 2.88$ μV, $SD = 7.06$) electrode sites than central ($M = 1.83$ μV, $SD = 6.86$) and centro-parietal ($M = 0.71$ μV, $SD = 7.74$) electrode sites [all ts > 3.03 ps < 0.02]. Follow-up analyses regarding Task x Hemisphere interaction showed that ERPs were larger at right ($M = 3.12$ μV, $SD = 7.1$) than left hemisphere ($M = 1.99$ μV, $SD = 6.83$) [$t(31) = 3.49$, $p = 0.001$] within the picture task while there was no effect of hemisphere on ERPs in the bar task [$t(31) = 1.21$, $p = 0.24$].

None of the remining interactions involving Task and/or Valence factors were significant [all Fs < 2.34, ps > 0.1].

3.3.2 Early-onset Negativity

A Task x Valence x Group x Location x Hemisphere ANOVA revealed a main effect of Valence [$F(2,124) = 3.79$, $p = 0.03$, $\eta^2_p = 0.06$] that was modified by interactions with Location [$F(6,372) = 3.31$, $p = 0.003$, $\eta^2_p = 0.05$], Group [$F(2,124) = 18.32$, $p < 0.001$, $\eta^2_p = 0.23$], and Task [$F(2,124) = 6.1$, $p = 0.003$, $\eta^2_p = 0.09$]. There was also a main effect of Task [$F(1,62) = 10.47$, $p = 0.002$, $\eta^2_p = 0.14$] that was modified by interactions with Location [$F(3,186) = 23.09$, $p < 0.001$, $\eta^2_p = 0.27$], Group [$F(1,62) = 16.41$, $p < 0.001$, $\eta^2_p = 0.21$], and a 3-way interaction with Location and Group factors [$F(3,186) = 3.17$, $p = 0.03$, $\eta^2_p = 0.05$]. Critically, the ANOVA revealed a significant 4 way Task x Valence x Location x Group interaction [$F(6,372) = 2.37$, $p = 0.03$, $\eta^2_p = 0.04$].

As can be seen in Figures 7 and 8, follow-up analyses for the younger adults showed that in the picture task, ERPs were larger for both positive and negative images than neutral images (with no significant difference between positive and negative images) at both central (C3/C4) and centro-parietal (CP1/CP2) electrode sites [all ts > 3.13, ps < .009], but the difference between emotional and neutral images was not reliable at fronto-central (FC1/FC2) and frontal (F3/F4) electrode sites [all ts < 1.73, ps > .09]. In the bar task, ERPs for positive images were larger than both negative and neutral images and ERPs for negative images were larger than ERPs for neutral images at centro-parietal, central, and fronto-central electrode sites [all ts > 2.94, ps < 0.02], this pattern, however, did not appear at frontal sites [all ts < 2.4, ps > 0.05]

As can be seen in Figures 9 and 10, follow-up analyses for the old group showed that in the picture task, regardless of location, ERPs were larger for both negative and neutral images than positive images (with no significant difference between negative and neutral images) [all *t*s > 2.39, *ps* < 0.02]. Additionally, the magnitude of ERPs associated with this effect was larger at frontal and central (F3/F4, FC1/FC2, C3/C4) than at centro-parietal (CP1/CP2) electrode sites in the picture task [all *t*s > 4.05, *ps* < 0.001], indicating larger involvement of frontal and central electrode sites in the negativity effect than centro-parietal electrode sites. In the bar task, however, no significant effect involving valence was observed [all *t*s < 1.99, *ps* > 0.06]. None of the other interactions involving Task and/or Valence factors were significant [all *F*s < 1.92, *p*s > 0.07] for this component.

3.3.3 Late-onset Negativity

A Task x Valence x Location x Hemisphere ANOVA revealed a main effect of Task [$F(1,31) = 17.43$, $p < 0.001$, $\eta^2_p = 0.36$], a main effect of Valence [$F(2,62) = 4.09$, $p = 0.02$, $\eta^2_p = 0.12$], and a 2-way Task x Valence interaction [$F(2,62) = 10.57$, $p < 0.001$, $\eta^2_p = 0.25$]. As can be seen in Figures 7 and 8, follow-up analyses showed that ERPs were larger for both negative (*M* = -12.93 µV, *SD* = 7.74) and neutral (*M* = -12.71 µV, *SD* = 7.93) images than positive (*M* = -10.13 µV, *SD* = 8.93) images in the picture task [all *ts* > 2.74, *ps* < 0.009] with no significant difference between negative and neutral images [$t(31) = 0.21$, $p = 0.83$]. In the bar task, ERPs were larger for both positive (*M* = -8.88 µV, *SD* = 10.53) and negative (*M* = -8.41 µV, *SD* = 11.22) images than neutral (*M* = -4.46 µV, *SD* = 11.33) images [all *ts* > 3.03 µV, *ps* < 0.005] with no significant difference between positive and negative images [$t(31) = 0.43$, $p = 0.67$]. Additionally, regardless of valence, the magnitude of ERPs were larger in the picture (*M* = -11.92 µV, *SD* = 8.2) than in the bar task (*M* = -7.24 μV, *SD* = 11.02) [$t(31) = 4.17$, $p < 0.01$]. No other interactions involving Task and/or Valence factors were significant [all *F*s < 2.5, *p*s > 0.1] for this component.

3.3.4 Late-onset Positivity

A Task x Valence x Group x Location x Hemisphere ANOVA revealed a main effect of Task [$F(1,62) = 20.17$, $p < 0.001$, $\eta^2_p = 0.25$] that was modified by interactions with Valence [$F(2,124) = 22.71$, $p < 0.001$, $\eta^2_p = 0.27$], and Group [$F(1,62) = 4.32$, $p = 0.04$, $\eta^2_p = 0.07$]. Importantly, there was a Task x Valence x Group interaction [$F(2,124) = 3.51$, $p = 0.03$, $\eta^2_p = 0.06$].

As can be seen in Figures 7 and 8, follow-up analyses within the younger group showed that ERPs were larger for both positive (*M* = 6.25 μV, *SD* = 8.01) and negative (*M* = 5.53 μV, *SD* = 6.59) images than neutral (M = 2.95 μV, SD = 7.41) images in the picture task [all *ts* > 3.2, *ps* < 0.004] with no significant difference between negative and positive images [$t(31) = 0.68$, $p = 0.5$]. In the bar task, however, ERPs were larger for neutral (*M* = 9.39, *SD* = 10.34) than positive (*M* = 4.66 μV, *SD* = 9.01) and negative (*M* = 5.67 μV, *SD* = 9.38) images [all *ts* > 2.49, *ps* < 0.01] with no significant difference between negative and positive images [$t(31) = 0.88$, $p = 0.38$]. As can be seen in Figures 9 and 10, follow-up analyses within the older group showed that ERPs were larger for positive (*M* = 10.32 μV, *SD* = 7.14) than negative (*M* = 8.35 μV, *SD* = 7.2) and neutral (*M* = 6.76 μV, *SD* = 6.59) images in the picture task [all *ts* > 2.8, *ps* < 0.009] with no difference between negative and neutral images [$t(31) =2.3$, $p = 0.03$]. In the bar task, however, there was no effect of image valence on ERPs [all *ts* < 0.77, *ps* > 0.4].

Between age group follow-up analyses revealed that in the picture task, older adults showed larger ERPs for positive and neutral images than younger adults [all $ts > 2.5$, $ps = 0.01$], with no age-related difference for negative images [$t(62) = 1.64$, $p = 0.11$]. In the bar task, older adults showed larger ERPs than younger adults for positive and negative images [all $ts > 3.11$, $ps < 0.004$], with no age-related difference for neutral images [$t(62) = 1.78$, $p = 0.08$]. Neither the main effect of Valence nor other interactions involving Task and/or Valence factors was significant [all Fs < 2.83, ps > 0.13] for this component.

