The effects of emotion on executive functions in ageing

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The effects of emotion on executive functions in ageing

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Declaration

I confirm that the work presented in this dissertation is my own. Where information has been derived from other sources, I confirm that this has been indicated in the work.

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Abstract

Executive functions are control mechanisms that allow us to direct thoughts and behaviour according to goals and play an important role in everyday life. Research suggests that emotion can affect these functions, but it is less clear how the emotion-cognition interactions change with age, as ageing is associated with changes in both emotional and cognitive functioning. The aim of the present research was to investigate the effects of emotion on younger and older adults' performance in tasks targeting three executive functions: updating, inhibition and task switching. It was also investigated whether emotional valence, the task relevance of emotion and the modality of emotional items (e.g., verbal or facial material) played a role in the modulating effect of emotion on cognition. Across nine behavioural experiments, the following main results were observed. First, it was found that age modulated the effects of emotional valence on executive functions. More specifically, positive emotion improved cognitive performance in both age groups, whereas the mixed but predominantly impairing effects of negative emotion were more pronounced in older adults. Second, emotion affected executive functions when it was task-relevant and older adults were not more affected by task-irrelevant emotional material than younger adults. Third, effects observed for emotional faces could not be replicated with emotional words and the effects of emotion varied for different executive functions, suggesting that the effects of emotion are modality- and task-specific. This dissertation highlights that theories aimed at explaining the effects of emotion on executive functions need to be extended to accommodate age-related differences in this interaction. A better understanding of the

facilitating and impairing effects of emotion on executive functions in ageing is important, as it can help identifying areas in which emotion buffers age-related cognitive decline.

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Chapter 1: Introduction

1.1. Cognition and emotion: Divergent trajectories in life-span development

Old age is often believed to be associated with cognitive, physical and health-related decline (Gluth, Ebner, & Schmiedek, 2010; Hummert, Garstka, Shaner, & Strahm, 1994; Scheibe & Carstensen, 2010b; J. Smith & Baltes, 1997). Studies that have investigated differences in the attitudes towards younger and older adults have shown that older adults were often described as less hopeful, more resigned and less optimistic than younger adults (Gluth et al., 2010). Studies from the domain of cognitive ageing seem to support the bleak picture many people have of old age, as they have documented age-related decline in cognitive functions such as speed of processing, working memory (henceforth WM) and episodic memory (e.g., Birren & Fisher, 1995; Buckner, 2004; Park et al., 2002; Salthouse, 1991, 2004; Salthouse, Atkinson, & Berish, 2003). A large body of research has also focused on changes in neurocognitive networks that are associated with age-related brain changes such as atrophy in grey and white matter, synaptic degeneration or blood flow reductions. Theories such as the Hemispheric Asymmetry Reduction in Old Adults (HAROLD; Cabeza, Anderson, Locantore, & McIntosh, 2002), the posterior-anterior shift in ageing (PASA; Davis, Dennis, Daselaar, Fleck, & Cabeza, 2008) or the Compensation-Related Utilization of Neural Circuits Hypothesis (CRUNCH; Cappell, Gmeindl, & Reuter-Lorenz, 2010; Reuter-Lorenz & Cappell, 2008b) represent compensation theories of age-related cognitive decline.

Research from the domain of emotional ageing, on the other hand, provides a picture of age-related changes that is far more positive and which is not in accordance with the negative stereotypes of the hopeless, depressed older person. It was shown that ageing is associated with preserved or even improved emotional functioning in ageing. For instance, evidence suggests that emotional well-being increases with age (Barrick, Hutchinson, & Deckers, 1989; Charles, Reynolds, & Gatz, 2001; Gross et al., 1997), that we become better at regulating our emotions as we age (Blanchard-Fields, 2007; Blanchard-Fields, Mienaltowski, & Seay, 2007) and that emotion regulation strategies that are costly for younger adults are not so costly for older adults (Scheibe & Blanchard-Fields, 2009).

Thus, two largely independent lines of research have shown opposing developmental trends: an age-related decline in cognitive performance on the one hand and preserved or even improved emotional functioning in ageing on the other hand. As a large body of research suggests that emotion and cognition interact, either through our ability to exert control over emotions (Gross, 2002; Ochsner & Gross, 2005; Ochsner et al., 2004; Richards & Gross, 1999; Richards & Gross, 2000) or through the effects that emotion might have on cognitive processes such as attention and episodic memory (Dolcos, Iordan, & Dolcos, 2011; Dolcos, Wang, & Mather, 2014; Eysenck, Derakshan, Santos, & Calvo, 2007; Gray, 2001; Patterson et al., 2016; Pessoa, 2009; Pessoa, Padmala, Kenzer, & Bauer, 2012; Van Dillen, Heslenfeld, & Koole, 2009; Vuilleumier & Huang, 2009), one intriguing topic for investigation is how these cognition-emotion interactions change in ageing. Given the contrasting trajectories of cognitive and emotional functioning, research on cognition-emotion interactions in ageing could serve an important purpose by helping to identify areas in which preserved emotional functioning can cushion age-related cognitive decline.

Age-related changes in emotion-cognition interactions have been investigated extensively in the domain of attention (e.g., Allard & Isaacowitz, 2008; Isaacowitz, Toner, & Neupert, 2009; Isaacowitz, Wadlinger, Goren, & Wilson, 2006a; Mather & Carstensen, 2005; for a review, see Murphy & Isaacowitz, 2008; Rösler et al., 2005; Samanez-Larkin, Robertson, Mikels, Carstensen, & Gotlib, 2009) and episodic memory (for comprehensive reviews, see Kensinger, 2009a; Mather, 2004; Mather & Carstensen, 2005; Murphy & Isaacowitz, 2008). In contrast, there are only a limited number of studies that have focused on age-related changes in cognition-emotion interactions in the domain of WM in general and in executive functioning in particular.

Executive functions are a set of control mechanisms that allow us to direct thoughts and behaviours according to internally represented goals (Braver, 2012; Miller & Cohen, 2001). As will be discussed in more detail in Chapter 2.1, executive functions are believed to play an important role in regulating both cognitive processes, including higher-order cognitive functions such as episodic memory, and behaviour (Braver, 2012; Friedman & Miyake, 2004; Miller & Cohen, 2001; Miyake & Friedman, 2012; Miyake et al., 2000). Given the importance of executive functions for everyday functioning, it is surprising that the effects of emotion and aging on these control mechanisms have received little attention so far. The aim of this research is to close this empirical gap by focusing on the intersection between executive functions, emotion and ageing.

1.2. The scope and focus of the present research

This thesis follows a triangular structure, with age, cognition and emotion forming the field of research (see Figure 1.1). To study a particular facet of this vast field, several restrictions were chosen for the present research: In line with conventions in research on ageing, old age was defined as corresponding with retirement age beginning at 60 to 65 years of age (cf., L. H. Phillips & Henry, 2008). Focus was placed on healthy ageing in the absence of identifiable brain diseases such as dementia, as evidence suggests that these are associated with their own, profound changes in how emotion and cognition interact. Also, an investigation across the entire adult life span including middle age (40 to 60 years of age) and very old age (from 80 years of age) would be desirable to understand whether age-related changes follow a linear, quadratic even a more complex trend over the life span. However, due to constraints in time and resources and also in accordance with conventions in research on cognitive ageing, the studies presented here focused on the comparison between younger adults from 18 to 40 years of age and older adults from 60 to 80 years of age.

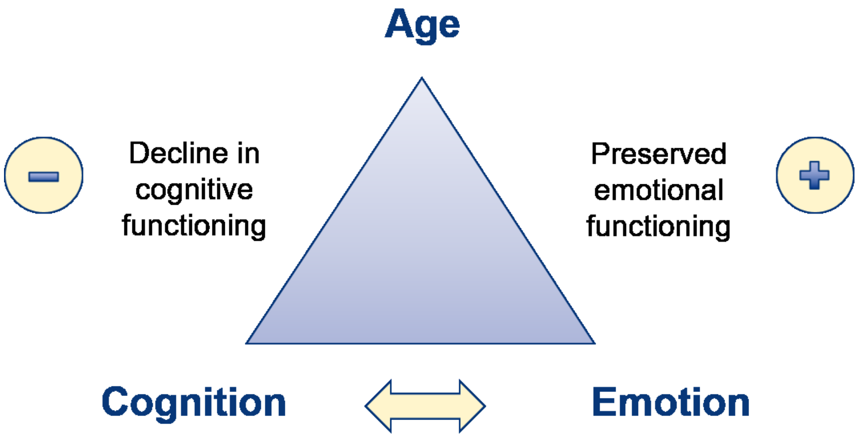

Figure 1.1. Triangular structure in the investigation of cognitive-emotion interactions in ageing.

Besides a narrow focus on two age groups, other limitations in scope were chosen in relation to which executive functions were selected for investigation and how emotion was operationalised in the present research. As will be discussed in more detail in Chapter 2.1, several models and theoretical frameworks have been proposed to explain what executive functions are. It is beyond the focus of the present research to assess the validity of these different models. Instead, Miyake et al.'s model of executive functions (Miyake & Friedman, 2012; Miyake et al., 2000) was selected as the basis for the present research. Lastly, in contrast to studies investigating the effects of mood or psychiatric disorders such as depression on cognition, the present research focused on transient emotional states as elicited by external stimuli such as pictures, faces or words.

Following the definition suggested by Ochsner and Gross (2005), emotion was defined as a valenced response to external stimuli that is associated with changes across different response systems (e.g., experiential, physiological). This response can also involve multiple types of appraisal processes (e.g., the significance of a stimulus for a particular goal). Following a widely used framework for the description of emotional experiences, the present research distinguished between the dimensions of valence, which describes how pleasant or unpleasant an emotion is, and arousal, which refers to the intensity of the emotion ranging from calm/placated to excited/agitated (Lang, Greenwald, Bradley, & Hamm, 1993; Reisenzein, 1994; Russell, 2003; Russell & Barrett, 1999).

There were a number of challenges associated with the study of how emotion affected executive functions in older as compared to younger adults. One of the most challenging issues was that many theoretical frameworks only focused on one of the relevant factors or described the interaction between two of them, such as theories of cognitive ageing or those explaining how emotion and cognition might interact. In contrast, theories covering all three factors, namely ageing, emotion and executive functions in particular, were not available, and thus, it was more difficult to make strong predictions for the present research.

A second issue was that the majority of data sets that have been developed to match stimuli such as pictures, faces or words on a number of variables (e.g., verbal frequency, valence, arousal etc.) were only evaluated by younger adults. For instance, the Affective Norms for English Words data base (ANEW; Bradley & Lang, 1999), provides a set of normative emotional ratings for a large number of words in the English language but these ratings were obtained from undergraduate students only. Research has shown that ratings for emotional stimuli may vary in different age groups (e.g., Grühn & Scheibe, 2008) and thus, it is not clear whether older adults would perceive them the same way as younger adults. Other stimulus sets such as the FACES database (Ebner, Riediger, & Lindenberger, 2010), which comprises naturalistic faces of different age groups showing a wide range of emotional expressions, were evaluated by different age groups. However, only collated evaluation data were published (i.e., ratings across stimulus sets and across participants). Based on these data, it was impossible to determine whether each individual stimulus had been rated in a similar way by younger and older adults. To overcome this issue, pilot studies had to be conducted asking younger and older adults to rate emotional stimuli from widely used data sets before stimuli, which have received similar ratings from both age groups, could be used in the main experiments.

Another challenging issue was the complexity of the experimental designs. Without any further manipulation of the factors age, cognition and emotion, the basic experimental design already comprised three factors. With further manipulations, for instance by manipulating the relevance of emotion for the task at hand or by varying WM load, the factor count increased rapidly even further. To detect any meaningful effects with such complex experimental design, it was necessary to recruit a relatively large number of participants and to be prepared to work through large and complex data sets.

Lastly, when comparing performance of younger and older adults it was necessary to decide whether to introduce any age-related adjustments to task difficulty. Age-related adjustments are often introduced to avoid ceiling or floor effects in each age group's task performance. In memory studies, for instance, the retention time between encoding and the memory test is often shorter for older compared to younger adults (e.g., Gallo, Foster, & Johnson, 2009; Kensinger, O'Brien, Swanberg, Garoff-Eaton, & Schacter, 2007) to keep the task manageable for both age groups. However, an important advantage of keeping the procedure constant for both age groups is that it allows a straightforward comparison of younger and older adults' performance. With age-related adjustments, any differences in performance would need to be closely examined to ensure that they were not simply due to changes to the procedure.

It has also been suggested that differences in younger and older adults' reaction times (henceforth RTs) need to be interpreted with caution. Researchers pointed out that older adults tend to be slower compared with younger adults (Salthouse, 1996, 2000), which can exacerbate age-related differences in RT measures of cognitive performance (e.g., Verhaeghen & Basak, 2005; Verhaeghen & De Meersman, 1998b). However, there is no agreement about how to restrict the effect of general slowing on RT measures in the best way. Whereas some researchers favoured transformations of RT data, others suggested that more sophisticated, multi-layered approaches might be needed instead (Verhaeghen & De Meersman, 1998b). There is also an ongoing debate about the use of alternative ways of modelling or representing RT data in ageing research, including Brinley plots (Verhaeghen & Cerella, 2008), as researchers disagree about how these can actually be interpreted (Myerson, Adams, Hale, & Jenkins, 2003; Ratcliff, Spieler, & Mckoon, 2000, 2004). It appears that every alternative way of transforming or presenting RT data in ageing research is associated with their own benefits and disadvantages. Thus, a transformation of RTs was only applied in the present research when age-related differences in RTs were so pronounced that the assumption of the data's homoscedasticity was violated. Raw RT scores were used in all other cases.

1.3. Chapter overview

Following Miyake et al.'s (Miyake & Friedman, 2012; Miyake et al., 2000) model of executive functions, this thesis will focus on three executive functions, namely, updating, inhibition and task switching. It will also explore how emotion and age affect these important control functions. These functions will be covered in three separate chapters and the overall structure of the present thesis will be as follows.

In Chapter 2, an overview of the present research's theoretical background will be given. After discussing what executive functions are and how they are conceptualised in the chosen model, the chapter will follow the triangular structure outlined in Figure 1.1 above. First, previous studies examining interactions between executive functions and emotion will be presented, covering the cognition-emotion axis of the triangle. Second, it will be discussed how executive functions are affected by ageing, covering the cognition-age axis of the triangle. Here, after an overview of theories that were proposed to explain age-related changes in executive functions, previous studies examining inhibition, updating and task switching in ageing will be presented. The final part of the chapter will cover the age-emotion axis of the triangle and will focus on age-related changes in emotional functioning. Theories explaining age-related changes in emotional functioning and how these changes might affect emotion-cognition interactions in ageing will be presented. The chapter will finish with an overview of previous studies that have assessed the effects of age and emotion on WM performance.

Chapters 3, 4 and 5 will present experiments that were conducted to assess the effects of emotion on updating, inhibition, and task switching, respectively. Each of the chapters will start with a detailed presentation of the relevant task and describe how previous research has used it in ageing research and in the investigation of emotion-cognition interactions.

Chapter 3 will be dedicated to the investigation of updating of emotional information in younger and older adults using an n-back paradigm. Experiment 3.1 was designed to assess the role of task-relevant and task-irrelevant emotional material on updating in two age groups. In this experiment, focus was placed on the effect of currently presented emotional and neutral probes. Based on the results obtained in Experiment 3.1, Experiment 3.2 was designed as a follow up to further investigate the role of emotional vs. neutral lures (i.e., previously presented items) on updating in younger and older adults. A final updating experiment, Experiment 3.3, explored whether the results obtained for emotional faces in Experiment 3.1 could be replicated with emotional words (tested in younger adults only).

Chapter 4 will focus on a set of Stroop experiments. In Experiment 4.1, only emotionally neutral material was used, while the remaining three experiments used emotional Stroop stimuli. In these experiments, it was investigated whether emotional targets could facilitate or impair the ability to exert proactive control in the presence of task-irrelevant information. It was also explored whether the effects of emotional targets on Stroop performance varied across different modalities. To assess this topic, faces were used in Experiment 4.2 and words in Experiment 4.4. Lastly, Experiment 4.3 also investigated whether the timing of distractor presentation mattered for the ability to exert cognitive control (tested in younger adults only).

In the final empirical chapter, Chapter 5, two task switching experiments will be presented. Experiment 5.1 was conducted to assess the ability to flexibly switch between an emotional and a non-emotional task set in younger and older adults. Experiment 5.2 was designed to follow up on the results by asking participants to switch between two non-emotional task sets in the presence of task-irrelevant emotional material.

The results from all experiments will be summarised, synthesised and discussed in Chapter 6 and implications for theoretical models of cognition-emotion interactions will be considered. It is hoped that the conclusions drawn from the present research will contribute to the understanding of enhancing and impairing effects of emotion on cognitive performance in ageing. Given the two contrasting trajectories of cognitive and emotional development in ageing, this research can help answer the question whether preserved emotional functioning can help in buffering age-related cognitive decline.

Chapter 2: Theoretical background

2.1. What are executive functions?

Executive functions are a set of control mechanisms that allow us to direct thoughts and behaviours according to internally represented goals (Braver, 2012; Miller & Cohen, 2001). They are believed to comprise a heterogeneous collection of skills, including the sequencing of behaviour, the inhibition of routine behaviour or of distractors and the ability to switch between tasks. The functions that fall within the umbrella term of executive functions are wide-ranging and there is no consensus which functions constitute the basic components.

Accordingly, different models have been suggested in an effort to integrate the variety of executive functions, including the central executive in Baddeley and Hitch's (1974) multi-component WM model or the Supervisory Attentional System (SAS) in the attentional control model by Norman and Shallice (1986). One common aspect of all theories of executive functions is that they link these functions with the prefrontal cortex of the brain, as evidence suggests that patients with damage to the frontal lobe exhibit difficulties in self-regulation and control of their behaviour (see Jorado & Roselli, 2007). In Baddeley and Hitch's (1974) WM model, the central executive is assisted by temporary storage systems, which are the phonological loop, the visuospatial sketchpad and – as a later addition to the original model – the episodic buffer (Baddeley, 2000, 2003).

One important research question in the field of executive functions is whether executive functions are distinct and separable skills or whether they reflect one common, underlying mechanism. For instance, Duncan and colleagues suggested that control functions of the frontal lobe are closely interlinked with Spearman's (1927) *g* and reported that performance in tests of executive functions in patients with damage to the frontal lobe was closely linked to measures of general intelligence (Duncan, Emslie, Williams, Johnson, & Freer, 1996; Duncan, Johnson, Swales, & Freer, 1997). Similarly, others found no evidence for distinct executive functions as most of the measures hypothesised to represent separate functions were related to one another (Brydges, Reid, Fox, & Anderson, 2012; McCabe, Roediger, McDaniel, Balota, & Hambrick, 2010; Salthouse et al., 2003; Salthouse & Davis, 2006). There is also evidence to suggest that different functions share resources, which supports the view that they are part of one mechanism (Duncan et al., 1996; Miyake et al., 2000; Pessoa, 2009).

Originally, the central executive in Baddeley and Hitch's (1974) WM model was conceptualised without specifying any distinct components or functions. However, it was later clarified that it was indeed compatible with the existence of sub-functions (Baddeley, 1998) and suggestions were made how to fractionate it (Baddeley, 2002). Evidence for the dissociation of executive functions comes from studies using factor analysis to explore their structure, from neuroimaging studies and from developmental research. For instance, studies using factor analysis showed that performance on measures of executive functions in a variety of populations including neurological patients and children loaded on different factors (Burgess, Alderman, Evans, Emslie, & Wilson, 1998; J. E. Fisk & Sharp, 2004; Robbins et al., 1998; St Clair-Thompson & Gathercole, 2006; Testa, Bennett, & Ponsford, 2012). Although many of these studies proposed different underlying factors (both in number and in their exact nature), their results were taken as evidence for the diversity of executive functions. Moreover, neuroimaging studies showed that despite involvement of common areas, performance on different measures of executive functions were associated with activity in distinct cortical systems (Collette et al., 2005; Garavan, Ross, Murphy, Roche, & Stein, 2002; Sylvester et al., 2003). Lastly, as will be discussed in detail further below (see Chapter 2.3), studies testing cognitive control in older adults also showed that not all frequently postulated control processes were affected by ageing in the exact same way.

Although the exact fractionation of the central executive still remains subject of debate, Miyake, Friedman and colleagues (Friedman & Miyake, 2004; Friedman et al., 2006; Miyake & Friedman, 2012; Miyake et al., 2000) suggested that there are three at least partially separable executive functions. In order to assess their structure, the authors used a latent variable approach, which allowed them to extract what is common across exemplar tasks targeting one particular executive function and to use the resulting latent variable as a measure of a particular function (Miyake & Friedman, 2012; Miyake et al., 2000). This approach was used to mitigate the problem that executive functions are difficult to measure in isolation, which is commonly labelled as the task impurity problem in the study of executive functions (Burgess, 1997; Chaytor, Schmitter-Edgecombe, & Burr, 2006; Jurado & Rosselli, 2007; Miyake & Friedman, 2012; Miyake et al., 2000; L. H. Phillips, 1997). Miyake et al. argued that the use of latent rather than manifest variables could help to get a cleaner measure of executive functions (Miyake & Friedman, 2012; Miyake et al., 2000). Their research has primarily focused on three executive functions, namely updating, inhibition and shifting (or task switching). These constructs will be explained in more detail below, as they form the basis of the research reported in this dissertation.

Separable executive functions according to Miyake et al.'s model

Miyake et al. (2000) originally conducted an individual differences study of the often postulated executive functions updating, inhibition and switching, and included three specific tasks to measure each of these functions. By running a confirmatory factor analysis on the resulting data, they extracted what was common among these three tasks per executive function and confirmed that a full three-factor model (with a separable factor per executive function) rather than one with fewer factors fitted the data best. They also investigated how each of the functions contributed to the performance of more complex executive functions tasks such as the Wisconsin Card Sorting Test (Heaton, 1981) through structural equation modelling.

These analyses revealed that each of the three executive functions contributed in a unique way to the more complex tasks, which was taken as evidence that all three executive functions could be treated as separable and distinct. However, the authors also highlighted that the three executive functions were not fully independent as evidenced by moderate to high correlations between them. Overall, these results were interpreted as evidence that the three commonly postulated executive functions updating, inhibition and shifting shared some commonality despite their separable nature, a pattern that was labelled the "unity and diversity" of executive functions (Miyake et al., 2000, p. 87). Whereas the ability to maintain goals and goal-related information was seen as the unifying, common ability needed for all three executive functions (Miyake & Friedman, 2012; Miyake et al., 2000), the three executive functions that were considered to be separable in Miyake et al.'s original model are described in more detail below:

Updating. Updating refers to the ability to monitor representations that are temporarily held in WM and to replace them with new ones if needed. In order to test this ability, Miyake et al. (2000) used the keep track task (Yntema, 1963), the letter memory task

(Morris & Jones, 1990) and the tone monitoring task (modified from the Mental Counters task developed by Larson, Merritt, & Williams, 1988). Another popular task that was used in previous research to assess updating performance is the n-back paradigm, which will be explained in more detail in Chapter 3.1.

One important feature of updating is that it goes beyond the passive maintenance of information in WM and requires the active manipulation of task-relevant information (Miyake et al., 2000; Szmalec, Verbruggen, Vandierendonck, & Kemps, 2011). Building on a concept of a region of direct access in WM (Cowan, 1988, 1999; Oberauer, 2009), where items (e.g., pictures, letters or words) and their context (e.g., position on the screen or the serial position) are temporarily linked, it was suggested that updating enables the flexible binding and unbinding of items and context in this region (Oberauer, 2009; Szmalec et al., 2011). For instance, in the letter memory task, a list of letters is presented serially and participants have to recall the last three (or any other number of) letters of the list. From the fourth letter on, participants have to constantly drop a letter from the previously memorised set, add the new letter and rehearse a new set of three items. Thus, participants have to find a balance between binding items and their context (as they have to recall the current set of three letters) and unbinding them (as they have to replace out-dated letters with new ones). Continuous updating is in turn believed to prevent the establishment of strong bonds between items and context to facilitate flexibility (Szmalec et al., 2011).

Inhibition. Miyake and colleagues originally defined inhibition as the ability to override a dominant or automatic response (2000) and used the Stroop task (MacLeod, 1991; Stroop, 1935), the anti-saccade task (Hallett, 1978) and the stop-signal task (Logan, 1994) to assess it. It should be noted that other definitions of inhibition were suggested and that the concept covers a variety of abilities (Aron, 2007; Harnishfeger, 1995; Kok, 1999; MacLeod, 2007). For instance, researchers suggested that inhibition relates to the ability to resist interference from irrelevant or no longer relevant information (Borella, Carretti, & De Beni, 2008; Harnishfeger & Bjorklund, 1993; Hasher & Zacks, 1988; Zacks & Hasher, 1994), an extension to the concept that was later also adopted by Friedman and Miyake (Friedman & Miyake, 2004).

As reviewed by Aron (2007), types of deliberate inhibition that have been suggested in psychological research included the abilities to override motor responses, to ignore distractors, to suppress emotions or to inhibit items in memory. This has prompted researchers to conclude that the notion of inhibition has been overextended (Aron, 2007; Friedman & Miyake, 2004). By placing stronger focus on what executive functions shared, Miyake and Friedman (2012) later dropped inhibition from their unity/diversity framework of executive functions as the inhibition factor was found to strongly correlate with what executive functions shared. Despite this, inhibition was included in the present research due to a strong interest in inhibition in the ageing literature (e.g., Bialystok, Craik, Klein, & Viswanathan, 2004; Borella et al., 2008; Braver et al., 2001; Dempster, 1992; J. E. Fisk & Sharp, 2004; Kleerekooper et al., 2016; Kramer, Humphrey, Larish, & Logan, 1994; L. H. Phillips & Henry, 2008), which is even reflected in a dedicated inhibition-related theory of ageing (Hasher, Stoltzfus, Zacks, & Rypma, 1991; Hasher, Zacks, & May, 1999).

Task switching. The third executive function that Miyake and colleagues (2000) focused on was shifting between different tasks or mental sets, which is also referred to as task switching (Monsell, 2003). In order to investigate task switching in laboratory settings, participants are often required to switch between two or more simple tasks that can be performed on the same set of stimuli. Usually, each of the tasks requires attention and response to a particular element or attribute of the stimuli. For instance, participants could be presented with pairs of letters and digits and in one task, they have to respond to the letter in the pair (e.g., by indicating whether it is a consonant or a vowel), whereas in the other task, they have to respond to the digit in the pair (e.g., by indicating whether it is odd or even). The requirements of each task (i.e., attending to and responding to the letter or attending to and responding to the digit) are acquired through instruction and stored in memory as task sets.

As reviewed by Monsell (2003), there are different ways of initiating switching in task switching paradigms. For instance, different background colours can be used as cues to indicate which task to perform (e.g., red background colour requires response to letters, whereas blue background colour requires response to digits). Moreover, task switching can be cued in an unpredictable way (e.g., participants do not know which colour will be presented in the next trial) or in a predictable way (e.g., background colour changes every two trials). Thus, task switching is believed to happen through an interplay of both internal goals (endogenous control) and external cues (exogenous influences) as reviewed by Monsell (2003). In order to assess switching, Miyake et al. (2000) asked participants to perform the plus-minus task (Jersild, 1927), the number-letter task (Rogers & Monsell, 1995) and the local-global task (Navon, 1977).

2.2. Interactions between executive functions and emotion

In everyday life, information is often emotional and how control can be exerted over emotion and emotional representations has been identified as an important topic in the study of emotional functioning. For instance, evidence suggests that updating emotional information in WM is linked to the efficacy of emotion regulation (Levens & Gotlib, 2010; Pe, Koval, & Kuppens, 2013; Pe, Raes, & Kuppens, 2013). It was also shown that impairments in the interaction between emotion and control processes are associated with psychological disorders such as depression or anxiety (Banich, 2009; Bishop, 2007; Bridgett, Oddi, Laake, Murdock, & Bachmann, 2013; Eysenck et al., 2007).