Younger Adults – Picture Task

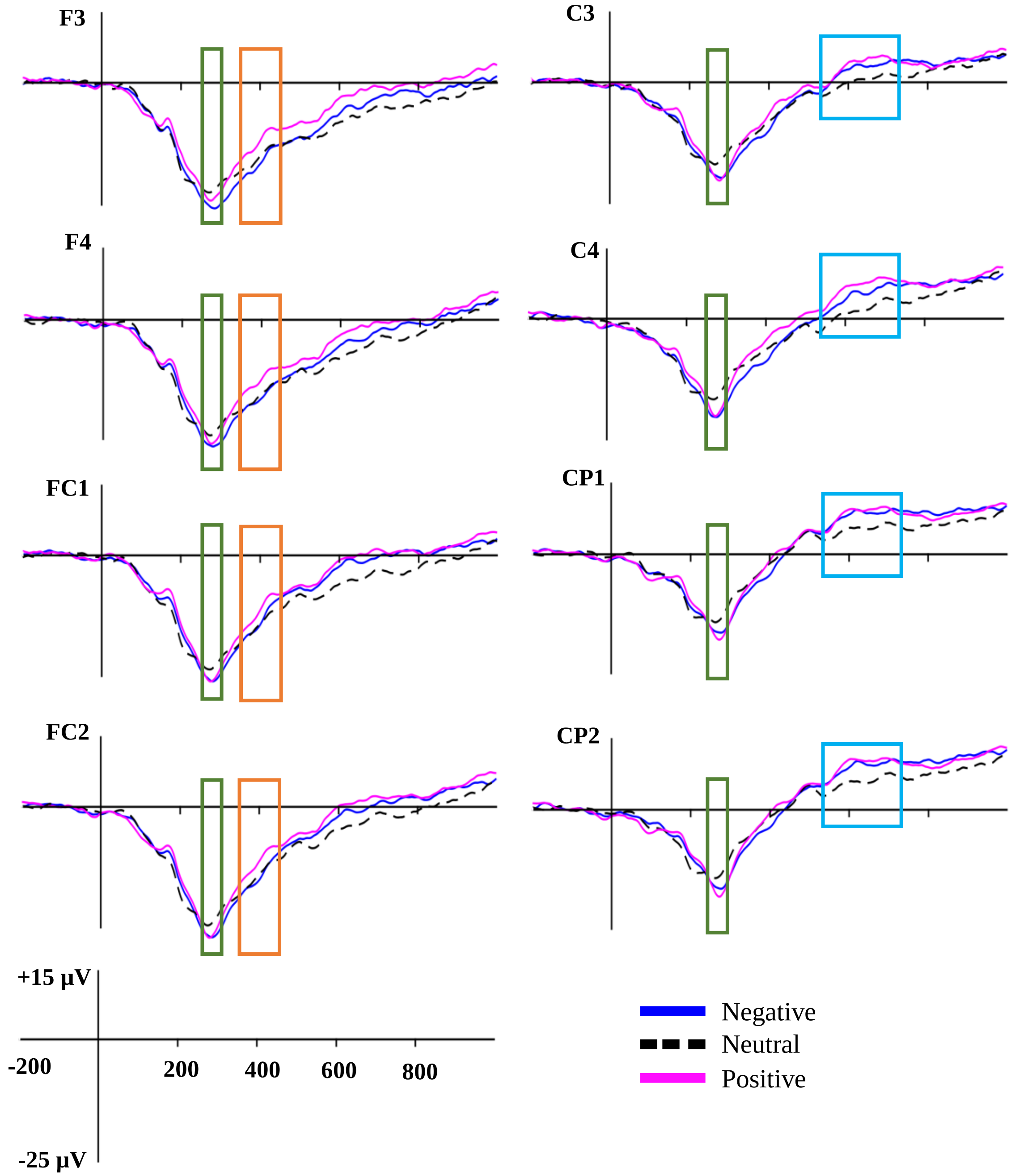

Figure 7 – ERPs elicited by negative, neutral, and positive images in the picture task by younger adults. Green rectangles indicate early-onset negativity (250-300 ms), orange rectangles indicate late-onset negativity (350-450 ms), and blue rectangles indicate late-onset positivity (550-750 ms) at the electrode sites associated with each component.

Younger Adults – Bar Task

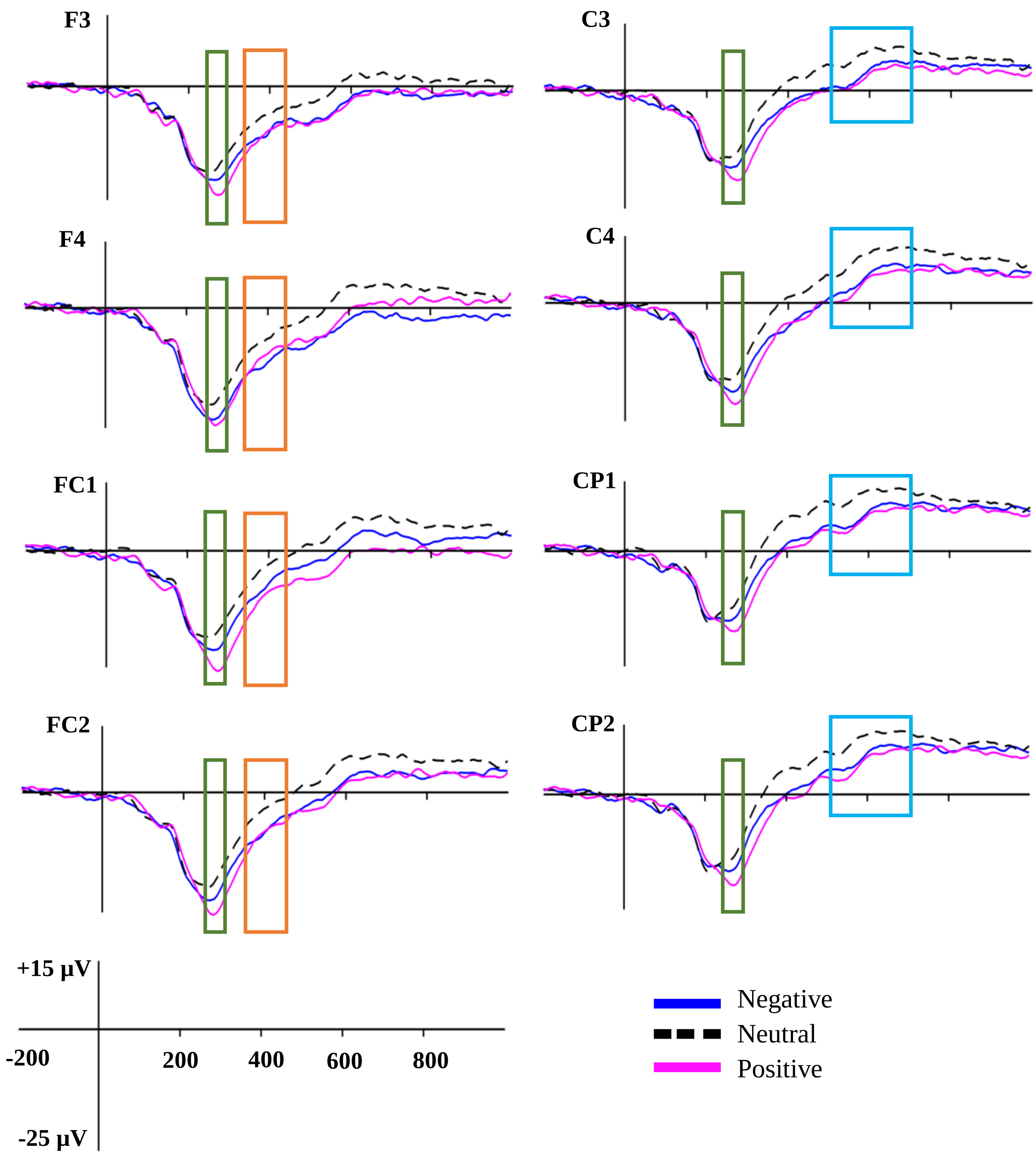

Figure 8 – ERPs elicited by negative, neutral, and positive images in the bar task by younger adults. Green rectangles indicate early-onset negativity (250-300 ms), orange rectangles indicate late-onset negativity (350-450 ms), and blue rectangles indicate late-onset positivity (500-700 ms) at the electrode sites associated with each component.