Although emotion was not included in the original WM model by Baddeley and Hitch (1974), Baddeley (2003) later acknowledged the important role that emotion and motivation play in the control of WM. It was also suggested that a hedonic detection system existed, which was believed to help assessing stimuli and choosing appropriate actions depending on their hedonic value (Baddeley, 2007; Baddeley, Banse, Huang, & Page, 2012). The concept of the hedonic detector built on the somatic marker hypothesis (Damasio, Everitt, & Bishop, 1996), which assumed that positive and negative cues from the environment were used to guide behaviour. Baddeley et al. (2012) suggested that the hedonic detector was needed to judge hedonic information and to select appropriate actions. To be able to serve this function, it was suggested that the detector had a storage system and that it had to rely on the central executive. Despite highlighting this link, it was not specified how the hedonic detector could be integrated in the WM model. In the following, a review of approaches linking emotion and control processes will be presented, focussing on – unless stated otherwise – phasic emotion as elicited by emotional stimuli.

The topic of how emotion affects control processes is particularly intriguing as it relates to an interaction between processes that are believed to be automatic and those believed to be controlled. Emotional information is prioritised in processing relative to non-emotional material (Bradley, Keil, & Lang, 2012; Pessoa & Ungerleider, 2004a; Phelps & LeDoux, 2005; Phelps, Ling, & Carrasco, 2006; Vuilleumier, 2005; Vuilleumier & Huang, 2009; Whalen, 1998), resulting in better encoding and memory for emotional relative to non-emotional material (Brandt, Sünram-Lea, & Qualtrough, 2006; Dolcos & Denkova, 2015; Dolcos, LaBar, & Cabeza, 2005; Dolcos et al., 2014;

Hamann, 2001). Moreover, enhanced processing was not only found for task-relevant but also for task-irrelevant emotional material, which led researchers to conclude that it is automatic (Öhman, 2002; Pessoa & Ungerleider, 2004a; Vuilleumier, 2005; Vuilleumier, Armony, Driver, & Dolan, 2001; Whalen et al., 1998). In contrast to these automatic processes, executive functions are control processes and are thus, per definition "controlled" (Hofmann, Schmeichel, & Baddeley, 2012; Jurado & Rosselli, 2007; Miyake & Friedman, 2012; Miyake et al., 2000; E. E. Smith & Jonides, 1999). Moreover, damage to brain areas linked to executive functions was found to be associated with impaired self-regulation and behaviour control (see Jorado & Roselli, 2007).

Whereas some aspects of emotion-cognition interactions such as the relevance of cognitive control in emotion regulation (Goldin, McRae, Ramel, & Gross, 2008; Ochsner & Gross, 2005; Ochsner et al., 2004; Richards & Gross, 1999; Richards & Gross, 2000) or the role of emotion for attention have received ample attention (Bradley et al., 2012; Lang, 1995; Lang, Bradley, & Cuthbert, 1990; Pessoa & Ungerleider, 2004b; Vuilleumier et al., 2001; Vuilleumier & Huang, 2009; Vuilleumier & Pourtois, 2007), the effects of emotional stimuli on executive functions have been studied less extensively to this date. In WM studies using emotional material, focus was often placed on tasks requiring participants to maintain information for a short period of time (e.g., in a delayed-response task) without the need to additionally manipulate it (for reviews, see Dolcos & Denkova, 2015; Dolcos et al., 2011; Dolcos & McCarthy, 2006; Dolcos et al., 2014; Iordan, Dolcos, & Dolcos, 2013). Although these studies might help to address questions regarding the effects of emotion on storage systems such as the phonological loop or the visuospatial sketchpad (Baddeley, 1992; Baddeley & Hitch, 1974), they are less suitable to assess how emotion affects executive functions that operate on temporarily stored material.

It has been suggested that emotion can have both enhancing and impairing effects on cognition, which has led researchers to dub it as a “double-edged sword” in relation to cognitive performance (Dolcos et al., 2011, p. 669). One theoretical framework, which was proposed to explain how emotion both facilitated and impaired executive functions, is the dual competition model by Pessoa (2009, 2015, 2017). According to this model, emotion influences both perceptual and executive competition and its effects can be either stimulus- or state-dependent (e.g., dependent on motivation or anxiety). The theory suggests that attention and executive functions share common-pool resources and that the level of threat or arousal as well as the relevance of emotion for the task modulates the effects of emotion on cognitive processes. In the case of low threat or arousal, processing is biased in favour of the emotional stimulus but this does not have an impairing effect on executive functions. In contrast, high threat and arousal are believed to recruit common-pool resources, on which executive functions rely. This in turn has an impairing effect on these executive functions.

Moreover, the dual competition model posits that in tasks requiring executive functions, task-relevant emotion typically improves performance through the recruitment of additional processing resources. In contrast, task-irrelevant emotion is believed to typically impair performance as resources needed for executive functions are detracted. In the case of state-dependent effects of motivation on executive functions, it is believed that motivation helps to sharpen or fine-tune the executive function that is needed for a particular task through efficient orienting of attention (e.g., sharpening updating processes in an n-back task) or by the allocation of more general common-pool resources to it (Pessoa, 2009, 2015, 2017). The theory also suggests that individual differences in state and/or trait anxiety and sensitivity to reward can modulate the impact of emotion on executive functioning. On a neural level, it is believed that the interaction happens as task networks (e.g., attentional network) and "valuation networks" (Pessoa, 2015, p. 10) including both cortical (e.g., orbitofrontal cortex) and subcortical regions (e.g., amygdala, hypothalamus) communicate with each other.

The assessment of interactions between emotion and executive functions

Although both the level of threat or arousal (with the latter explicitly including positive material), and the relevance of emotion for task performance were proposed as two different dimensions in the dual competition theory (Pessoa, 2009, 2015, 2017), research on the effects of emotion on cognitive control has rarely investigated these factors independently from each other. Instead, studies mainly focused on one particular combination, namely on emotional information that is negative and also task-irrelevant (cf. Dolcos & Denkova, 2015; Dolcos et al., 2011; Dolcos & McCarthy, 2006; Dolcos et al., 2014; Iordan et al., 2013). In the following, the issues associated with these and related challenges in the investigation of emotion-cognition interactions are discussed in more detail.

Task-relevant vs. task-irrelevant emotional stimuli. In previous investigations of the effects of emotion on executive functions, task relevance of emotion for the task was often not explicitly considered or only task-irrelevant material was used. For instance, in updating studies with emotional material, it was not always clear to participants whether emotional features of items were relevant or irrelevant for the task. One popular task that was used to assess updating was the n-back paradigm, in which participants were required to make match/non-match decisions. As will be reviewed in Chapter 3.2, a large proportion of studies provided unspecific match/non-match instructions in studies with emotional material by asking participants whether the stimulus was the same or different from the one presented *n* positions earlier (e.g., Döhnel et al., 2008; Kensinger & Corkin, 2003; Kopf, Dresler, Reicherts, Herrmann, & Reif, 2013; Lindström & Bohlin, 2011; L. K. Phillips et al., 2011; Richter et al., 2013; Schoofs, Pabst, Brand, & Wolf, 2013; Weigand et al., 2013). As participants could have based their decision on different features of a stimulus, it was not explicitly clear whether they responded to the emotional features (e.g., emotional expression of a face) or other non-emotional features (e.g., identity of a face). These studies produced an incongruent pattern of results, which might, as will be argued in Chapter 4.2, be due to the fact that the effects of task-relevant and task-irrelevant emotion were intermixed.

In the investigation of the effects of emotion on inhibition, focus was primarily placed on the impairing effects of task-irrelevant emotion. One task that was widely used was an adaptation of the Stroop paradigm (MacLeod, 1991; Stroop, 1935). In this task, negative words (e.g., “death”, “bomb”) and neutral words (e.g., “desk”, “square”) were printed in different colours and participants were asked to name the ink colour while ignoring the word. Generally, participants were found to respond slower to the colour of the emotional relative to neutral words (McKenna & Sharma, 1995; van Hooff, Dietz, Sharma, & Bowman, 2008; Williams, Mathews, & MacLeod, 1996) and this result was usually interpreted as evidence that the affective nature of the emotional words interfered with colour-naming to a greater extent than neutral words by capturing attentional resources. Studies using emotional pictures or faces with colour filters and asking participants to name the colour of the picture or face (Constantine, McNally, & Hornig, 2001; Kindt & Brosschot, 1997) reported similar results.

In contrast, the effects of task-relevant emotion on the ability to inhibit task-irrelevant information have received less attention so far. Given that emotional information is processed in an enhanced manner (Phelps & LeDoux, 2005; Phelps et al., 2006; Vuilleumier, 2005; Vuilleumier & Huang, 2009; Whalen, 1998), the inclusion of emotional targets might help participants to focus on task-relevant and inhibit task-irrelevant information, and thus, might improve cognitive control. In terms of response inhibition, this positive effect of task-relevant emotion was shown in a stop-signal task (Exp. 1, Pessoa et al., 2012), as it was found that fearful and happy stop signals decreased the stop-signal RTs as compared to neutral faces. The authors offered the interpretation that emotional faces generated enhanced sensory representations of the stop stimulus in the visual cortex, which in turn led to overall better stopping performance. However, impairing effects of task-relevant emotion were also found. In a second experiment, Pessoa et al. (Exp. 2, 2012) used high-threatening stimuli (tones paired with a shock), which were task-relevant, and found that they impaired stop performance. The authors interpreted this result as support for the dual competition framework by showing that highly threatening stimuli detracted processing resources that were needed for inhibition. Overall, inhibition studies demonstrated both impairing and enhancing effects of task-relevant emotion. However, focus was primarily placed on the investigation of negative or threatening material on response inhibition or the ability to inhibit task-irrelevant information.

The issue of confounding task-relevant and task-irrelevant emotional material also applies to a number of studies that have investigated the effects of emotion on task switching (Aboulafia-Brakha, Manuel, & Ptak, 2016; de Vries & Geurts, 2012; Gul & Khan, 2014; Johnson, 2009; Paulitzki, Risko, Oakman, & Stolz, 2008; Piguet et al., 2016; Piguet et al., 2013; Reeck & Egner, 2015). A focus of these studies was to assess switching between emotional and non-emotional task sets. However, many of these studies presented emotional stimuli on every trial (Aboulafia-Brakha et al., 2016; Paulitzki et al., 2008; Reeck & Egner, 2015), which means that participants not only had to switch between different task sets but also had to perform tasks in which emotion was either task-relevant or task-irrelevant. As none of these studies addressed this issue (e.g., by comparing switching between two non-emotional tasks sets in the presence of task-irrelevant emotion), task relevance of emotional material was a confounding variable in their analyses, which might explain the mixed pattern of results these studies produced (see Chapter 5).

The effects of valence vs. arousal on cognition. As mentioned above, many studies investigating the effects of emotion on control processes only included negative stimuli, while the effect of positive material remained unstudied (e.g., Kensinger & Corkin, 2003; Lindström & Bohlin, 2012; Ozawa, Matsuda, & Hiraki, 2014; Padmala, Bauer, & Pessoa, 2011; Patterson et al., 2016; Paulitzki et al., 2008). Others included both positive and negative material, but did not compare the effects of emotional to neutral material (e.g., Aboulafia-Brakha et al., 2016; Bertocci et al., 2012; Gul & Khan, 2014; Johnson, 2009; Ladouceur et al., 2009; Mitchell, 2007; Mitchell & Bouças, 2009; Pe, Raes, et al., 2013; Rämä et al., 2001). Although conclusions about the effects of emotion on executive functions were drawn from results of these studies, the former set did not allow researchers to assess whether the observed effects were driven by arousal or by valence. In contrast, the latter set of studies did not allow researchers to test whether the effects were truly due to emotion or due to other stimulus features (e.g., distractive nature of task-irrelevant material). Pessoa (2009) used threat as an example of cognitive-emotional interactions and also included positive material in his model. However, in the dual competition model, arousal is believed to drive the effect of emotion on cognitive control irrespective of valence (Pessoa, 2009; Pessoa et al., 2012).

Whether the effects of emotion on cognitive control are in fact only driven by arousal or valence is subject of debate, as results regarding the effects of valence are mixed. On the one hand, evidence suggests that valence does not play an important role in emotion-cognition interactions. For instance, Lindström and Bohlin (2011) used positive, negative and neutral pictures in a visual 2-back task and found improved accuracy and faster RTs in updating of positive and negative pictures relative to neutral pictures. The authors attributed the facilitating effects of emotional items on updating to the enhanced processing of arousing material. As reported above, there is also evidence that both happy and fearful faces had facilitating effects on response inhibition in a stop-signal task (Pessoa et al., 2012). The authors noted that the effect was more pronounced for fearful than for happy faces, but due to missed significance of the difference between them, they concluded that arousal rather than valence was driving the effect.

On the other hand, there is also evidence that valence does indeed play a role in the effects of emotion on cognitive control. For instance, Levens and Gotlib (2010) asked participants to update the emotional expressions of happy, sad, and neutral faces in an n-back task. Non-depressed participants matched happy faces faster in WM than neutral or sad faces and took longer to disengage (i.e., when giving non-match responses) from happy faces relative to neutral or sad faces. This was interpreted as a bias for happy faces in healthy adults. Similarly, Cromheeke and Mueller (2015) used happy, neutral, and angry faces in a 2-back task and found that updating was fastest for happy faces, whereas there was no difference between angry and neutral faces. Other studies showed impairing effects of task-relevant negative stimuli that were not observed for neutral or positive material. For instance, Kopf et al. (2013) asked participants to perform an n-back task with emotional words and found that more updating errors occurred in the presence of negative relative to positive or neutral items.

In sum, these results suggest that valence can have an effect on cognitive control processes. They also suggest that happy faces facilitate control to a greater extent than negative (e.g., sad or angry) faces. This might be related to findings that happy faces are generally more quickly and accurately recognised than other expressions (Becker, Anderson, Mortensen, Neufeld, & Neel, 2011; Becker & Srinivasan, 2014; Juth, Lundqvist, Karlsson, & Öhman, 2005). As reviewed by Becker and Srinivasan (2014), happy faces are prioritised in attention and memory by the perceiver. The authors argue that happiness is efficiently displayed and decoded as it serves important social goals such as forestalling conflict.

Additionally, the rewarding effect of smiling faces might contribute to improved cognitive performance. Previous research has shown that happy faces were rated as being more attractive (O'Doherty et al., 2003; Otta, Abrosio, & Hoshino, 1996) and more approachable (Tsukiura & Cabeza, 2008) than neutral faces. Moreover, happy faces were found to engage the orbitofrontal cortex, which is associated with reward (O'Doherty et al., 2003; Tsukiura & Cabeza, 2008). According to the dual competition framework, reward modulates cognitive control by fine-tuning executive functions that are needed for the task through efficient orienting of attention (e.g., sharpening updating processes in an n-back task) and by rearranging the allocation of more general common-pool resources (Pessoa, 2009, 2015, 2017). Thus, it is likely that happy faces facilitated performance on a motivational level, contributing to a happy face advantage in cognitive tasks. In contrast, despite the fact that angry faces are often efficiently detected among distractors (Hansen & Hansen, 1988; Öhman, Lundqvist, & Esteves, 2001), they were also found to be more difficult to disengage from once detected, resulting in longer "dwelling" times due to their threatening nature (Fox, Russo, Bowles, & Dutton, 2001). Overall, these results suggest that conclusions about effects of negative material (e.g., angry faces) on cognitive control might not apply to positive items (e.g., happy faces), as they appear to have contrasting effects on cognition.

Faces vs. words. Another aspect that might play an important role in the investigation of cognition-emotion interactions is whether emotional items have similar effects on executive functions across different stimulus types. Specifically, it is not clear whether stimuli that are believed to be "evolutionary prepared" such as emotional faces have similar effects to emotional words on cognition. On the one hand, there is evidence for enhanced processing of a wide range of emotional stimuli, including faces (e.g., Brosch, Sander, Pourtois, & Scherer, 2008; Calvo & Nummenmaa, 2008; Juth et al., 2005), images (e.g., Fox, Griggs, & Mouchlianitis, 2007; Langeslag & Van Strien, 2008; Olofsson, Nordin, Sequeira, & Polich, 2008) and words (e.g., Gotoh, 2008; Hamann & Mao, 2002; Kopf et al., 2013). It has also been shown that pictures of threat-relevant items affected processing irrespective of their appearance in evolutionary history (e.g., guns vs. snakes; Brosch & Sharma, 2005). On the other hand, studies have shown that orienting to affective material is more pronounced for faces than for words (Kensinger & Corkin, 2003; Kensinger & Schacter, 2006; Vuilleumier, 2005). Moreover, it was found that automatically enhanced processing of emotional content did not occur for words whereas it did for faces (Rellecke, Palazova, Sommer, & Schacht, 2011).

These contrasting results for different stimulus types were explained by differences in extracting significance of emotion in words and faces. It was argued that words must be processed to a higher level than faces before their meaning could be assessed (Kensinger & Corkin, 2003) and that their emotional significance needed to be extracted based on semantic knowledge (Rellecke et al., 2011; Schacht & Sommer, 2009). In contrast, it was suggested that the emotional significance of faces could be extracted based on perceptual features (Vuilleumier, 2005; Vuilleumier & Huang, 2009). For instance, ERP studies have shown that the processing of emotional words and faces shared similar brain systems, but that responses varied in speed with an advantage for faces compared to words, suggesting a more direct effect (Schacht & Sommer, 2009). Given these differences in the processing of emotional faces and words, these stimuli might affect cognitive control differently. However, different stimulus types are often used in research on emotion-cognition interactions without taking into account their specificities and conclusions drawn from the results are often broad and relate to emotional material in general.

Overall, these results suggest that researchers who want to assess cognitive control in the presence of emotional material are faced with a number of challenges. First, task relevance of emotion needs to be taken into consideration as evidence suggests that enhancing and impairing effects of emotion are modulated by its relevance for the task. Second, there is evidence that arousal is not the only factor driving the effects of emotion on cognition and that the effects of valence might also play a role. This is particularly important, as previous research has often used negative material and extended conclusions about their impairing effects to emotional material in general. Lastly, it is important to consider that not all stimulus types might have the same effects on cognitive control given that some are evolutionary prepared whereas others are not (e.g., faces vs. words) and that emotional significance from these items is extracted on different levels.

2.3. Executive functions and ageing

It has been suggested that cognitive decline in ageing is associated with impaired effectiveness of WM processes, particularly those requiring the manipulation and control of content in WM beyond its passive storage (Babcock & Salthouse, 1990; Braver & West, 2008; MacPherson, Phillips, & Della Sala, 2002; Reuter-Lorenz & Sylvester, 2005; Salthouse, 1990, 1991; Zelazo, Craik, & Booth, 2004). As reviewed by

Braver and West (2008), the structural distinction in the WM model by Baddeley and Hitch (1974) between pure storage systems and the central executive has encouraged the investigation of age-related differences to move from tasks that focus on storage capacity to those that do not require storage at all. These studies have consistently shown an age-related decline in cognitive control processes (for comprehensive reviews, see Braver & West, 2008; L. H. Phillips & Henry, 2008).

One theory that was proposed to explain age-related differences in executive functioning and associated cognitive changes in a wide range of cognitive tasks was the frontal lobe theory of ageing (Dempster, 1992; Moscovitch & Winocur, 1992, 1995; Robbins et al., 1998; Troyer, Graves, & Cullum, 1994; West, 1996). According to this theory, age-related changes in the frontal lobes of the brain are associated with deficits in functions that are supported by these regions, including executive functions. Previous research has provided evidence that was interpreted as support for this framework. For instance, Troyer and colleagues (1994) measured recall from episodic memory and executive functions in a group of older adults. Their results showed that age was not a significant predictor of memory recall once the effects of executive functions were partialled out of the equation and that executive functions accounted for 36% of the variance in recall performance.

Moreover, a variety of studies have shown that functional activation of the frontal lobes changed with ageing (for reviews, see Spreng, Wojtowicz, & Grady, 2010; Turner & Spreng, 2012). On the one hand, there is evidence of an age-related decline of activation in prefrontal areas during WM tasks such as the Stroop task (Milham et al., 2002). Underactivation was also found under conditions of high cognitive load (Cappell et al., 2010; Mattay et al., 2006; Persson, Lustig, Nelson, & Reuter-Lorenz, 2007; Reuter-Lorenz & Cappell, 2008a). On the other hand, studies provided evidence for age-related overactivation. For instance, more widespread and greater activation in frontal lobe structures were found in older than in younger adults (Mattay et al., 2006; Reuter-Lorenz & Cappell, 2008a). It was suggested that this pattern of over- and underactivation was due to compensatory mechanisms: additional prefrontal cortical activity in ageing was believed to maintain task performance. In contrast, age-related underactivation relative to levels observed in younger adults was believed to occur when the limit of physical compensation was reached (Buckner, 2004; Cabeza et al., 2002; Cappell et al., 2010; Mattay et al., 2006; Reuter-Lorenz & Cappell, 2008a).

As reviewed by Phillips and Henry (2008), a large proportion of research interested in frontal lobe theory of ageing used so-called frontal lobe tests, which are thought to tap into functions associated with the frontal lobe, without sufficiently taking into account the complexity of the area. The authors highlighted that many studies using frontal lobe tasks such as the WCST reported results that were mediated by a complex set of cognitive skills rather than a particular function. Thus, the authors highlighted that these tasks did not allow drawing strong conclusions regarding age-related differences in individual executive functions. Instead, Phillips and Henry (2008) suggested that measures of specific executive functions such as updating or inhibition can help to elucidate specific age-related changes (see also Stuss, 1992). This suggestion is also reflected in Miyake et al.'s discussion of the task impurity problem in the study of executive functions (Miyake & Friedman, 2012; Miyake et al., 2000).

Another theory that has been proposed to explain age-related difference in cognitive control is the goal maintenance account of PFC function by Braver and West (2008). This framework is also known as the context processing theory (Braver et al., 2001) and guided activation theory (Miller & Cohen, 2001). According to this account, a common feature of executive functions tasks is their reliance on the internal representation of task sets or goals, which helps to suppress irrelevant information or inappropriate response tendencies. In contrast, impairments in cognitive control can be thought of as goal neglect (see also Bhandari & Duncan, 2014; Duncan et al., 2008). The theory proposes that the lateral PFC serves as a source of cognitive control that utilises maintained goals to exert a top-down bias on posterior and subcortical systems in the brain that are involved in task-relevant processing (Braver & West, 2008). It also postulates that dopamine plays an important role in goal maintenance by regulating access of afferent inputs to the lateral PFC and thus, insulating goal information from task-irrelevant distraction (Braver & Barch, 2002; Braver & Cohen, 2000). According to the goal maintenance theory, older adults show difficulties in maintaining internal representations of goals due to age-related changes in lateral PFC and dopamine function (Botvinick, Braver, Barch, Carter, & Cohen, 2001; Braver & Barch, 2002; Braver & West, 2008). This impairment in goal maintenance is believed to contribute to age-related differences in tasks targeting executive functions.

Following Miyake et al.'s (2000) model of executive functions and the recommendation by Philipps and Henry (2008) to focus on specific rather than complex tests of executive functions, the following review will provide an overview of age-related changes in updating, inhibition and task switching. While this review will give a broad overview by taking into account a wide range of different tasks, age-related changes specifically in the n-back task and in the Stroop task will be reviewed in Chapters 3 and 4, respectively.

Updating in ageing

Research suggests that ageing is associated with a decline in updating performance (T. Chen & Li, 2007; De Beni & Palladino, 2004; J. E. Fisk & Sharp, 2004; Hartman, Dumas, & Nielsen, 2001; Salthouse et al., 2003; Schmiedek, Li, & Lindenberger, 2009;

Van der Linden, Brédart, & Beerten, 1994). For instance, De Beni and Palladino (2004) presented younger, young-old (55 – 65 years) and old-old adults (over 75 years) with lists of items and asked them to remember the three smallest items of each list. It was found that older adults were more susceptible to intrusion errors from no longer relevant items than younger adults and that performance was poorer in old-old adults relative to young-old adults. The authors interpreted the finding as evidence that older adults have greater difficulty to replace out-dated and therefore irrelevant information in WM. Similar results were reported by Schmiedek et al. (2009), who found that interference from task-irrelevant items was more pronounced in older than in younger adults' RTs in a WM updating task. Moreover, it was shown that reduced updating performance mediated age-related decline in other cognitive measures. For instance, Salthouse et al. (2003) found that executive functions and particularly updating mediated a large proportion of age-related effects on fluid intelligence. Similarly, it was shown that ageing was associated with reduced updating performance and that lower efficiency in updating was associated with poorer performance on tests of fluid intelligence (T. Chen & Li, 2007).

Findings from other studies suggested that age-related differences in updating become particularly apparent under conditions of high cognitive load (Van der Linden et al., 1994; Verhaeghen & Basak, 2005). For instance, Van der Linden et al. (1994) asked younger and older adults to watch strings of items and to recall serially the four or six most recent items. No age-related differences were found when participants had to recall four items but age-related decrements emerged for six items. The authors concluded that when memory load is high and exceeds older adults' processing capacities, age-related differences in updating are revealed.

It should be noted that some studies in the literature on updating in ageing have conceptualised updating as the ability to maintain information in WM. For instance, two studies have used a delayed response paradigm, in which younger and older adults had to compare a probe with a previously presented target (Hartman et al., 2001; Mikels, Larkin, Reuter-Lorenz, & Carstensen, 2005). Poorer performance in older adults was found with increased delay between target and probe (Hartman et al., 2001) and when non-emotional rather than emotional items were used (Mikels et al., 2005). However, as reviewed in section 2.1 of this chapter, updating refers to the ability to manipulate task-relevant information in WM by monitoring and replacing it if needed (Miyake et al., 2000; Szmalec et al., 2011). Thus, tasks that require passive storage in WM such as delayed response paradigms cannot help to elucidate age-related differences in the ability to update information.

Overall, these results suggest that ageing is associated with difficulties in updating information in WM. They also indicate that older adults are disproportionately affected by load compared to their younger counterparts.

Inhibition in ageing

It has been suggested that ageing is associated with a reduced ability to inhibit irrelevant information and that this decline in inhibition might contribute to cognitive decline in later life (Hasher & Zacks, 1988; Hasher et al., 1999; Zacks, Radvansky, & Hasher, 1996). Hasher and Zacks (1988) suggested that a global decrease in the efficiency of inhibitory processes in ageing contributed to ineffective selective attention and to an intrusion of task-irrelevant information into WM in older adults. This intrusion in turn was believed to lower WM capacity and to increase processing time. Due to the important role of WM in many cognitive tasks, it was suggested that impaired inhibition could explain age-related changes in a variety of cognitive measures.

Previous literature indeed suggests that older adults are more susceptible to distraction than younger adults and that they have greater difficulty to inhibit motor responses. For instance, it was shown that older adults had difficulties ignoring task-irrelevant information in reading tasks, particularly if distractors were related to the text they were instructed to read (Carlson, Hasher, Connelly, & Zacks, 1995; Connelly, Hasher, & Zacks, 1991; Li, Hasher, Jonas, Rahhal, & May, 1998). Neuroimaging studies showed that older adults were less able than younger adults to suppress cortical activity associated with task-irrelevant faces or scenes in a delayed response task (Gazzaley, Cooney, Rissman, & D'Esposito, 2005). Moreover, it was found that older adults were disproportionally more affected by distractors in visual search tasks (A. D. Fisk & Rogers, 1991; Hommel, Li, & Li, 2004) and that they showed less efficient low-level motor inhibition (Schlaghecken & Maylor, 2005) compared to younger adults.

A large proportion of studies on age-related differences in inhibition have used the negative priming paradigm (Tipper, 1985) as a measure of inhibition. Negative priming refers to slower responses to a target, if it has been a distractor on a previous trial. It is believed that on trials in which the item is the distractor, inhibitory processes block its representation from access to the response systems (Tipper, 1985; Verhaeghen & De Meersman, 1998a). When the same item is then presented as the target, it is believed that additional time is needed to overcome its inhibition, resulting in longer RTs as well as more errors on trials in which the target was previously a distractor than on trials in which the target was not previously a distractor (Verhaeghen & De Meersman, 1998a).

Studies using this task in research on ageing found no or reduced negative priming effects in older relative to younger adults, which was interpreted as evidence for impaired inhibition in ageing (Hasher et al., 1991; Mayas, Fuentes, & Ballesteros, 2012; McDowd & Oseas-Kreger, 1991). Verhaeghen and Meersman (1998a) included results from 29 studies on negative priming in ageing in a meta-analysis and found that overall, older adults showed smaller negative priming effects than younger adults. They suggested that this age-related change was due to slowed information processing in the older age group. However, another set of studies found comparable negative priming effects in younger and older adults (Buchner & Mayr, 2004; Schooler, Neumann, Caplan, & Roberts, 1997; Sullivan, Faust, & Balota, 1995). In a second meta-analysis, which found no age-related differences in negative priming effects (Gamboz, Russo, & Fox, 2002), the authors suggested that cognitive factors other than inhibition contribute to the negative priming effect and make the task inappropriate to test age-related changes in inhibition.