Older Adults – Picture Task

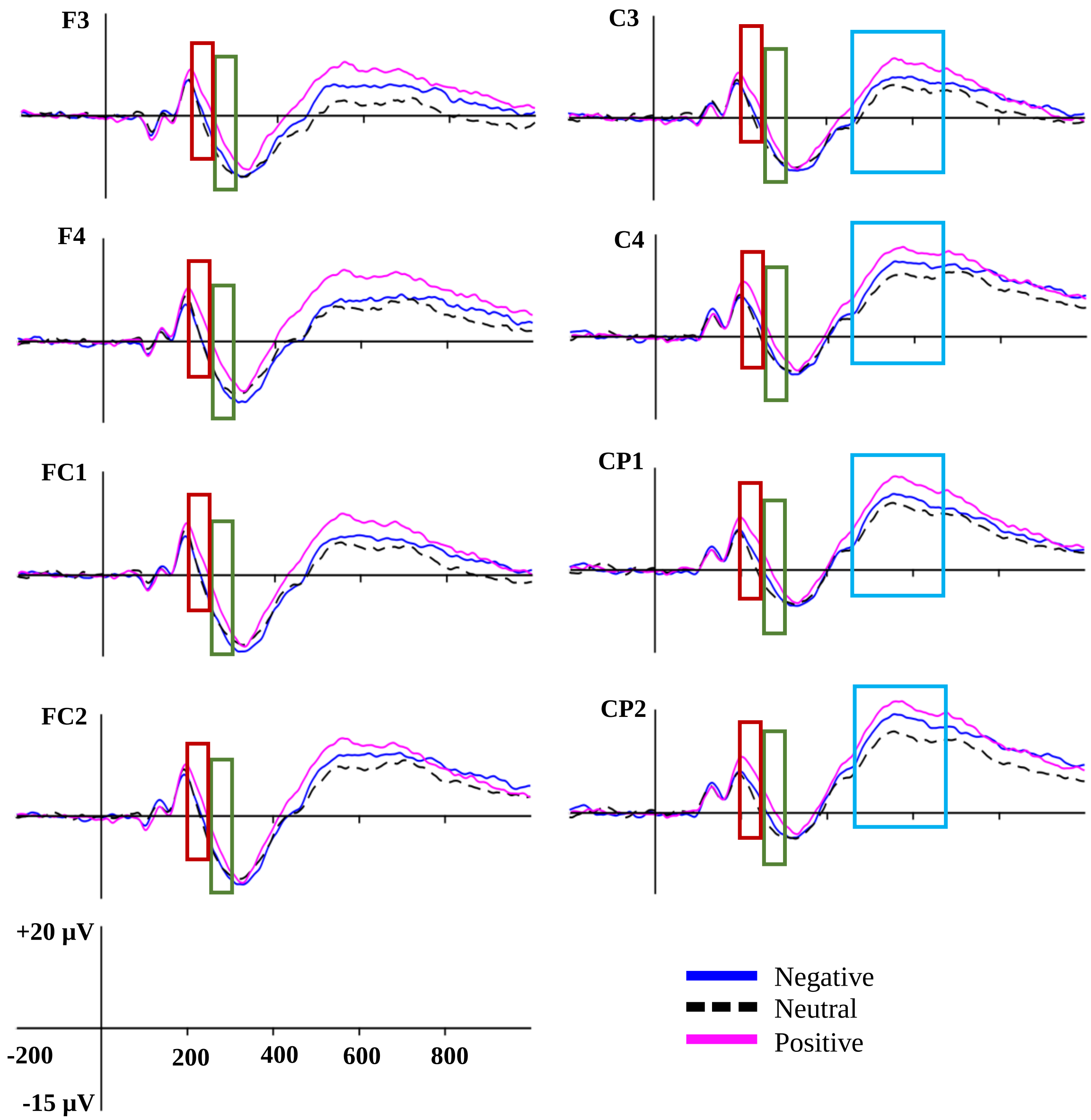

Figure 9 – ERPs elicited by negative, neutral, and positive images in the picture task by older adults. Red rectangles indicate early-onset positivity (200-250 ms), green rectangles indicate early-onset negativity (250-300 ms), and blue rectangles indicate late-onset positivity (450-650 ms) at the electrode sites associated with each component.

Older Adults – Bar Task

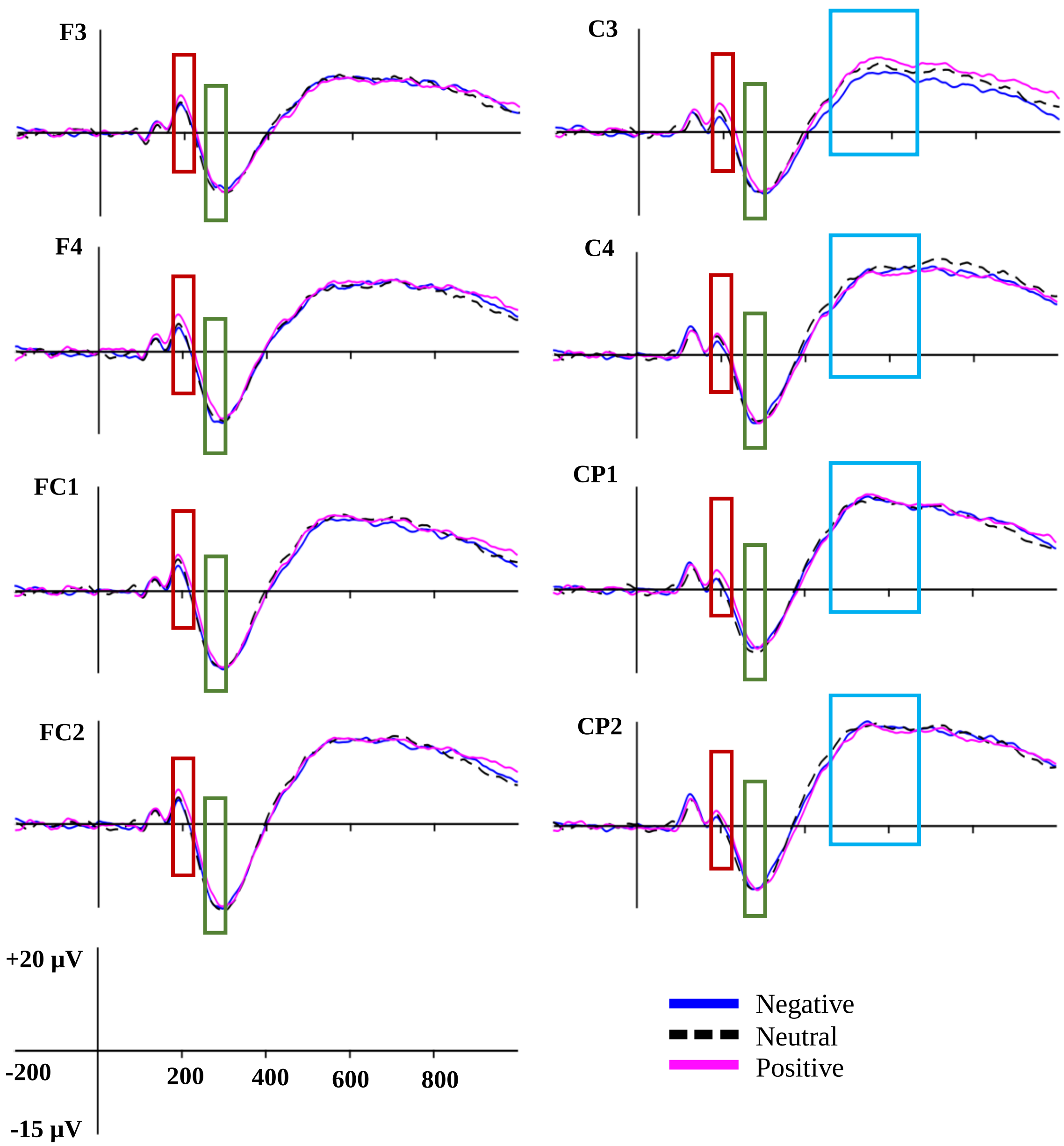

Figure 10 – ERPs elicited by negative, neutral, and positive images in the bar task by older adults. Red rectangles indicate early-onset positivity (175-225 ms), green rectangles indicate early-onset negativity (250-300 ms), and blue rectangles indicate late-onset positivity (450-650 ms) at the electrode sites associated with each component.

Table 5 – Summary of ERP data containing the time windows, relevant electrodes, and the nature of the effect associated with each component in the picture and bar tasks for younger adults.

		Younger Adults		
Picture Task				
		Time Window	**Electrodes of Interest**	**Effect**
	Early-onset Positivity	—	—	—
	Early-onset Negativity	250-300 ms	F3/F4, FC1/FC2, C3/C4, CP1/CP2	Positive ≈ Negative > Neutral
	Late-onset Negativity	350-450 ms	F3/F4, FC1/FC2	Negative ≈ Neutral > Positive
	Late-onset Positivity	550-750 ms	C3/C4, CP1/CP2	Positive ≈ Negative > Neutral
Bar Task				
		Time Window	**Electrodes of Interest**	**Effect**
	Early-onset Positivity	—	—	—
	Early-onset Negativity	250-300 ms	F3/F4, FC1/FC2, C3/C4, CP1/CP2	Positive > Negative > Neutral
	Late-onset Negativity	350-450 ms	F3/F4, FC1/FC2	Positive ≈ Negative > Neutral
	Late-onset Positivity	500-700 ms	C3/C4, CP1/CP2	Neutral > Positive ≈ Negative

Table 6 – Summary of ERP data containing the time windows, relevant electrodes, and the nature of the effect associated with each component in the picture and bar tasks for older adults.

		Older Adults		
Picture Task				
		Time Window	**Electrodes of Interest**	**Effect**
	Early-onset Positivity	200-250 ms	F3/F4, FC1/FC2, C3/C4, CP1/CP2	Positive > Negative ≈ Neutral
	Early-onset Negativity	250-300 ms	F3/F4, FC1/FC2, C3/C4, CP1/CP2	Negative ≈ Neutral > Positive
	Late-onset Negativity	—	—	—
	Late-onset Positivity	450-650 ms	C3/C4, CP1/CP2	Positive > Negative ≈ Neutral
Bar Task				
		Time Window	**Electrodes of Interest**	**Effect**
	Early-onset Positivity	175-225 ms	F3/F4, FC1/FC2, C3/C4, CP1/CP2	Positive > Negative ≈ Neutral
	Early-onset Negativity	250-300 ms	F3/F4, FC1/FC2, C3/C4, CP1/CP2	Positive ≈ Negative ≈ Neutral
	Late-onset Negativity	—	—	—
	Late-onset Positivity	450-650 ms	C3/C4, CP1/CP2	Positive ≈ Negative ≈ Neutral

CHAPTER 4

DISCUSSION

In the current study, I examined age-related differences in neural correlates of a selective attention task that required younger and older adults to selectively attend to either pictures (positive, negative, neutral) or line bars, concurrently presented on the screen. The task was either to make a decision about the color of the pictures (picture task, where emotional processing was expected; (e.g., Sand & Wiens, 2011; Wiens & Syrjänen, 2013) or about the orientation of the bars (bar task, where the cognitive demands of the task was expected to preclude emotional processing; Lavie, 1995). The goal was to examine whether the emotional content of the pictures, expected to show through in the picture task, would also be discernable in the bar task, as revealed by behavioral effects and selected ERP components. Specifically, the question was whether such emotional break-through effects, if any, would be larger within a group of older adults compared to a group of younger adults, as predicted by standard theories on age-related deficits in inhibition (Hasher & Zacks, 1988). The critical manipulation was to calibrate the demands of the bar task for each individual to the same difficulty level, way below ceiling, implying a strong cognitive load in this task.