Others suggested that inhibitory processes are not generally impaired in ageing, which might explain the mixed pattern of findings in the research field of inhibition. For instance, Kramer et al. (1994) asked younger and older adults to perform a battery of tests all designed to assess inhibitory functions, and found no age-related difference in negative priming. In contrast, differences were observed in tasks measuring response inhibition (e.g., the stop-signal task), suggesting that some inhibitory functions are more affected in ageing than others. Lastly, it has been argued that negative priming effects reflect more automatic inhibitory processes, which, in contrast to controlled processes, were found to remain intact in ageing (Andrés, Guerrini, Phillips, & Perfect, 2008; for a review, see L. H. Phillips & Henry, 2008).

Many studies suggested that age-related changes in inhibition provide evidence for the frontal lobe theory of ageing (Dempster, 1992; Hartley, 1993; West, 1996). For instance, Hartley (1993) found that older adults ignored distractors in a locally predefined space as well as younger adults, whereas they had difficulties ignoring a line of processing (e.g., the word in a colour-word Stroop task). Referring to research showing that the former ability was associated with an attention system involving posterior structures, and the latter with an attention system involving anterior structures, the author suggested that ageing is associated with decline in frontal lobe functioning. Similarly, Chao and Knight (1997) used ERP measures in a delayed response task and found reduced attention-related activity over frontal regions in older than in younger adults and suggested that impaired attention in ageing may be due to altered prefrontal cortex function. Others suggested that age-related differences in tasks with competing, task-irrelevant processes or information could be explained without reference to a dedicated mechanism for inhibition. Instead, it was proposed that impairments in the ability to maintain task-relevant representations, which compete efficiently against task-irrelevant ones, are sufficient to explain age-related changes (Braver & Barch, 2002; Braver & West, 2008) in line with the goal maintenance theory (Braver & West, 2008).

Overall, a large body of research suggests that ageing is associated with impairments in tasks that require controlled and conscious inhibition. Whereas some researchers argue that inhibition is generally impaired in older adults, others favour the view that certain inhibitory processes, particularly automatic inhibitory processes, remain relatively spared in ageing.

Task switching in ageing

Task switching in ageing has been investigated in a large number of studies and focus has been placed on two types of switch costs. First, *global* switch costs were examined by comparing performance in single-task blocks with performance in blocks with multiple tasks requiring task switching. This measure is thought to assess the ability to maintain and schedule two different tasks in WM. Second, *local* switch costs were calculated by comparing performance on trials that required a switch and those that did not in blocks with multiple tasks. This measure was used to examine the ability to flexibly activate and deactivate different task sets.

In a meta-analysis on task switching in ageing (Wasylyshyn, Verhaeghen, & Sliwinski, 2011), the authors analysed global and local switch costs across 23 and 36 groups of subjects (contained in 26 articles), respectively. It was shown that no overall age-related changes were observed for local task switching, whereas global task switching was found to be age-sensitive with deficits beyond those expected due to general slowing. The authors concluded that age-related changes in global task switching are related to age-related WM deficits that become apparent with increased task demand. Similar conclusions have been drawn in an earlier meta-analysis by Verhaeghen and Cerella (2002), who found age-related differences in global but not in local task switching. They also reported that age-related changes in global task switching exceeded those expected for age-related general slowing, indicating that the ability to maintain multiple tasks sets in WM indeed decreases with age.

It should be noted, however, that there are factors that might affect the magnitude in age-related differences in local task switching. For instance, Kray, Li and Lindenberger (2002) found age-related changes in local task switching when relevant task sets were increased from two to four and when cues indicating which task to perform were unpredictable. This pattern of findings was interpreted as evidence that age-related changes in task switching vary as a function of task uncertainty. Other studies have also shown that local task switching is affected by age. In a set of experiments, Meiran, Gotler and Perlman (2001) found that, despite no age-related changes in the ability to prepare for a switch, older adults showed overall increased switch costs compared with younger adults. Finally, in a large web-based study with 5,271 participants between the ages of 10 and 66 years, Reimers and Maylor (2005) found that age affected local switch costs even though local switch costs remained more stable across the life span than the age-sensitive measure of global switch costs.

Overall, these results suggest that age-related changes are more pronounced in global than in local task switching. They also suggest that despite findings suggesting that local task switching is a less age-sensitive measure, age-related changes can emerge under particular task requirements.

2.4. Cognition-emotion interactions in ageing

Research suggests that ageing is not only associated with changes in cognitive but also in emotional functioning (Blanchard-Fields, 2007; Blanchard-Fields et al., 2007; Carstensen, Pasupathi, Mayr, & Nesselroade, 2000; Charles & Carstensen, 2007; Charles et al., 2001; Gross et al., 1997; Larcom & Isaacowitz, 2009; Scheibe & Blanchard-Fields, 2009). For instance, studies have shown that compared with younger adults, older adults report fewer negative emotional experiences with no changes in positive affect (Barrick et al., 1989; Charles et al., 2001; Gross et al., 1997) and greater emotional control (Charles & Carstensen, 2007; Gross et al., 1997; Urry & Gross, 2010). It has also been suggested that older adults are better at tailoring regulatory strategies to contextual demands due to their experience (Blanchard-Fields, 2007) and that regulatory strategies become less costly as people age (Scheibe & Blanchard-Fields, 2009). Evidence suggesting that these findings were not simply due to cohort effects come from longitudinal studies showing that older age is associated with increased subjective well-being (Cacioppo et al., 2008). It was also shown that a decline in some aspects of subjective well-being was not related to age per se but to factors such as health constraints (Kunzmann, Little, & Smith, 2000).

Socioemotional selectivity theory and motivated cognition

It was suggested that an increased motivation to regulate emotions might underlie age-related changes in emotional functioning (Carstensen & Mikels, 2005; Fung & Carstensen, 2003). According to the socioemotional selectivity theory (SST; Carstensen, 1993), perceiving one's future time as limited promotes a focus on emotional well-being in the moment in contrast to efforts to maximise future rewards. Consequently, older adults are thought to prioritise emotion regulation goals and to be less inclined to accept negative experience for the sake of long-term goals (Scheibe & Carstensen, 2010b). Although the SST is often cited in the ageing literature, it does not claim that motivational changes occur due to chronological age. Instead, the theory was developed to explain motivational changes that occur in the context of perceived time constraints, for instance due to disease (Carstensen & Fredrickson, 1998), or when faced with major socio-economic changes (Fung, Carstensen, & Lutz, 1999). The theory proposes that with limited time perspective, people seek meaningful social relationships and positive experiences. Thus, the SST emphasises selective processes that are believed to underlie changes in emotional well-being.

The SST has also been used to explain age-related changes in cognition-emotion interactions (Carstensen & Mikels, 2005; Fung & Carstensen, 2003). According to the SST, older adults allocate more cognitive resources to emotional and more specifically to positive information than younger adults in order to enhance well-being, resulting in the "positivity effect" in ageing (for reviews, see Reed & Carstensen, 2012; Scheibe & Carstensen, 2010b). For instance, older adults were found to show attentional preferences towards positive and away from negative material in viewing tasks (Allard & Isaacowitz, 2008; Isaacowitz, Wadlinger, Goren, & Wilson, 2006b) and better memory for positive than negative information (Charles, Mather, & Carstensen, 2003; Thomas & Hasher, 2006).

Age-related differences in emotional processing have not been found at relatively automatic stages in visual detection tasks (Kensinger & Leclerc, 2009; Leclerc & Kensinger, 2008) but were observed in tasks requiring sustained attention (e.g., Rösler et al., 2005). This suggests that differences were due to controlled processing of emotional information in older adults. It should be noted, however, that results are inconsistent regarding the effect of cognitive load on the positivity effect in older adults: Some studies demonstrated that the positivity effect in older adults' memory can be eliminated under divided-attention conditions when availability of cognitive resources is limited (Mather & Knight, 2005). Other studies have shown preserved attentional focus on positive information even with increased cognitive load (Allard & Isaacowitz, 2008) and a reduced impact of distractors on performance in tasks with high self-relevance in ageing (Germain & Hess, 2007; Hess, 2014). These findings suggest that motivational factors can affect cognitive performance under conditions of increased cognitive load.

Although the SST plays an important role in research investigating age-related changes in emotional functioning and emotion-cognition interactions, some studies reported results that were not fully compatible with its assumptions. For instance, a number of studies did not find an age-related positivity effect in cognitive tasks. Instead, a reduced negativity effect was reported (Grühn, Scheibe, & Baltes, 2007; Grühn, Smith, & Baltes, 2005; Kisley, Wood, & Burrows, 2007; Langeslag & van Strien, 2009). Studies also highlighted that older adults not only showed increased true but also increased false recognition of positive items compared with younger adults (Fernandes, Ross, Wiegand, & Schryer, 2008; Werheid et al., 2010). Whereas the SST would predict enhanced true recognition for positive items due to higher attention at encoding (Mather & Carstensen, 2005), enhanced false recognition would require a broadening of the theory. For instance, it was suggested that a positivity effect reflected older adults' higher receptiveness for positive information (Kapucu, Rotello, Ready, & Seidl, 2008; Spaniol, Voss, & Grady, 2008) rather than a greater focus.

Furthermore, Werheid and colleagues (2010) showed that older patients with amnestic mild cognitive impairments exhibited a comparable positivity effect in recognition memory relative to controls with normal memory performance. Moreover, patients with mild Alzheimer's disease showed even increased positivity-related response bias rates as compared to age-matched controls in a memory task (Werheid, McDonald, Simmons-Stern, Ally, & Budson, 2011). These results are incompatible with the assumption that cognitive resources are required to actively exhibit positivity effects in the processing of and memory for emotional material as suggested by the SST (Carstensen, 1993). It was also questioned whether age-related changes in emotion-cognition interactions indeed reflected emotion regulation goals (Isaacowitz & Blanchard-Fields, 2012). The authors pointed out that links between cognitive processes and affective experience were often claimed but not tested. They argued that evidence was needed to show that positivity effects in attention or memory are in fact related to increased positive or reduced negative affect, which was often not provided.

Compensatory strategies for cognitive decline

Alternatively, it has been suggested that changes in emotion-cognition interactions might be linked to diminished cognitive resources in ageing. In contrast to the SST, which suggested that active selection processes underlie the age-related positivity effect, other theories focused on compensation processes instead. For instance, the dynamic integration theory (for reviews, see Labouvie-Vief, 2003, 2009b) suggests that older adults are less able to tolerate negative affect, as it is cognitively more demanding than positive affect. According to this theory, basic emotions become more embedded in complex cognitive networks as individuals mature into adulthood, resulting in significant growth in cognitive-affective complexity. Individuals are believed to get better insight into aspects of emotions and there is an increased blending of emotions (for instance, a mix between joy and sadness). However, cognitive-affective complexity was found to decrease again in older age and older adults not only reported less negative affect but also a reduced integration of negative affect (Labouvie-Vief, 2003). Labouvie-Vief (2003) reported that affective complexity was associated with negative affect as well as with measures of cognitive functioning, such as that individuals reporting higher affective complexity also reported experiencing more negative affect and scored higher on measures of cognitive functioning. Consequently, it was suggested that older adults might favour affect optimisation over affect complexity and integration, as they have fewer cognitive resources to process and integrate negative affect. This might also link well with studies showing age-related changes in the processing of negative material (Grühn et al., 2007; Grühn et al., 2005; Kisley et al., 2007; Langeslag & van Strien, 2009).

In a similar vein, the life-span theory of control (Heckhausen & Schulz, 1995) also emphasised compensatory strategies in ageing. According to this theory, older adults focus more on emotion regulation, which is aimed at changes within the self, as the capacity and resources to change the environment declines with age. Thus, according to the latter two theories, an age-related focus on positive rather than negative affect reflects a compensatory strategy for *limited* cognitive resources, whereas the SST suggests that this focus is a selective process, which *requires* cognitive resources.

Supportive evidence for the view that positive information is less resource-demanding than negative information comes from other areas of psychological research. Negative stimuli were found to elicit more cognitive activity and more complex cognitive representations than positive stimuli (for a review, see Peeters & Czapinski, 1990). For example, it was observed that individuals consider negative events longer and reflect more potential causal information than they do for positive events (e.g., Bohner, Bless, Schwarz, & Strack, 1988). As presented in a review by Taylor (1991), negative stimuli elicit stronger and more rapid physiological, cognitive and emotional responses than positive stimuli, resulting in an asymmetrical mobilization of resources.

Similar findings were observed in research on facial processing, as angry faces were found to capture attention and to be more difficult to disengage from (Fox et al., 2001; Hansen & Hansen, 1988; Öhman et al., 2001; Olofsson et al., 2008) compared to other expressions. Similarly, negative and positive mood were reported to foster different processing strategies: Negative mood was found to elicit local and more detailed processing, whereas positive mood was found to be associated with global and more heuristic processing (Basso, Schefft, Ris, & Dember, 1996; Fredrickson & Branigan, 2005; Gasper & Clore, 2002). Research also suggests that positive information is associated with an enhanced feeling of familiarity, whereas negative information is associated with greater memory for detail (Kensinger, Garoff-Eaton, & Schacter, 2007; Levine & Bluck, 2004; Werheid et al., 2010; Werheid et al., 2011).

These differences between positive and negative information also formed the basis of approaches aiming to explain age-related differences in emotional memory in terms of a compensatory framework. For instance, Kensinger, Garoff-Eaton and Schacter (2007) tested memory specificity for negative and positive information and found that both younger and older adults showed enhanced memory for detail only for negative but not for positive items. Older adults additionally showed enhanced general recognition for positive information as compared to neutral information, whereas younger adults did not. The authors suggested that positive items might be associated with increased familiarity due to schematic or heuristic processing in contrast to more detailed processing of negative information. Referring to evidence that memory specificity is generally reduced but that familiarity is largely preserved in ageing, they suggested that preserved recognition for positive items in ageing may reflect a "synergy" between what is generally recorded for positive information and the type of information older adults tend to remember well (see also Kensinger & Schacter, 1999). Consequently, they suggested that the age-related positivity effect in memory is limited to the extraction of general features (Kensinger, Garoff-Eaton, et al., 2007). Similarly, Werheid et al. (2010; 2011), who used emotional faces in memory studies with younger and older adults, argued that cues such as those of familiarity in smiling faces are powerful when memory traces are weak. According to the authors, older adults are more vulnerable to cues of familiarity from smiling faces in recognition tests due to reduced recollection and greater reliance on familiarity in ageing.

Age-related changes in effects of emotion on WM

Despite evidence that ageing is not only associated with cognitive decline but also with preserved or even improved emotional functioning, so far only a limited number of studies have investigated age-related changes in the effects of emotion on WM in general and on executive functions in particular. These studies have shown that emotion-cognition interactions in the domain of WM change across the adult life span. For instance, Mikels et al. (2005) asked younger and older adults to perform a delayed-response task in which they maintained and compared either the brightness of two neutral IAPS pictures or the emotional intensity of two emotional IAPS pictures (no neutral pictures were used in the latter task, in which positive and negative pictures were intermixed). They found that older adults performed more poorly than younger adults when maintaining the brightness of neutral pictures but not when maintaining the emotional intensity of emotional pictures. Moreover, older adults were found to perform better when having to maintain positive relative to negative material, whereas younger adults showed the opposite pattern. It was also reported that in a modified version of the operation WM span test that requires participants to maintain words while solving mathematical operations, older adults performed worse than younger adults when neutral but not when emotional words were used (Mammarella, Borella, Carretti, Leonardi, & Fairfield, 2013).

These findings were interpreted in light of SST (Carstensen, 1993) and taken as evidence for older adults' stronger focus on emotional and particularly positive material relative to younger adults. These findings also suggest that age-related differences in WM performance can be reduced or even eliminated when using emotional material. However, as these studies focused on maintenance of material, it is less clear whether emotion can boost older adults' performance in more complex WM tasks, which require additional manipulation of information.

Whereas some results from WM studies suggest that emotion may boost older adults' WM performance, there is also evidence that it can disrupt WM to a greater extent in older than in younger adults. For instance, in a delayed-response WM task (Truong & Yang, 2014), emotional and neutral words were presented as targets or distractors and younger and older adults had to indicate whether subsequently presented probe words had been presented as targets. Both age groups were faster and more accurate when emotional words were task-relevant targets. However, older but not younger adults were less accurate when task-irrelevant distractors were negative rather than neutral. The authors suggested that due to their preference for positive information, older adults processed negative items insufficiently at encoding, which resulted in weaker representations of negative items as distractors.

In another study (Borg, Leroy, Favre, Laurent, & Thomas-Antérion, 2011), older and younger adults were asked to bind four negative or neutral pictures with their respective locations on the screen and to indicate whether the pictures were shown in the original location after a delay. Older but not younger adults were less accurate when binding negative than neutral pictures. The authors suggested that older adults' focus on emotion contributed to a disruption of task-relevant binding for emotional material. Lastly, interference from task-irrelevant emotional information was found for older but not for younger adults in two emotional Stroop tasks (Wurm, Labouvie-Vief, Aycock, Rebucal, & Koch, 2004). The authors suggested that fewer available cognitive resources in ageing made older adults more susceptible to the disruptive effects of automatic activation in the presence of emotional stimuli. In sum, these findings suggest that emotion might facilitate but also impair older adults' performance on WM tasks to a greater extent than in younger adults.

Whilst some studies interpreted age-related changes in how emotion affects WM in light of cognitive decline in ageing (e.g., Wurm et al., 2004), others interpreted them based on the SST (e.g., Borg et al., 2011). However, it is not clear whether the SST can offer an appropriate interpretation, given that WM tasks might undermine some mechanisms that are thought to underlie motivated cognition. More specifically, WM is conceptualised as a limited capacity system (Baddeley, 2003; Baddeley & Hitch, 1974; Logie, 2011) and thus, per definition there is limited scope for participants to let their attention be guided according to their motivational preferences. It has been argued that the positivity effect emerges under instructions encouraging participants to process material freely (for a review, see Reed & Carstensen, 2012) without imposing any other goals. For instance, if participants are simply asked to "view" material, an age-related positivity effect was found in attention and memory tasks (Charles et al., 2003; Isaacowitz et al., 2006b). In contrast, under conditions of specific instructions that impose specific goals on participants (e.g., to commit all items to memory or to encode stimulus valence), no age-related positivity effects were found (Grühn et al., 2005; Kensinger, Brierley, Medford, Growdon, & Corkin, 2002). Overall, this pattern of results suggests that chronically activated goals can be masked or supplanted by other goals that participants have to adopt through instructions (Reed & Carstensen, 2012).

While it is possible to assume that processing that is free of external requirements can be achieved in attention and memory tasks (e.g., in attention tasks or in surprise memory tests that allow participants to view items as if they are watching TV), WM tasks usually require very specific and restrictive instructions. For instance, in an n-back task, participants are required to compare each item with the one presented *n* positions earlier, to respond to each item via button press and to update the content in WM continuously. These instructions do not leave room for individual preferences about what to process and what to ignore. Often, cognitive resources are also restricted in WM tasks (e.g., in n-back tasks with increased load), which would leave even fewer cognitive resources to let processing be guided by motivation. It can be concluded that these characteristics of WM tasks could restrict older adults' ability to process material freely and thus, make it difficult for them to exhibit chronically active motivational biases.

Overall, the results of previous research presented here suggest that emotion can enhance but also impair WM performance to a greater extent in older than in younger adults. However, the majority of these studies have focused on WM tasks that require the storage of emotional information in WM. In contrast, it is less clear how emotion affects older adults' performance in more complex WM tasks, which require additional manipulation of information. As research suggests that ageing is associated with impaired effectiveness of WM processes, particularly those involved in the manipulation and control of content in WM (Babcock & Salthouse, 1990; Braver & West, 2008; MacPherson et al., 2002; Reuter-Lorenz & Sylvester, 2005; Salthouse, 1990, 1991; Zelazo et al., 2004), it is an intriguing question whether emotion can help in boosting these processes in older adults. This dissertation presents a series of studies designed to systematically investigate how the effects of emotion on executive functions vary with age to close this empirical gap. The most important theories that informed this research are summarised in Table 2.1.

Table 2.1. *Overview of relevant theories for the present research*

Field	Theory	Claims
Executive functions & emotion	Dual competition model (Pessoa, 2009)	Effects of emotion on executive functions are either stimulus- or motivation-dependent. Stimulus-dependent effects of emotion on EFs driven by arousal and task relevance of the emotional stimulus. On a neural level, it is believed that task networks (e.g., attentional network) and "valuation networks" including cortical and subcortical regions interact.
	WM model of Baddeley and Hitch (1974) including a hedonic buffer (Baddeley, 2007)	Hedonic detector involved in assessing stimuli and choosing appropriate actions depending on their hedonic value. In order to fulfil this task, the hedonic detector is believed to have a storage system and to rely on the central executive.
Executive functions & ageing	Frontal lobe theory of cognitive ageing (West, 1996)	Localised changes in the frontal lobes of the brain associated with deficits in functions that are supported by these regions including executive functions.
	Goal maintenance theory of PFC function (Braver & West, 2008)	Older adults have greater difficulty to maintain internal representation of goals due to age-related changes in lateral PFC and in dopamine function.
	Inhibition account of cognitive ageing (Hasher & Zacks, 1988)	Global decrease in the efficiency of inhibitory processes in ageing, which is associated with intrusion of task-irrelevant information in WM in older adults.
Emotion & ageing	Socioemotional selectivity theory (Carstensen, 1993)	Older adults prioritise emotion regulation goals and allocate more cognitive resources to emotional and specifically to positive information than younger adults to enhance well-being.
	Dynamic integration theory (Labouvie-Vief, 2003, 2009)	Older adults favour affect optimisation over affect complexity and integration as they have fewer cognitive resources to process and integrate negative affect.

Note. EF = executive function, PFC = prefrontal cortex

Chapter 3: Updating of emotional content in younger and older adults

3.1. Introduction

This chapter will focus on the ability to maintain and update information in WM, which is crucial for adaptive cognitive functioning and everyday life. As discussed in Chapter 2.1, updating is conceptualised as the ability to replace old representations that are temporarily maintained in a region of direct access in WM (Cowan, 1988, 1999; Oberauer, 2009) with new representations.

The n-back task (Kirchner, 1958) is one of the most popular tasks in the investigation of WM in general and updating in WM in particular (Conway et al., 2005; Jaeggi, Buschkuehl, Perrig, & Meier, 2010; Kane, Conway, Miura, & Colflesh, 2007). In this task, participants are required to monitor a sequence of items such as digits or letters that are presented one at a time. For each presented item they have to press one of two keys to indicate whether it is the same as or different from the one presented *n* positions back in the sequence. The task is thought to involve a number of cognitive processes targeting both the maintenance and the manipulation of content in WM. More precisely, while maintaining a set of *n* most recently presented items in serial order in the focus of attention (Oberauer, 2009), participants need to process new items at the same time and update the set continually. For instance, as soon as a new item is presented, the former *n*-back target item turns into a distractor, the item that was formerly *n*-1 back becomes the new target, and all items within the *n*-back buffer must be maintained as future targets (McElree, 2001).

Due to this continuous nature of the task, flexible binding and unbinding of the specific item and its context (i.e., serial position) in the direct access region of WM is needed (Oberauer, 2009; Szmalec et al., 2011). It is believed that the continuous nature of the task also prevents strong binding, making it difficult to distinguish between relevant items (i.e., targets at position *n*) and their neighbours (i.e., n+1 or n-1 lures) that are irrelevant for the current trial (Szmalec et al., 2011). The n-back task is particularly popular as task difficulty can be easily varied by increasing *n*. For instance, by implementing an increase from 1-back to 2-back, 3-back and so on, participants are required to manipulate a larger amount of items in WM across different blocks. This makes the n-back paradigm a suitable task to investigate the effects of load on WM in general and on updating in WM in particular.

Effects of age and emotion on n-back performance

Despite its popularity, the n-back task has only been used in a limited number of studies on cognitive ageing so far. These studies have shown that performance in an n-back task decreased with age and that age-related differences were larger in the 1-back and 2-back tasks relative to the 0-back variant of the task (Salthouse et al., 2003). Given that the 0-back task does not require updating, these results suggest that ageing is associated with less efficient updating rather than with impairments to cognitive mechanisms needed across all task levels (e.g., perception and categorisation of items). Similarly, Verhaeghen and Basak (2005) reported that the focus-switching costs, which were operationalised as differences in RTs and accuracy between *n*=1 and *n*=2 variants of the n-back task, were higher in older adults than younger adults. The authors suggested that increased focus-switch costs may underlie age-related differences observed in complex tasks, for instance those requiring dual tasking or the coordination of multiple processing steps. In another n-back study, interference effects from n+1 and n-1 lures were more pronounced in older than in younger adults' RTs (Schmiedek et al., 2009). Additionally, older adults were faster when responding to matches than younger adults. This pattern of increased susceptibility to lures and faster responses to matches led the authors to conclude that older adults relied on familiarity to a greater extent than younger adults, possibly due to reduced recollection. Overall, these results suggest that the n-back paradigm is an age-sensitive task, which can help to assess age-related differences on a variety of WM processes.

In recent years, researchers have started investigating the effects of emotion on updating, as there is evidence that the ability to update emotional information in WM is linked to the efficacy of emotion regulation (Levens & Gotlib, 2010; Pe, Koval, et al., 2013; Pe, Raes, et al., 2013). However, studies assessing updating of emotional material in n-back tasks mainly focused on younger participants (e.g., Cromheeke & Mueller, 2015; Levens & Gotlib, 2010, 2012; Miendlarzewska, Van Elswijk, Cannistraci, & van Ee, 2013; L. K. Phillips et al., 2011) and only a few studies have examined age-related differences in updating of emotional material. Given that ageing is not only associated with changes in cognitive but also in emotional functioning (see Chapter 2.4), it is an intriguing question how the emotion-cognition interactions in updating vary with age.

The aim of the present study is therefore to close the empirical gap by investigating updating of emotional material in ageing. In the following, emotional n-back tasks will be reviewed with a focus on the use of emotional material as task-relevant items or task-irrelevant distractors. This chapter will then cover three experiments, which focussed on different aspects of emotional updating. In Experiment 3.1, emphasis was placed on how task-relevant and task-irrelevant emotion affected updating performance in older relative to younger adults. Based on the results observed for task-relevant emotions in Experiment 3.1, Experiment 3.2 was conducted to investigate how the emotionality of negative lures affected performance in older relative to younger adults. Finally, Experiment 3.3 was conducted to assess whether a happy face advantage in updating, which was observed in Experiment 3.1, could also be found for positive words.

3.2. The role of task-relevant and task-irrelevant emotion on WM updating

When investigating the effects of emotion on updating, emotion can be treated as a task-relevant (i.e., targets are emotional in nature) or task-irrelevant (i.e., distractors are emotional in nature) stimulus. This distinction needs to be considered, as research suggests that task-relevant and task-irrelevant can have contrasting effects on cognitive performance (see Chapter 2.2). In tasks with task-relevant emotion, enhanced processing of emotional items might be beneficial for task performance, which was found in WM studies (Levens & Phelps, 2008; Lindström & Bohlin, 2011). However, impairing effects of emotion on WM have also been reported (Gotoh, 2008; Kensinger & Corkin, 2003; Kopf et al., 2013; Lindström & Bohlin, 2012), particularly when emotional items were task-irrelevant (Dolcos et al., 2013; Dolcos & McCarthy, 2006; Hart, Lucena, Cleary, Belger, & Donkers, 2012; Iordan et al., 2013). In many studies using the n-back paradigm, the effects of emotion were investigated without taking into account the distinction between task-relevant and task-irrelevant emotion: Some studies used explicitly task-relevant emotion and directed the participants' attention to the emotional features of items. Others used explicitly task-irrelevant emotional material. However, a third group used nonspecific match/non-match instructions and it was not clear whether participants perceived emotion as relevant or irrelevant for the task.