To summarize, the behavioral data showed no interference from emotional material in the bar task. Accuracy, however, was higher for emotional relative to neutral pictures in the picture task, regardless of age. During the time window associated with negative deflection, younger adults showed evidence for emotional processing in the picture task. Specifically, ERPs were larger for emotional relative to neutral pictures during the early stage of processing (250-300 ms) whereas more valence-based effect (reflected by a negativity bias) was observed during later stage of processing (350-450 ms). The negative deflection was followed by a late-onset positivity during which younger adults showed larger ERPs for emotional relative to neutral images in the picture task. In the bar task, there was evidence of ERPs for task-irrelevant emotional distractors both in the early (positive > negative > neutral) and late-onset (positive ≈ negative > neutral) negative components, but this intrusion was not found (as reflected by ERPs larger for neutral than emotional images) in the late-onset positive component that followed the negative deflection. ERP results for the older adult group provided evidence for an emotional positivity effect in both early and late-onset positive components in the picture task whereas an emotional negativity effect was evident in the early-onset negative component. In the bar task, although a positivity effect was evident during early-onset positive component, ERPs were similar for emotional and neutral pictures during the time windows associated with early-onset negative and late-onset positive component, suggesting no intrusion from emotional distractors for the older group in the bar task.

4.1 Behavioral Results

Although both younger and older showed higher accuracy for emotional relative to neutral images in the picture task, there was no evidence of valence-based effects (either a positivity or negativity bias). The absence of negativity bias in the younger group could be related to the characteristics of the stimuli. Although the negative images used in the current study were more arousing than positive and neutral images, the arousal level of negative images ranged from moderate to high (see Table 3), and extremely arousing negative images were not included in order to keep mean arousal level of positive and negative images as close as possible. Negativity effects have typically been found in studies extremely arousing negative stimuli (Cacioppo, Gardner, & Berntson, 1997; Ito et al., 1998; Rozin & Rozyman, 2001). Therefore, the current study suggests that a negativity effect in younger adults appears only when extremely arousing negative stimuli are used. The absence of positivity bias in the older group could be related to task demands: Participants were asked to make a decision about color of images presented for a very short duration (250 ms). Previous studies showed that positivity effect in older adults tends to appear when older adults are asked to view images passively with no explicit or implicit instructions (Reed et al., 2014) and under relatively long presentation durations (Isaacowitz, Allard, Murphy, & Schlangel, 2009). Thus, it is possible that the nature of the orienting task and the presentation duration of images in the current study might have resulted in absence of positivity effect in the older group. Lastly, a ceiling effect in performance observed in the picture task may have masked potential valence-based effects in younger and older adults in the present study. Overall, accuracy data from the picture task do not allow me to make an inference regarding age-related differences in emotion processing.

Contrary to the picture task, accuracy data in the bar task did not show any emotion-related effects. This is not surprising, as previous behavioral studies have often located the effect of interference from task-irrelevant emotional material in slowing in response times (e.g., Erthal et al., 2005; Padmala & Pessoa, 2014). However, in the present study, response times also did not differ as a function of emotion either, suggesting no intrusion from emotional material in the bar task at least at the behavioral level. Absence of interference from task-irrelevant emotional images in the bar task seems to be in line with the load theory of attention (Lavie, 1995), and might be a natural consequence of the calibration procedure used to yield equivalent performance across participants in the present study. Lastly, as expected, there was age-related slowing reflected by longer response times in the older compared to the younger group in both picture and bar tasks.

4.2 ERP Results

4.2.1 Picture Task

The picture task offers insights into how the participants responded to emotional pictures that were not explicitly scrutinized for emotional content. The earliest component modulated by emotional stimuli in the picture task was the early-onset positivity (200-250 ms), which was observed only in the older group. This component was larger for positive compared to negative and neutral images as consistent with a previous study showing early-onset positivity to pleasant relative to unpleasant stimuli in older adults (Newsome et al., 2012). The positivity effect in older adults reflected by this component might indicate selective attention to positive material early in the processing stream.

The results also showed that the positivity effect in the older adults during this early ERP component was larger in the right than in the left hemisphere in the picture task, whereas there was no effect of hemisphere in the bar task. Currently, there are two main hypotheses regarding hemispheric asymmetries in emotional processing: the right hemisphere hypothesis (Borod, Koff, & Caron, 1983) and the valence hypothesis (Davidson, 1995). The right hemisphere hypothesis proposes that emotions are mainly processed in the right hemisphere, independent of emotional valence. The valence hypothesis proposes that pleasant emotions are mainly processed in the left hemisphere and unpleasant emotions are mainly processed in the right hemisphere. In the current study, the data seem to support the right hemisphere hypothesis: The right hemisphere was involved in the positivity effect, opposite from the predictions of the valence hypothesis.

Last but not least, it is important to note that younger adults did not show any emotion-related effects during the time window associated with the early-onset positivity, although they did in later time windows. This finding suggests that emotion-related modulation of ERPs starts later in the processing sequence in younger adults than older adults, perhaps supporting the idea of improved emotional regulation with aging (Carstensen et al., 1999)

Following the early-onset positivity, the early-onset negativity (250-300 ms) appeared in both age groups. In the younger adults, this effect was reflected by larger ERPs for emotional relative to neutral images at central and centro-parietal electrode sites (but not at frontal sites). This early-onset negativity has been shown to be sensitive to arousing information (e.g., Sand & Wiens, 2011). Although the current finding suggests that younger adults show larger ERPs for arousing (emotional) relative to non-arousing (neutral) stimuli, it is important to note that negative images were rated as more arousing than positive images in the norming study. Thus, this finding is not completely in line with previous studies with arousal levels that were better matched, which showed larger early-onset negativity for arousing than non-arousing material (e.g., Schupp et al., 2007a). Based on the results from previous studies, I would have expected to find larger ERPs for negative relative to positive and neutral images in the current study. Absence of this pattern may be explained by the fact that extremely arousing negative images were not included in the present study, which, in turn, may have masked arousal-related effects.

In addition to this early-onset negativity, the younger adults showed a sustained late-onset negativity (350-450 ms) only at frontal electrode sites in the picture task. To my knowledge, this type of ERP effect has not been found/reported in previous studies investigating how ERPs are modulated by emotion as a function of task relevancy. Thus, discussion of this effect will be speculative. During the time window associated with this component, the younger adults showed a valence-based effect reflecting negativity bias at frontal sites. This ERP pattern is different than the ERP pattern I observed in the earlier stage of negative deflection (250-300 ms) at central and centro-parietal electrode sites during which younger adults showed larger ERPs for emotional material (both positive and negative) more than non-emotional material (neutral). Combined, these results show that the ERP pattern reflecting discrimination of emotional content from non-emotional content was only evident at central and centro-parietal but not at frontal electrode sites during the early-portion of the negative component whereas valence-based effect reflected by a negativity bias was only evident at frontal but not central and centro-parietal electrode sites during the later portion of the negative component. This dissociation could suggest that modulation of the ERPs by emotion is qualitatively different at different electrode sites in different time windows, such that initial overall emotion-based modulation at central and centro-parietal electrode sites is followed by more specific valence-based effect at frontal sites during the later portion of the negative component. Conceptually, it is possible that ERPs to emotional material during the earlier portion of the negative deflection might be reflecting selective attention to emotion in the service of conscious representation of this material during the later portion of the negative deflection, which in turn leads to semantic elaboration on the emotional content as reflected by a bias toward negative material.

Additionally, given that previous studies consistently showed an evidence for negativity bias in younger adults (e.g., Baumeister, Bratslavsky, Finkenauer, & Vohs, 2001; Rozin & Royzman, 2001), it is not surprising that the pattern of valence-based effect obtained at this later stage of processing is in the form of an emotional negativity bias. It is important to note that although ERPs to negative images were not larger than neutral images, ERPs to positive images were significantly reduced compared to these two valence categories, suggesting not an enhancement of negative content, but a suppression of positive content in the young group at this later stage of the negative component.

Only early-onset negativity, but not late-onset negativity was observed in the older adults. This early-onset negativity (250-300 ms) was associated with an emotional negativity effect (reflected by larger ERPs for negative and neutral than positive images). So far, Wieser et al., (2006) are the only group that have examined age-related differences in the early-onset negativity; they demonstrated that both younger and older adults showed larger negativity for high, relative to low arousing IAPS pictures regardless of valence. In the current study, the ERP pattern reflecting the negativity effect in the older group is not consistent with the findings of Wieser and colleagues, as it does not reflect arousal-based effect. As I mentioned before, extremely arousing negative images were not included in the current study and this may have reduced ERPs for negative pictures to the level of neutral pictures, giving rise to valence-based effect (reflected by larger ERPs for negative and neutral than positive images) instead of the usual arousal-based effect (which is supposed to be reflected by ERPs largest for negative images) in the older group during the time window associated with the early-onset negativity. It is possible that what is happening is that older adults exhibit an emotional negativity effect in the early and relatively automatic stages of processing, resulting from a natural inclination to focus on the negative material (e.g., Baumeister et al., 2001; Rozin & Royzman, 2001). This negativity effect may have led to an emotion regulation response, by transferring attention away from negative to positive material at later stages as reflected by the positivity effect during the late-onset positivity component.

It is important to note that, as discussed before, older adults also showed a positivity effect even before the negativity effect appeared during the early-onset positivity component (200-250 ms). This finding is counterintuitive, based on the argument that older adults show a negativity effect first, which eventually leads to a shift in attention from negative to positive material resulting in a positivity effect at the later stage of processing. One speculative explanation for the very early positivity effect preceding the negativity effect in the older adults could invoke the nature of the cognitive operations involved. Specifically, it is possible that the very early positivity effect observed could be reflecting early attentional and automatic processes, whereas the late-onset positivity effect might be more associated with sustained attention to motivationally salient stimuli.

The negative deflection was followed by a late-onset positivity in both age groups. In the younger group, the late-onset positivity, which was observed from 550 to 750 ms, was larger for emotional relative to neutral images, suggesting that in this time window younger adults are sensitive to the difference in arousal value between stimuli. In the older group, late-onset positivity, which was observed from 450 to 650 ms, was associated with larger ERPs for positive compared to negative and neutral images. This finding is consistent with previous ERP studies showing larger late-onset positivity for positive relative to negative images (e.g., Kisley et al., 2007; Mathieu et al., 2014) and may also imply that the older adults engaged in some form of emotion-regulation mechanism that accentuated the positive content of the pictures (Carstensen et al., 1999).

One of the goals of the picture task was to elucidate the underlying mechanisms for the positivity effect in older adults. In the current study, a positivity effect was consistently observed during the time window associated with the early and late-onset positivity in the older adult, with larger deflections for positive relative to negative and neutral images. Moreover, during late-onset positivity, there was no age-related difference in ERPs for negative images and in fact, relative to younger adults, older adults showed larger ERPs for positive images. Thus, in the current study, relative to younger adults, older adults seem to focus on positive material more than negative and neutral material, with no age-related decline in ERPs to negative materials. This pattern is conceptually more consistent with SST (Carstensen et al., 1999) than the alternative explanation which argues that the positivity effect is driven by age-related deficits in processing of negative material (Cacioppo et al., 2011). Additionally, the pattern of the negativity effect in the older adults that emerged before the positivity effect occurred during the late-onset positive component provides further support for SST, as it suggests that attending to negative images earlier in the time course led to a shift in attentional focus to divert attention away from negative to positive images. It is important to note that a direct age group comparison regarding the positivity effect is not possible during the time window associated with the early-onset positivity because younger adults did not show this ERP effect in the current study. Thus, the ERP patterns associated with the late-onset rather than early-onset positivity provide a better interpretation regarding the source of the positivity effect; this late-onset positivity effect seems to provide stronger support for SST. Stronger evidence for a positivity bias in older adults during later ERP component is also consistent with underlying processes reflected by the late-onset positivity component given this component has been associated with sustained attention to motivationally salient material (e.g., Schupp et al., 2006). Thus, these results show that relative to younger adults and negative content, older adults showed increased attention to motivationally salient positive material which in turn may reflect semantic elaboration focusing on the positive content during this ERP component in older adults. This is consistent with the assumptions of SST, but not ABM.

Although older adults showed valence-based effect reflecting positivity bias during the late-onset positivity, no valence-based effect reflecting negativity bias was observed in younger adults during this time window. Instead, the younger group showed an overall emotion-based effect reflected by enlarged ERPs for emotional relative to neutral material. Although this ERP pattern is consistent with previous studies with younger adults showing an increase in magnitude of the late-onset positivity for both pleasant and unpleasant compared to neutral stimuli (e.g., Cuthbert et al., 2000; Schupp et al., 2000; Schupp et al., 2004), it is inconsistent with some previous studies providing evidence for a negativity bias during the time window associated with the late-onset positivity (e.g., Ito et al., 1998). One possible reason for this may be that the valence effect might be moderated by arousal. Wiens and Syrjänen (2013) showed that when emotional material is task-relevant, ERPs reflecting the late-onset positivity are similar for pleasant and unpleasant images when arousal level ranged from medium to high, whereas valence-based effects on ERPs appeared at extreme levels of arousal. Although negative images were more arousing than positive and neutral images in the current study, extremely arousing negative images were not included, which in turn may have prevented the negativity bias to appear in the younger group. Therefore, the current study suggests that during late-onset positivity component, younger adults' sustained attention was evident for both positive and negative material which reflects more semantic elaboration focusing on motivationally salient emotional content regardless of valence.

4.2.2 Bar Task

In the bar task, participants were asked to ignore the emotional (or emotionally neutral) pictures shown at the center of the screen while engaged in an absorbing cognitive task. The findings from this task thus shed light on the extent to which older and younger adults are capable of effectively inhibiting emotional content.

In the older adults, ERP data during time window associated with early-onset positivity (175-225 ms) in the bar task showed interference from task-irrelevant emotional material. Specifically, similar to the picture task, a positivity effect appeared during the early-onset positivity time window, such that older adults showed larger ERPs for task-irrelevant positive images than for negative and neutral images. This finding suggests that initial valence-based processing does not depend on attentional task instructions. At the later stages of processing reflected by early-onset negativity (250-300 ms) and late-onset positivity (450-650 ms), however, older adults showed similar ERPs for task-irrelevant emotional and neutral images in the bar task, suggesting that emotional content does not break through during later ERP components. The ERP pattern in the older group observed at these later stages of processing therefore, seems to be inconsistent with the inhibitory deficit hypothesis (Hasher & Zacks, 1988). Instead, the data might be more consistent with Lavie's load theory (1995): When the main task is hard enough, older adults prioritize task-relevant stimuli, resulting in effective rejection of task-irrelevant material. Overall, the data especially from later ERP components during the bar task in older group support the idea that age-related inhibitory deficits could be an artifact of task difficulty.

Additionally, absence of positivity bias during later ERP components during the bar task in older adults is more consistent with SST (Carstensen et al., 1999) which argues that the positivity effect requires cognitive control (Mather & Knight, 2005), rather than the competing perspective which argues that processing of positive information is not effortful (Cacioppo et al., 2011). This explanation, however, does not hold for the earlier time period (early-onset positivity) during which older adults showed the positivity effect. Although speculative, these findings suggest that during early stages of processing a positivity effect can be obtained even in the presence of competing task demands (Allard & Isaacowitz, 2008) whereas at later stages of processing appearance of the positivity effect becomes more dependent on cognitive control.

Although the results for older adults were clear, ERP data for the younger adults showed a different pattern that reflects emotion effects for task-irrelevant material during all ERP components of interest. Specifically, ERPs to task-irrelevant emotional material was evident during the time window associated with both early-onset negativity (250-300 ms) and late-onset negativity (350-450 ms) in the younger adults. Thus, although the bar task difficulty was set at 75% through calibration, these data suggest an interference from emotional material in the bar task for the younger adults. Interestingly, ERP patterns in the bar task during the time associated with early and later-onset negativity differed. In the early portion, valence-based differences for task-irrelevant images as reflected by larger ERPs for task-irrelevant positive than negative and neutral images and for task-irrelevant negative than neutral images appeared. These data seem to imply that directing attention away from pictures decreased ERP amplitudes more strongly for negative relative to positive distractors. Given that in our norming study negative images were rated as more arousing than positive images, this result might suggest that ERPs were reduced more for highly arousing (negative) stimuli than for moderately arousing (positive) stimuli. This finding is consistent with the idea that sensory facilitation provided by arousing stimuli decreases when attention is directed away from arousing material (Pourtois, Schettino, & Vuilleumier, 2013) and that this decrease occurs linearly based on intensity of arousal (Wiens, Molapour, Overfeld, & Sand, 2012). In line with this argument, Wiens and Syrjänen (2013) found that when emotional pictures are task-irrelevant, ERPs decreased more strongly for highly arousing than moderately arousing pictures. Thus, the apparent valence-based differences regarding ERPs for task-irrelevant positive versus negative images during the early portion of the negative component in the current study might boil down to differences in the arousal level of these stimuli. Different from the ERP pattern during the early portion, ERPs to task-irrelevant emotional material were more about discrimination of emotional content from non-emotional content in the younger group as reflected by larger ERPs for both positive and negative relative to neutral images during the later portion of the negative ERP component. Overall, these data suggest that younger adults perceived pictures that are supposed to be ignored up to the level of meaning at earlier stage while ERPs to task-irrelevant emotional material in younger adults are less differentiated during the later portion of the negative ERP component.