In the first type of n-back studies, participants were explicitly instructed to respond to the emotional content of the stimuli (e.g., Cromheeke & Mueller, 2015; Levens & Gotlib, 2012; Mikels et al., 2005; Mitchell, 2007; Mitchell & Bouças, 2009; Neta & Whalen, 2011; Pe, Koval, et al., 2013; Rämä et al., 2001). These studies typically demonstrated that positive material improved updating, whereas no such facilitating effect was observed for negative material. For instance, Levens and Gotlib (2010) asked participants to respond to the emotional expression of happy, sad, and neutral faces in an n-back task. Non-depressed participants matched happy faces faster in WM than neutral or sad faces and took longer to disengage (i.e., when making non-match responses) from happy faces relative to neutral or sad faces, an effect that was interpreted as a bias for happy faces. In a similar vein, Cromheeke and Mueller (2015) presented happy, neutral, and angry faces in a 2-back task and found that responses were fastest to happy faces, whereas no difference was found between angry and neutral faces. Pe et al. (2013) observed faster updating for positive than negative words. However, as there was no neutral material, it cannot be determined whether there was a speed-up for positive items or a slowing for negative items or both. Other studies reported combined results for different valences without comparison with neutral material, which does not allow evaluating the effect of emotion on updating (Mitchell, 2007; Mitchell & Bouças, 2009; Neta & Whalen, 2011; Rämä et al., 2001).

In the second type of n-back studies, non-emotional targets (e.g., letters or digits) were presented with explicitly task-irrelevant neutral or emotional distractors (e.g., Bakvis, Spinhoven, Putman, Zitman, & Roelofs, 2010; Bertocci et al., 2012; Ladouceur et al., 2009; Marx et al., 2011; Miendlarzewska et al., 2013; Mullin et al., 2012; Ozawa et al., 2014). In many of these studies, the effects of distractors, whether negative, positive or neutral, were combined in the analyses (e.g., Bakvis et al., 2010;

Bertocci et al., 2012; Ladouceur et al., 2009), mixing the effects of irrelevant emotional and neutral material and also the effects of different emotional valences. Many studies, in which the effects of neutral and emotional distractors were compared, reported no difference between the effects of emotional (negative or positive) and neutral distractors on accuracy or RTs (Miendlarzewska et al., 2013; Mullin et al., 2012; Ozawa et al., 2014). However, it is possible that no difference was found in studies with mildly arousing material. Research suggests that arousal of distractors dominates in the competition for selective attention and impairs attention for non-arousing targets (for reviews, see Bradley et al., 2012; Mather & Sutherland, 2011) and lower accuracy was found for highly but not for mildly arousing negative distractor pictures in an n-back task (Marx et al., 2011).

In the third category of n-back studies, participants were presented with neutral and emotional targets and were not provided with explicit instructions to respond to or to ignore the emotional properties of target stimuli. Instead, they were asked to make match/non-match responses (e.g., Döhnel et al., 2008; Kensinger & Corkin, 2003; Kopf et al., 2013; Lindström & Bohlin, 2011; L. K. Phillips et al., 2011; Richter et al., 2013; Schoofs et al., 2013; Weigand et al., 2013). As match/non-match responses could have been based on stimulus features other than emotion (e.g., identity of an emotional face), it is not clear whether all participants focused on the same (emotional) features.

These studies have yielded mixed results, as some reported higher accuracy or faster RTs for negative relative to neutral or positive items (Döhnel et al., 2008; L. K. Phillips et al., 2011) or for both negative and positive items relative to neutral items (Lindström & Bohlin, 2011). Others found reduced accuracy or slower RTs for negative relative to neutral or positive items (Kensinger & Corkin, 2003; Kopf et al., 2013). It should be noted that these results were obtained using interleaved designs mixing emotional and neutral stimuli. In contrast, studies using unspecified match/non-match instructions in blocked designs (i.e., blocks with all emotional vs. blocks with all neutral items) reported no effect of emotion (Richter et al., 2013; Schoofs et al., 2013; Weigand et al., 2013). Kensinger and Corkin (2003) suggested that blocked designs may obscure emotion effects as participants may notice patterns and adopt strategies, which could result in similar performance in different blocks. In support of this notion, they found slower responses for angry compared to neutral faces in an n-back task with interleaved but not with blocked stimulus presentation. Thus, these results indicate that nonspecific instructions regarding the emotional content of stimuli and design choices regarding stimulus presentation can obscure enhancing and impairing effects of emotion on updating.

Another aspect, which has received little attention in the reviewed studies, is that the effect of emotion might vary depending on the trial types in an n-back task. Many studies analysed n-back data without distinguishing between match and non-match trials (e.g., Bakvis et al., 2010; Cromheeke & Mueller, 2015; Marx et al., 2011; Miendlarzewska et al., 2013; Ozawa et al., 2014; Rämä et al., 2001; Schoofs et al., 2013) or focused on match responses only (e.g., Bertocci et al., 2012; Döhnel et al., 2008; Mullin et al., 2012; Pe, Koval, et al., 2013; Richter et al., 2013; Weigand et al., 2013). However, it has been suggested that only non-match trials actually require updating, as an old representation needs to be replaced with a new one (Verhaeghen & Basak, 2005). Instead, when having to make match responses, participants maintain the same representation and even rehearse it. Studies have shown that non-match responses took longer than match responses (Y.-N. Chen, Mitra, & Schlaghecken, 2008; Szmalec et al., 2011; Verhaeghen & Basak, 2005), which was attributed to the process of updating (Verhaeghen & Basak, 2005).

With different mechanisms being involved in these different trial types, emotion might have different effects on match and non-match responses if it affects the underlying mechanisms differently. Indeed, previous research has shown that replacing happy faces was found to be slower relative to neutral faces in healthy adults (Levens & Gotlib, 2010, 2012). Similarly, it was found that RTs were slowest when participants responded to an emotional face that followed another emotional face and that they were fastest when participants responded to a neutral face, which followed a neutral face (Kensinger & Corkin, 2003). These findings suggest that it is important to distinguish between trial types in n-back studies in general but particularly when using emotional material, as emotion might have differential effects on mechanisms targeted by the different trial types.

In sum, the literature suggests that task-relevant and particularly positive emotion enhances updating performance, whereas no such enhancing effects were observed for task-irrelevant emotional content. Task-irrelevant emotional items were not found to be more distracting than task-irrelevant neutral items, but highly arousing negative distractors interfered with updating in an n-back task to a greater extent than mildly arousing negative items.

So far, only a limited set of studies has compared the effects of emotional relative to neutral items on WM updating while systematically varying the relevance of emotion for task performance. Moreover, age-related differences were not always considered. Only two studies have systematically varied the relevance of emotional information to investigate the effect of emotion on WM updating in different age groups. Cromheeke and Mueller (2015) asked adolescents and adults to update emotional and neutral faces in an n-back task and to respond to either the gender or the expression of the face. Slower responses for happy faces were found in adolescents but not in adults when gender was the focus, suggesting that only adolescents were distracted by task-irrelevant positive emotion. In contrast, both age groups responded faster to happy than neutral faces when emotion was task-relevant. Although the authors included a 0-back and a 2-back task, it is not possible to determine the effects of load without a 1-back or 3-back variant of the task. In a 0-back task, participants do not actually have to update and replace information in WM, and thus, only the 2-back task required updating. Moreover, only two emotions per block were included (happy vs. neutral, happy vs. angry or angry vs. neutral) to match the difficulty of the gender condition (male vs. female). Thus, the number of possible combinations of emotions in an n-back sequence was reduced and the task overall easier than one with three emotional categories. Finally, no distinction has been made between match and non-match trials despite evidence that emotion might affect trial types differently (Kensinger & Corkin, 2003; Levens & Gotlib, 2010, 2012).

In another study, Pehlivanoglu, Jain, Ariel and Verhaeghen (2014) asked younger and older adults to update emotional and neutral faces in an n-back task and to base their decision on either the expression, the identity, or on both features of the face. Although this design allowed the investigation of (un-)binding processes in both age groups, which was the study's focus, the effects of task-relevant and task-irrelevant emotion were not examined. It is therefore unclear whether irrelevant emotion affected updating and whether there were age-related differences. As discussed in Chapter 2.4, there is evidence that older adults focus more on emotional and particularly positive material (for reviews, see Reed & Carstensen, 2012; Scheibe & Carstensen, 2010b). Moreover, research suggests that the inclusion of emotion might come at a cost for older adults as their attention is detracted from non-emotional item features or from the on-going task (Borg et al., 2011; Kensinger, 2009b; Truong & Yang, 2014; Wurm et al., 2004). Thus, an important but largely unexplored question is how updating in younger and older adults is affected by task-relevant relative to task-irrelevant emotion.

3.3. Experiment 3.1: Updating of emotional faces in two age groups

The aim of the present experiment was to compare older and younger adults' performance in an emotional n-back task while systematically varying the task relevance of emotion. Three additional aspects were considered in extension to previous literature on this topic: Firstly, unlike many previous studies, three levels of emotion were used (happy, neutral, and angry) in all comparisons. Secondly, two different levels of load (1-back and 2-back) were included in order to assess whether WM updating of emotional material is affected by load in younger and older adults. The effect of load in updating of emotional material in two age groups was of interest as there is evidence that a focus on emotional and particularly on positive information in ageing requires the availability of sufficient cognitive resources (for reviews, see Reed & Carstensen, 2012; Scheibe & Carstensen, 2010b). In contrast, increased cognitive load has been found to reduce the positivity bias in ageing (Mather & Knight, 2005). Thirdly, both match and non-match trials were included in the analysis of RTs as evidence suggests that emotion can interact with trial type (Kensinger & Corkin, 2003; Levens & Gotlib, 2010, 2012) and that non-match trials require participants to replace old representations with new ones, which is not the case in match trials (Verhaeghen & Basak, 2005).

This study aimed to investigate the following hypotheses: 1. Task-relevant positive emotion will have facilitating effects on WM updating in terms of higher accuracy and faster RTs, with no such effect for task-irrelevant emotion. 2a. Given previous research showing that older adults show a preference towards positive material in cognitive tasks (for reviews, see Reed & Carstensen, 2012; Scheibe & Carstensen, 2010b), it was expected that task-relevant positive emotion will boost performance to a greater extent in older than in younger adults. 2b. Given research suggesting that task-irrelevant emotion can have impairing effects on cognitive performance in older adults (Borg et al., 2011; Truong & Yang, 2014; Wurm et al., 2004), it was hypothesised that task-irrelevant emotion will impair updating in older but not in younger adults. 3. It was hypothesised that emotion by age interactions would be attenuated by load (i.e., 2-back vs. 1-back) as cognitive load has been found to reduce emotional biases in ageing (Mather & Knight, 2005).

Methods

Participants

Twenty-five younger adults (20 – 34 years old) and 25 older adults (63 – 80 years old) participated in the study (see Table 3.1 for participant characteristics). The young adults were undergraduate and postgraduate students at Birkbeck College and received either course credits or a small fee for participating. The older adults were recruited from the University of the Third Age in the Greater London area and were reimbursed at the same rate as younger adults. All participants were community-dwelling and reported to be in good health. They were pre-screened for history of psychiatric or neurological disorders and had normal or corrected-to-normal vision and hearing. Older participants had a score of 27 or above on the MMSE (Folstein, Folstein, & McHugh, 1975).

As can be seen in Table 3.1, younger and older adults differed in years of schooling, with fewer years in older adults. Consistent with typical profiles in the literature, older adults had better verbal knowledge as assessed with the NART (Nelson & Willison, 1991) and scored marginally lower on the Digit Symbol Substitution Test from the WAIS-R (Wechsler, 1955) suggesting slower processing speed than in younger adults. No other significant differences were observed. The ethics board of Birkbeck, University of London, approved the procedure prior to the start of the study and written informed consent was obtained from each individual.

Table 3.1. *Participant characteristics, Experiment 3.1*

	Younger adults		Older adults		Group difference	
Variable	*M*	*SD*	*M*	*SD*	*t*	*p*
Age	25.32	4.14	68.80	5.94		
Gender (male/female)	8/17		7/18			
Education (yrs)	17.30	2.52	15.70	2.33	2.33	.024*
NART Verbal IQ	110.54	5.04	120.06	4.52	-5.38	<.001***
Digit Symbol Test	64.64	12.09	58.06	11.73	1.78	.082
BDI II	5.84	5.76	3.84	2.64	1.58	.121
STAI Trait Anxiety	32.16	9.02	29.96	9.58	.836	.407
MMSE			29.20	.91		

Note. NART = The National Adult Reading Test, BDI II = Beck Depression Inventory II, STAI = State-Trait Anxiety Inventory, MMSE = Mini-Mental State Examination; *$p < .05$, **$p < .01$, ***$p < .001$

Materials

Stimuli consisted of 72 images of faces from the FACES database (Ebner et al., 2010), a validated set of colour photographs of naturalistic, front-facing faces of different ages. In a preliminary rating study, ten younger (21 – 32 years old; *M* = 27.80, *SD* = 3.12) and ten older adults (66 – 76 years old; *M* = 71.27, *SD* = 3.13) rated 234 preselected faces on valence and arousal. They also estimated the age of each face. From this set, 72 faces (24 happy, 24 angry, 24 neutral expressions) with the highest agreement in ratings between younger and older raters were selected for the main experiment. Age group and sex of the face models were balanced in each emotion category, resulting in eight pictures per age group and emotion category with four male faces and four female faces. Each picture showed a unique individual. For counterbalancing purposes, two face sets were created that had similar arousal and valence levels (all *ts*(19) < 1.30, *ps* < .208; see Appendix A for more details).

Procedure

After giving informed consent, participants completed a demographic questionnaire. A short computer-based visual acuity test (Bach, 1996) was then administered at a distance of approximately 65 cm to ensure that vision was normal. Participants then performed the computerised n-back, starting with the 0-back task, which was followed by the 1-back and 2-back tasks. Short breaks were offered between tasks. Participants then completed the Beck Depression Inventory (BDI-II; Beck, Steer, & Carbin, 1988), the A-Trait version of the State-Trait Anxiety Inventory (Spielberger, Gorsuch, Lushene, Vagg, & Jacobs, 1983) as well as the Digit Symbol Substitution Test (Wechsler, 1955) and the National Adult Reading Test (NART; Nelson & Willison, 1991) as measures of fluid and verbal intelligence, respectively. Older adults were additionally administered the MMSE (Folstein et al., 1975) as a screening for cognitive impairments. All participants were debriefed at the end of the session, with each session lasting approximately 1.5 to 2 hours in total.