What is surprising is that during the time window associated with the late-onset positivity (500-700 ms), younger adults showed larger ERPs for neutral relative to emotional images – the opposite of what would be expected during unimpeded perception of emotion and also, the opposite of the pattern that was found in the picture task in younger adults, where emotional images showed increased ERPs. This finding suggests that after the initial breakthrough of the emotional and/or arousal content of the pictures during earlier ERP components in the bar task, an attentional shift from task-irrelevant emotional to neutral material occurred in younger adults which allowed them to differentiate between neutral and emotional material at the later stage of processing.

This finding is also different from what I have observed in older adults at this later stage of processing. The data thus reveal an interesting and unexpected age-related difference: While older adults showed similar ERPs for task-irrelevant images regardless of valence in the bar task at later processing stage, the younger group showed larger ERPs for neutral relative to emotional images. Additionally, although ERPs for task-irrelevant neutral images were similar across age groups during the bar task, ERPs for task-irrelevant positive and negative images were reduced in the younger group compared to the older group. Combined, these patterns suggest that younger (but not older) adults engaged in suppression of task-irrelevant emotional images (as reflected by reduced ERPs for task-irrelevant emotional images relative baseline neutral images). Given that performance of both age groups was successfully calibrated to yield the same level of accuracy, the results are hard to explain, unless one assumes that, somehow, the bar task was objectively easier to perform for younger adults, so that they were able to perceive task-irrelevant material while performing the bar task without sacrificing the desired performance level (around 75%). Although speculative, an age-related difference in ERP pattern for task-irrelevant material during the bar task might imply that the bar orientation task was more effortful for older adults than younger adults.

4.3 Limitations and Future Directions

In the current study, stimuli were selected based on valence and arousal ratings obtained through picture rating experiment in which set of images were rated by a separate group of younger and older adults. Conducting a rating experiment prior to the actual experiment helped me to minimize potential age differences in perception of valence and arousal levels associated with images. Due to time constraints, it was not possible to obtain additional (confirmatory) subjective ratings of valence and arousal associated with the images from the actual participants in the ERP experiment. This is a limitation: Some have argued that such subjective assessment of materials should be performed within each ERP session (Dolcos & Cabeza, 2002). For instance, it has been shown that normative ratings associated with the IAPS stimuli may not always be consistent with subjective rating obtained in the actual ERP recording session, suggesting that procedural differences between the IAPS normative rating and ERP recording sessions might be of importance (Pollatos, Kirsch, & Schandry, 2005). Although stimulus selection in the present study relied on a picture rating experiment in which participants of both age groups rated images presented in a similar fashion to the actual experiment (in terms of presentation duration and picture size), the rating procedure (see Appendix) was not identical as in the actual experiment setup in which bars and pictures were presented concurrently on the screen. Thus, it could be the case that procedural differences between the rating and actual experiment may have led some (age-related) differences in perception of valence and arousal levels of images which in turn might potentially change interpretation of the findings of the current study. In future studies, it is important to obtain ratings of valence and arousal for the stimuli not just in a norming study, but also at the end of the experiment.

Additionally, although the picture rating experiment helped me to equate arousal level of emotional images used in the current study across age groups, it was not possible to match arousal level for the two valence categories – the negative pictures were rated, on average, as more arousing. It is therefore possible that some of the behavioral and ERP effects of valence might be attributable to differential levels of arousal. It is important to note that the older adults in the experiment proper showed an emotional positivity effect in both early and late-onset positivity, even though positive stimuli were rated as less arousing than negative stimuli by older adults in the current study. Thus, arousal related limitation may not hold for this effect.

Lastly, given that the current data from the bar task demonstrated that older adults showed similar ERPs for task-irrelevant images regardless of valence during late-onset component while the younger group suppressed task-irrelevant emotional images without any trade-off in bar task performance, there seems to be an age-related difference regarding what each age group is capable of doing during the bar task. This raises questions about the level of effort required in the bar task across age groups and the performance criterion employed in the current study. Thus, these questions need to be examined in future studies, probably by varying bar task difficulty both between (by varying performance criterion) and within subjects (e.g., by varying individual threshold for angular disparity systematically, such that mismatch stimuli reflect angular difference at, below, and above threshold).

CHAPTER 5

CONCLUSIONS

The results from the current study show that when emotional material is task relevant, younger adults do not only appear to discriminate emotional content from non-emotional content (during both early-onset negativity and late-onset positivity) but also show valence-based effect (reflected by negativity bias during the late-onset negativity component), as evidenced in ERP. Older adults show both an emotional positivity bias (reflected by both early and late-onset positive components) and an emotional negativity bias (reflected by early-onset negative component) in ERP. Because older adults, relative to younger adults, showed increased ERPs for positive images compared to negative and neutral images, with no decline in ERPs for negative material relative to younger adults (during the late-onset component), older adults' positivity effect seems to be more consistent with SST (Carstensen et al., 1999) than a competing theory which bases the positivity effect in an age-related decline in processing of negative information (Cacioppo et al. 2011). ERP results from the bar task (especially late-onset positivity component) provided further evidence for SST as an explanation for the positivity effect in older adults, because the positivity effect did not appear when older adults were required to do bar orientation judgment, suggesting that processing of positive information does require cognitive control (Mather & Knight, 2005).

The main focus of the study was on age-related differences in ERPs for task-irrelevant emotional material under conditions where the foreground task was effortful. Although older adults showed an emotional positivity bias during the early stage of processing in the bar task, there was no intrusion from task-irrelevant emotional material during the late stage. This result is inconsistent with the inhibitory deficit hypothesis (Hasher & Zacks, 1988) and instead, more consistent with the perceptual load theory (Lavie, 1995) which argues that when the task is sufficiently demanding, individuals (in here in particular older adults) prioritize task-relevant stimuli, resulting in effective rejection of task-irrelevant material. In the younger group, results from the bar task showed evidence for intrusion from task-irrelevant emotional distractors during the time windows associated with the negative components (as reflected by early and late-onset negativity), with suppression of task-irrelevant emotional distractors only at a later stage of processing (as reflected by late-onset positivity). These results suggest that the bar task was not too effortful for younger adults as they perceived task-irrelevant emotional distractors during relatively early stages of processing and were able to suppress the emotional content during the later stage in the bar task, consistent with perceptual load theory which predicts increased susceptibility to distractors under easier task conditions.

APPENDIX

PROCEDURE FOR THE PICTURE RATING EXPERIMENT

Eighty-eight younger (34 female) and 90 older (52 female) adults participated in the picture rating experiment designed with Qualtrics survey software. Participants were recruited through MTurk, which is an internet-based platform that allows one to request jobs, such as survey completions, from participants seeking monetary compensation. MTurk facilitates high-quality data collection from a large pool of diverse participants by allowing job requesters to reject participants' work if they do not follow instructions. For the purposes of the current rating study, I limited participation to individuals whose age ranged from 18-25 (for younger adults) or 60- 80 (for older adults) and who were located in the United States, to reduce potential cultural differences in perception of images (Gruhn & Scheibe, 2008). To get more reliable data, I limited participation to individuals who had demonstrated reliable MTurk performance in the past (HIT approval rate > 98%) and had sufficient experience with MTurk (Number of HITs approved > 1,000). Additionally, self-reported colorblind subjects were excluded from the study. Participants were paid $4/hour as compensation for participation. The mean age of younger adults was 22.5 (SD = 1.89); the mean age of older adults was 63.38 (SD = 5.32). Older adults (M = 15.45, SD = 2.81) had completed more years of education than younger adults (M = 14.53, SD = 1.62), $t(175) = 2.65$, $p = .009$.

For the picture rating experiment, 720 images (see pg. 15 for sources of the images and the criteria I used to create the stimulus pool in the picture rating experiment) were divided into 4 groups of 180 pictures, which included an equal number of images (60) from three predefined valence categories (i.e., positive, negative, neutral). Each group of pictures were rated by 10 younger and 10 older adults. There were 2 blocks of picture rating: In one of the blocks, the subjects completed a valence rating for 180 pictures; in the other block, they completed an arousal rating for the same 180 pictures. The order of rating blocks was counterbalanced. Before starting the rating study, younger and older adults electronically signed a consent form and filled out a brief demographic information form. During the picture rating study, the subjects were first presented with a fixation cross on the screen. After presentation of the fixation cross, a picture was presented at fixation for 200 ms for the younger participants; this presentation time was increased to 250 ms for the older participants to compensate for age-related slowing in perceptual processing (Verhaeghen, 2013). Next, participants were asked to rate the presented picture using the Self-Assessment Manikin (SAM) scale (Bradley & Lang, 1994). The SAM is a visual analog scale portraying a series of graphical figures ranging from 1 (extremely pleasant) to 9 (extremely unpleasant) for ratings of valence, and 1 (extremely aroused) to 9 (extremely calm) for ratings of arousal. Specifically, for the valence rating, the participants were asked to decide how positive or negative an image made them feel according to the following instructions: "This scale is the happy-unhappy scale, which ranges from a smile to a frown. At one extreme of the happy vs. unhappy scale, you felt happy, pleased, satisfied, contented, and hopeful. These feelings are represented by the figure number 1 in the scale. So, if you felt completely happy while viewing the picture, you can indicate this by clicking on the figure number 1. The other end of the scale is when you felt completely, unhappy, annoyed, unsatisfied, melancholic, despaired, bored. These feelings are represented by the figure number 9 in the scale. Thus, you can indicate feeling completely unhappy by clicking the figure number 9. If you felt completely neutral, neither happy nor sad, indicate this by clicking on the figure 5. The figures also allow you to describe intermediate feelings of pleasure. You can indicate intermediate feelings of pleasure by clicking on the figures number 3 and 7. To make more finely graded judgments of pleasure or displeasure, you can click on the digits 2, 4, 6, and 8 on the scale." For the arousal rating, participants were asked to decide how calm or excited the picture made them feel, according to the following instructions: "At one extreme of the scale you felt stimulated, excited, frenzied, jittery, wide-awake, aroused. These feelings are represented by the figure number 1 in the scale. So, if you felt completely aroused while viewing the picture, you can indicate this by clicking on the figure 1. At the other end of the scale, you felt completely relaxed, calm, sluggish, dull, sleepy, unaroused. These feelings are represented by the figure number 9 in the scale. Thus, you can indicate you felt completely calm by clicking on the figure 9. If you are not at all excited nor at all calm, click on the figure 5. Intermediate levels of excitement are represented by the figures number 3 and 7. To make a more finely tuned rating of how excited or calm you feel, you can click on the digits 2, 4, 6, and 8 on the scale." Once the participant made their response, the next image was presented. After completing all ratings, the participants were asked to report whether they encountered any technical problems while completing the survey. Additionally, they were asked to report their viewing distance and screen resolution because the viewing distance and screen resolution may influence perception of pictures. The study took about 1 hour for the younger adults and 1.5 hours for the older adults.

REFERENCES

Allard, E. S., & Isaacowitz, D. M. (2008). Are preferences in emotional processing affected by distraction? Examining the age-related positivity effect in visual fixation within a dual-task paradigm. *Aging, Neuropsychology, and Cognition, 15*(6), 725-743.

Backs, R. W., da Silva, S. P., & Han, K. (2005). A comparison of younger and older adults' self-assessment manikin ratings of affective pictures. *Experimental Aging Research*, *31*(4), 421-440.

Baumeister, R. F., Bratslavsky, E., Finkenauer, C., & Vohs, K. D. (2001). Bad is stronger than good. *Review of General Psychology*, *5*(4), 323.

Borod, J. C., Koff, E., & Caron, H. S. (1983). Right hemispheric specialization for the expression and appreciation of emotion: A focus on the face. In E. Perecam (Ed.), *Cognitive functions in the right hemisphere* (pp. 83-110). New York, NY: Academic Press.

Bradley, M. M., & Lang, P. J. (1994). Measuring emotion: the self-assessment manikin and the semantic differential. *Journal of Behavior Therapy and Experimental Psychiatry, 25*(1), 49-59.

Brainard, D. H., & Vision, S. (1997). The psychophysics toolbox. *Spatial Vision*, *10*, 433-436.

Cacioppo, J. T., Berntson, G. G., Bechara, A., Tranel, D., & Hawkley, L. C. (2011). Could an aging brain contribute to subjective well-being? The value added by a social neuroscience perspective. *Social Neuroscience: Toward Understanding the Underpinnings of the Social Mind*, 249-262.

Cacioppo, J. T., Gardner, W. L., & Berntson, G. G. (1997). Beyond bipolar conceptualizations and measures: The case of attitudes and evaluative space. *Personality and Social Psychology Review, 1*(1), 3-25.

Carretié, L., Hinojosa, J. A., Martín- Loeches, M., Mercado, F., & Tapia, M. (2004). Automatic attention to emotional stimuli: neural correlates. *Human Brain Mapping*, *22*(4), 290-299.

Carretié, L., Martín-Loeches, M., Hinojosa, J. A., & Mercado, F. (2001a). Emotion and attention interaction studied through event-related potentials. *Journal of Cognitive Neuroscience, 13*(8), 1109-1128.

Carstensen, L. L., Isaacowitz, D. M., & Charles, S. T. (1999). Taking time seriously: A theory of socioemotional selectivity. *American Psychologist, 54*(3), 165.

Codispoti, M., De Cesarei, A., & Ferrari, V. (2012). The influence of color on emotional perception of natural scenes. *Psychophysiology, 49*(1), 11-16.

Cuthbert, B. N., Schupp, H. T., Bradley, M. M., Birbaumer, N., & Lang, P. J. (2000). Brain potentials in affective picture processing: covariation with autonomic arousal and affective report. *Biological Psychology, 52*(2), 95-111.

Daffner, K. R., Zhuravleva, T. Y., Sun, X., Tarbi, E. C., Haring, A. E., Rentz, D. M., & Holcomb, P. J. (2012). Does modulation of selective attention to features reflect enhancement or suppression of neural activity?. *Biological Psychology, 89*(2), 398-407.

Dan-Glauser, E. S., & Scherer, K. R. (2011). The Geneva affective picture database (GAPED): a new 730-picture database focusing on valence and normative significance. *Behavior Research Methods, 43*(2), 468.

Davidson, R.J. (1995). Cerebral asymmetry, emotion and affective style. In R.J. Davidson & K. Hugdahl (Eds.), *Brain Asymmetry* (pp. 361-387). Cambridge, MA: MIT Press.

De Cesarei, A., Codispoti, M., & Schupp, H. T. (2009). Peripheral vision and preferential emotion processing. *Neuroreport*, *20*(16), 1439-1443.

Delplanque, S., Lavoie, M. E., Hot, P., Silvert, L., & Sequeira, H. (2004). Modulation of cognitive processing by emotional valence studied through event-related potentials in humans. *Neuroscience Letters*, *356*(1), 1-4.

Delorme, A., & Makeig, S. (2004). EEGLAB: an open source toolbox for analysis of single-trial EEG dynamics including independent component analysis. *Journal of Neuroscience Methods*, *134*(1), 9-21.

Dolcos, F., & Cabeza, R. (2002). Event-related potentials of emotional memory: encoding pleasant, unpleasant, and neutral pictures. *Cognitive, Affective, & Behavioral Neuroscience, 2*(3), 252-263.

Donderi, D. C. (2006). Visual complexity: a review. *Psychological bulletin, 132*(1), 73.

Erthal, F. S., De Oliveira, L., Mocaiber, I., Pereira, M. G., Machado-Pinheiro, W., Volchan, E., & Pessoa, L. (2005). Load-dependent modulation of affective picture processing. *Cognitive, Affective, & Behavioral Neuroscience, 5*(4), 388-395.

Fabiani, M. (2012). It was the best of times, it was the worst of times: A psychophysiologist's view of cognitive aging. *Psychophysiology*, *49*(3), 283-304.

Foster, S. M., Davis, H. P., & Kisley, M. A. (2013). Brain responses to emotional images related to cognitive ability in older adults. *Psychology and Aging*, *28*(1), 179.

Foti, D., Hajcak, G., & Dien, J. (2009). Differentiating neural responses to emotional pictures: evidence from temporal- spatial PCA. *Psychophysiology, 46*(3), 521-530.

Gazzaley, A., Clapp, W., Kelley, J., McEvoy, K., Knight, R. T., & D'Esposito, M. (2008). Age-related top-down suppression deficit in the early stages of cortical visual memory processing. *Proceedings of the National Academy of Sciences*, *105*(35), 13122-13126.

Gazzaley, A., Cooney, J. W., McEvoy, K., Knight, R. T., & D'esposito, M. (2005). Top-down enhancement and suppression of the magnitude and speed of neural activity. *Journal of Cognitive Neuroscience, 17*(3), 507-517.

Gilbert, A. J. (1967). Factors involved in judgments made by the method of constant stimuli. *American Journal of Psychology, 80*, 586-593.

Grühn, D., & Scheibe, S. (2008). Age-related differences in valence and arousal ratings of pictures from the International Affective Picture System (IAPS): Do ratings become more extreme with age?. *Behavior Research Methods, 40*(2), 512-521.

Hajcak, G., Dunning, J. P., & Foti, D. (2009). Motivated and controlled attention to emotion: time-course of the late positive potential. *Clinical Neurophysiology*, *120*(3), 505-510.

Hasher, L., & Zacks, R. T. (1988). Working memory, comprehension, and aging: A review and a new view. *Psychology of Learning and Motivation, 22,* 193-225.

Holmes, A., Kiss, M., & Eimer, M. (2006). Attention modulates the processing of emotional expression triggered by foveal faces. *Neuroscience Letters, 394*(1), 48-52.

Huang, Y. X., & Luo, Y. J. (2006). Temporal course of emotional negativity bias: an ERP study. *Neuroscience Letters, 398*(1-2), 91-96.

Isaacowitz, D. M., Allard, E. S., Murphy, N. A., & Schlangel, M. (2009). The time course of age-related preferences toward positive and negative stimuli. *Journals of Gerontology: Series B, 64*(2), 188-192.

Ito, T. A., Larsen, J. T., Smith, N. K., & Cacioppo, J. T. (1998). Negative information weighs more heavily on the brain: the negativity bias in evaluative categorizations. *Journal of Personality and Social Psychology, 75*(4), 887.

Kisley, M. A., Wood, S., & Burrows, C. L. (2007). Looking at the sunny side of life: Age-related change in an event-related potential measure of the negativity bias. *Psychological Science, 18*(9), 838-843.

Kurdi, B., Lozano, S., & Banaji, M. R. (2017). Introducing the open affective standardized image set (OASIS). *Behavior Research Methods, 49*(2), 457-470.

Lang, P. J., Bradley, M. M., & Cuthbert, B. N. (1999). International affective picture system (IAPS): Technical manual and affective ratings. *Gainesville, FL: The Center for Research in Psychophysiology, University of Florida.*

Lavie, N. (1995). Perceptual load as a necessary condition for selective attention. *Journal of Experimental Psychology: Human Perception and Performance, 21*(3), 451.

Lopez-Calderon, J., & Luck, S. J. (2014). ERPLAB: an open-source toolbox for the analysis of event-related potentials. *Frontiers in Human Neuroscience, 8,* 213.

Lustig, C., Hasher, L., & Zacks, R. T. (2007). Inhibitory deficit theory: Recent developments in a “new view”. *Inhibition in Cognition, 17,* 145-162.

Marchewka, A., Żurawski, Ł., Jednoróg, K., & Grabowska, A. (2014). The Nencki Affective Picture System (NAPS): Introduction to a novel, standardized, wide-range, high-quality, realistic picture database. *Behavior Research Methods, 46*(2), 596-610.

Mather, M., & Knight, M. (2005). Goal-directed memory: the role of cognitive control in older

Mathieu, N. G., Gentaz, E., Harquel, S., Vercueil, L., Chauvin, A., Bonnet, S., & Campagne, A. (2014). Brain processing of emotional scenes in aging: effect of arousal and affective context. *PloS ONE, 9*(6), e99523.

Murphy, N. A., & Isaacowitz, D. M. (2008). Preferences for emotional information in older and younger adults: a meta-analysis of memory and attention tasks. *Psychology and Aging, 23*(2), 263.

Newsome, R. N., Dulas, M. R., & Duarte, A. (2012). The effects of aging on emotion-induced modulations of source retrieval ERPs: Evidence for valence biases. *Neuropsychologia, 50*(14), 3370-3384.

Norberg, J., Peira, N., & Wiens, S. (2010). Never mind the spider: late positive potentials to phobic threat at fixation are unaffected by perceptual load. *Psychophysiology, 47*(6), 1151-1158.

Nuwer, M. R., Comi, G., Emerson, R., Fuglsang-Frederiksen, A., Guérit, J. M., Hinrichs, H., ... & Rappelsburger, P. (1998). IFCN standards for digital recording of clinical EEG. *Clinical Neurophysiology, 106*(3), 259-261.

Olofsson, J. K., & Polich, J. (2007). Affective visual event-related potentials: arousal, repetition, and time-on-task. *Biological Psychology, 75*(1), 101-108.

Padmala, S., & Pessoa, L. (2014). Motivation versus aversive processing during perception. *Emotion, 14*(3), 450.

Pelli, D. G. (1997). The VideoToolbox software for visual psychophysics: Transforming numbers into movies. *Spatial Vision, 10*(4), 437-442.

Pessoa, L., Kastner, S., & Ungerleider, L. G. (2002). Attentional control of the processing of neutral and emotional stimuli. *Cognitive Brain Research, 15*(1), 31-45.

Pollatos, O., Kirsch, W., & Schandry, R. (2005). On the relationship between interoceptive awareness, emotional experience, and brain processes. *Cognitive Brain Research, 25*(3), 948-962.

Poulton, E. C. (1973). Unwanted range effects from using within-subject experimental designs. *Psychological Bulletin, 80*(2), 113.

Pourtois, G., Schettino, A., & Vuilleumier, P. (2013). Brain mechanisms for emotional influences on perception and attention: what is magic and what is not. *Biological Psychology, 92*(3), 492-512.

Reed, A. E., Chan, L., & Mikels, J. A. (2014). Meta-analysis of the age-related positivity effect: age differences in preferences for positive over negative information. *Psychology and Aging, 29*(1), 1.

Rozin, P., & Royzman, E. B. (2001). Negativity bias, negativity dominance, and contagion. *Personality and Social Psychology Review, 5*(4), 296-320.

Sabatinelli, D., Keil, A., Frank, D. W., & Lang, P. J. (2013). Emotional perception: correspondence of early and late event-related potentials with cortical and subcortical functional MRI. *Biological Psychology, 92*(3), 513-519.

Sand, A., & Wiens, S. (2011). Processing of unattended, simple negative pictures resists perceptual load. *Neuroreport, 22*(7), 348-352.

Schupp, H. T., Cuthbert, B. N., Bradley, M. M., Cacioppo, J. T., Ito, T., & Lang, P. J. (2000). Affective picture processing: the late positive potential is modulated by motivational relevance. *Psychophysiology, 37*(2), 257-261.

Schupp, H. T., Flaisch, T., Stockburger, J., & Junghöfer, M. (2006). Emotion and attention: event-related brain potential studies. *Progress in Brain Research, 156,* 31-51.

Schupp, H. T., Junghöfer, M., Weike, A. I., & Hamm, A. O. (2003). Attention and emotion: an ERP analysis of facilitated emotional stimulus processing. *Neuroreport, 14*(8), 1107-1110.

Schupp, H. T., Junghöfer, M., Weike, A. I., & Hamm, A. O. (2004). The selective processing of briefly presented affective pictures: an ERP analysis. *Psychophysiology, 41*(3), 441-449.

Schupp, H. T., Stockburger, J., Bublatzky, F., Junghöfer, M., Weike, A. I., & Hamm, A. O. (2007a). Explicit attention interferes with selective emotion processing in human extrastriate cortex. *Bmc Neuroscience, 8*(1), 1.

Schupp, H. T., Stockburger, J., Codispoti, M., Junghöfer, M., Weike, A. I., & Hamm, A. O. (2006). Stimulus novelty and emotion perception: the near absence of habituation in the visual cortex. *Neuroreport, 17*(4), 365-369.

Shipley WC. *Institute of Living Scale.* Los Angeles: Western Psychological Services; 1946.

Verhaeghen, P., Geigerman, S., & Yang, H. (2016, April). *The old and the young remember equally well: An effect of calibrating resolution of memoranda to individuals' change detection thresholds.* Paper presented at the 16th Cognitive Aging Conference, Atlanta, GA.

Watson, A. B., & Pelli, D. G. (1983). QUEST: A Bayesian adaptive psychometric method. *Perception & Psychophysics, 33*(2), 113-120.

Weinberg, A., & Hajcak, G. (2010). Beyond good and evil: The time-course of neural activity elicited by specific picture content. *Emotion, 10*(6), 767.

Weinberg, A., & Hajcak, G. (2011). The late positive potential predicts subsequent interference with target processing. *Journal of Cognitive Neuroscience, 23*(10), 2994-3007.

Wiens, S., Molapour, T., Overfeld, J., & Sand, A. (2012). High negative valence does not protect emotional event-related potentials from spatial inattention and perceptual load. *Cognitive, Affective, & Behavioral Neuroscience*, *12*(1), 151-160.

Wiens, S., Sand, A., & Olofsson, J. K. (2011b). Nonemotional features suppress early and enhance late emotional electrocortical responses to negative pictures. *Biological Psychology, 86*(1), 83-89.

Wiens, S., Sand, A., Norberg, J., & Andersson, P. (2011a). Emotional event-related potentials are reduced if negative pictures presented at fixation are unattended. *Neuroscience Letters, 495*(3), 178-182.

Wiens, S., & Syrjänen, E. (2013). Directed attention reduces processing of emotional distracters irrespective of valence and arousal level. *Biological Psychology, 94*(1), 44-54.

Wieser, M. J., Mühlberger, A., Kenntner-Mabiala, R., & Pauli, P. (2006). Is emotion processing affected by advancing age? An event-related brain potential study. *Brain Research, 1096*(1), 138-147.

Wood, S., & Kisley, M. A. (2006). The negativity bias is eliminated in older adults: Age-related reduction in event-related brain potentials associated with evaluative categorization. *Psychology and Aging, 21*(4), 815.