N-back tasks

The experiment comprised two tasks: (i) a 1-back task, in which the current face was compared with the face presented one trial earlier and (ii) the 2-back task, in which the current face was compared with the face presented two trials earlier. They were preceded by a 0-back task, which was included to familiarise participants with the procedure and the stimuli and in which the current face was compared to a target label. In each task, participants were instructed to make "same" (match) or "different" (non-match) judgments and to base their decisions either on the emotion of the face (angry vs. neutral vs. happy; emotion was task-relevant) or the age of the face (young vs. middle-aged vs. old; emotion was task-irrelevant). In the instructions to focus on the age, the emotion of the faces was not mentioned (i.e., they were not told to ignore distractors). If participants are instructed to ignore distractors, then this can become part of the goal structure and may result in paradoxical effects as shown in a flanker task (Davelaar, 2012). Participants could still incorporate an ignore-emotion goal, due to the within-subject manipulation of task relevance of emotion. However, it was expected that this would be minimal.

In each task, a fixation cross appeared for 1000 ms and was then replaced by a face for 2000 ms after which a blank screen was presented for 1000 ms. Participants were instructed to respond by pressing one of two labelled buttons (“S” for same, “D” for different). On the computer keyboard, the buttons “1” and “2” of the numeric keypad were used and participants were instructed to leave the index finger and middle finger on the two buttons for the duration of the task. The face remained on the screen for the full 2000 ms even if participants made a response during that time. All 72 stimuli were included in the preparatory 0-back task; they were separated into six blocks of 12 items and presented once. Before each block, an emotion label (“angry”, “neutral”, or “happy”), or an age label (“young”, “middle-aged”, or “old”) was presented. Participants compared the emotional expression or age of the face with the label, and the order of expression and age blocks was randomised. Half of the stimuli were then used in the 1-back and the other half in the 2-back task. Assignment of the two stimulus sets to the 1-back or 2-back task was counterbalanced across participants. In each n-back task, for half of the blocks the emotion of the face was task-relevant and for the other half it was task-irrelevant. Within each block, 50% of trials required a “same” response and 50% a "different" response and participants were instructed to respond as accurately and quickly as possible.

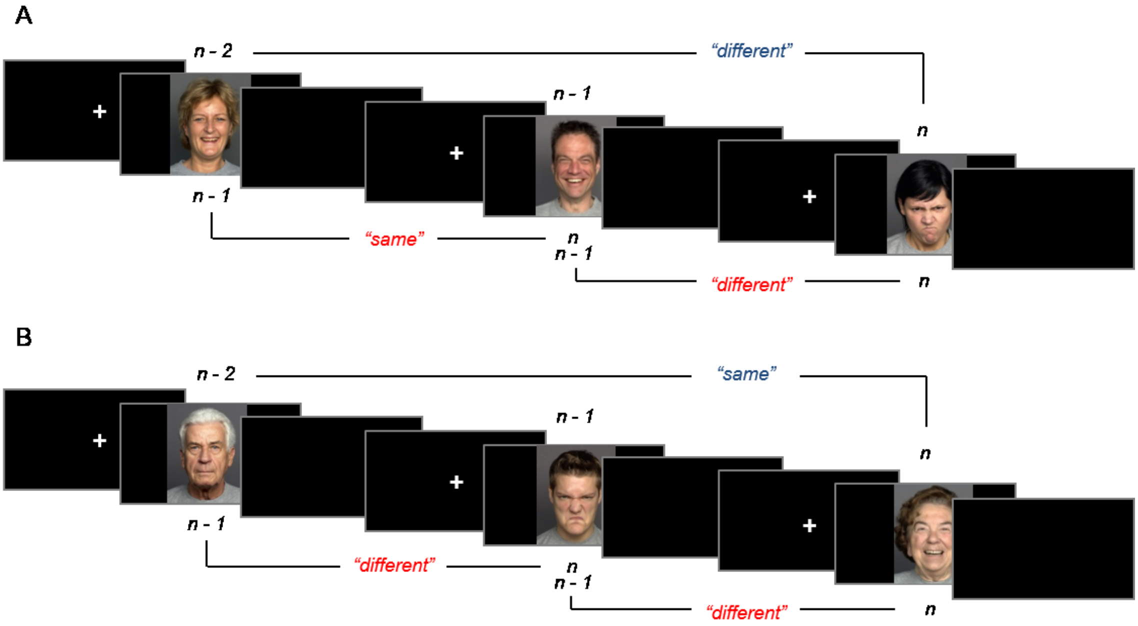

Figure 3.1. Examples of trials under emotional task instructions (panel A) and under non-emotional task instructions (panel B), including correct responses. Correct responses in the 1-back task are shown in red font at the bottom of each panel and those in the 2-back task are shown in blue font at the top of each panel.

1-back task. The 1-back task consisted of 220 trials, which were divided into four blocks of 55 items. Emotion and age blocks were presented in alternating order and beginning with either emotion or age block was counterbalanced across participants. Twenty practice trials were presented before the experimental block. For each block, participants were instructed to view the first face without pressing a key; from the second face onwards, participants were instructed to start responding, resulting in 54 usable trials per block (see Figure 3.1.A for example trials). Each item was presented on average 6 times during the task.

2-back task. The 2-back task consisted of 304 trials that were separated into eight blocks of 38 items. Emotion and age blocks were presented in alternating order and beginning with either emotion or age block was counterbalanced across participants. Twenty-four practice trials were presented before the experimental blocks. The same decisions were made as for the 1-back task, but this time, participants were required to compare the current face with the face presented two trials earlier. For the first two faces in each block of trials, participants viewed the faces without pressing a key; from the third face on, participants were instructed to start responding, resulting in 36 usable trials per block (see Figure 3.1.B for example trials). Each item was presented on average 8 times during the task.

Trial types and statistical analysis

Responses and RTs were recorded for each trial and the percentages of hits (correct match) and false positives (incorrect match) were calculated for each condition. RTs will be analysed as the primary dependent variable based on procedures of previous studies (Kensinger & Corkin, 2003; Levens & Gotlib, 2010, 2012). Any RTs faster than 200 ms or 2.5 standard deviations above or below the mean of the respective age group for the 1-back or 2-back task were excluded, resulting in an exclusion of an average of 2.4% of trials for younger adults and 1.62% for older adults per task. Median RTs for correct trials were then calculated for each condition. To obtain corrected measures of recognition, hits and false positives were used to calculate *A'*, a non-parametric index of detection sensitivity (Grier, 1971), for each condition. Thus, the analysis of detection sensitivity will not allow assessing differences in how emotion affects different trial types and consistent with previous research (Cromheeke & Mueller, 2015; Levens & Gotlib, 2010, 2012), RTs will be analysed as the main dependent variable. Accuracy scores for Experiment 3.1 are, however, presented in Appendix B.

Statistical analyses were conducted with SPSS 22 (IBM Corp., Armonk, NY). Detection sensitivity scores for the 1-back and 2-back tasks were submitted to a mixed factors ANOVA including the within-subjects factors load (1-back vs. 2-back), task instructions (emotional vs. non-emotional), and emotion (angry vs. neutral vs. happy) as well as the between-subjects factor of age (younger vs. older). RTs for correct responses were analysed with the same factors as above plus an additional within-subjects factor of trial type (match vs. no match), allowing the assessment of emotion effects on different trial types. Bonferroni-corrected post-hoc t-tests were performed to follow up significant main effects and interactions. All tests were two-tailed with $\alpha = .05$. All statistical results for detection sensitivity and RTs are presented in Table 3.2, and separate results for emotion instructions and age instructions are reported in Table 3.3. Results that were relevant for the hypotheses are reported in the text below.

Results

Detection sensitivity

Discrimination sensitivity scores in both age groups under instructions to focus on the emotional expression or the age of the faces are presented in Figure 3.2. The four-way omnibus ANOVA (see Table 3.2) yielded a main effect of age, which was driven by lower detection sensitivity in older (*M* = 74.59, *SD* = 6.91) than in younger adults (*M* = 80.11, *SD* = 6.02). There was also a significant task instructions × emotion interaction, which qualified the main effect of emotion. It was relevant for hypothesis 1 predicting a facilitating effect of task-relevant but not of task-irrelevant emotion. Separate analyses were conducted for performance under emotional and non-emotional task instructions and there was a main effect of task-relevant emotion under emotional task instructions (when participants responded to the emotion of the face, Table 3.3 and Figure 3.2, left).

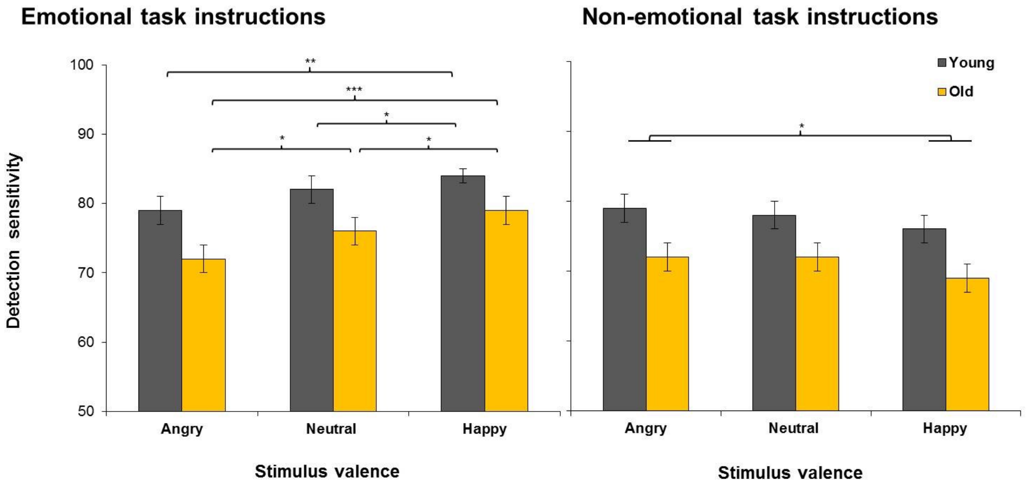

Figure 3.2. Detection sensitivity in younger and older adults in Experiment 3.1. Performance under emotional task instructions (i.e., emotion is task-relevant) is presented on the left and performance under non-emotional task instructions (i.e., emotion is task-irrelevant) is presented on the right, collapsed across the 1-back and 2-back tasks. Error bars represent SEM.

As expected, detection sensitivity was higher for happy (*M* = 81.94, *SD* = 8.77) than for neutral (*M* = 78.93, *SD* = 9.90), *t*(49) = 2.95, *p* = .005, or angry faces (*M* = 75.26, *SD* = 10.19), *t*(49) = 6.37, *p* < .001. Detection sensitivity was lower for angry than for neutral faces, *t*(49) = 3.40, *p* = .001. There was also a less pronounced main effect of task-irrelevant emotion under non-emotional task instructions (Figure 3.2, right). Participants showed lower sensitivity when responding to the age of happy (*M* = 72.47, *SD* = 9.36) than of angry faces (*M* = 75.15, *SD* = 9.00), *t*(49) = 2.53, *p* = .015. However, the difference in detection sensitivity for happy and neutral faces was non-significant (*p* = .057) as was the difference between angry and neutral faces (*p* = .576). The task instruction × emotion interaction was not part of any higher-order interaction. Contrary to the hypotheses that the effect of emotion would differ for younger and older adults (hypotheses 2a. and 2b.) and that any emotion × age interactions would be attenuated by load (hypothesis 3), the task instruction × emotion interaction did not change with age or load (see Tables 3.2 and 3.3).

Table 3.2. *Statistical results for performance in Experiment 3.1*

Effect	*F*	*MSE*	*p*	*Partial* η^2
Detection sensitivity				
Load	60.47	.02	<.001***	.56
Task instructions	35.22	.01	<.001***	.42
Emotion	4.30	.01	.016*	.08
Age	9.08	.05	.004**	.16
Load × Task instructions	3.99	.01	.051	.08
Load × Emotion	.65	<.01	.526	.01
Load × Age	7.75	.02	.008**	.14
Task instructions × Emotion	19.15	.01	<.001***	.29
Task instructions × Age	1.14	.01	.291	.02
Emotion × Age	.56	.01	.571	.01
Load × Task instructions × Emotion	1.04	<.01	.358	.02
Load × Task instructions × Age	7.39	.01	.009**	.13
Load × Emotion × Age	.39	<.01	.681	.01
Task instructions × Emotion × Age	.23	.01	.791	.01
Load × Task instructions × Emotion × Age	.06	<.01	.944	<.01
Correct response time				
Load	31.10	76418	<.001***	.39
Task instructions	14.21	15855	<.001***	.23
Trial type	54.97	17059	<.001***	.53
Emotion	31.43	5366	<.001***	.40
Age	69.39	14712	<.001***	.59
Load × Task instructions	8.52	7988	.005**	.15
Load × Trial type	11.22	11391	.002**	.19
Load × Emotion	4.45	7494	.014*	.09
Load × Age	11.16	76418	.002**	.19
Task instructions × Trial type	2.07	8417	.157	.04
Task instructions × Emotion	23.32	7439	<.001***	.33
Task instructions × Age	3.12	15855	.084	.06
Trial type × Emotion	31.83	6086	<.001***	.40
Trial type × Age	.42	17059	.522	.01
Emotion × Age	.18	5366	.535	<.01
Load × Task instructions × Trial type	4.44	5681	.040*	.09
Load × Task instructions × Emotion	.32	5004	.728	.01

Load × Task instructions × Age	3.70	7988	.060	.07
Load × Trial type × Emotion	1.44	4268	.243	.03
Load × Trial type × Age	.01	11391	.909	<.01
Load × Emotion × Age	.34	7494	.715	.01
Task instructions × Trial type × Emotion	36.15	7024	<.001***	.43
Task instructions × Trial type × Age	.39	8417	.534	.01
Task instructions × Emotion × Age	.85	7439	.432	.02
Trial type × Emotion × Age	2.85	6068	.063	.06
Load × Task instructions × Trial type × Emotion	1.24	4689	.294	.03
Load × Task instructions × Trial type × Age	.61	12178	.520	.01
Load × Task instructions × Emotion × Age	1.36	5004	.261	.03
Load × Trial type × Emotion × Age	1.50	4268	.228	.03
Task instructions × Trial type × Emotion × Age	1.97	7024	.145	.04
Load × Task instructions × Trial type × Emotion × Age	3.46	4689	.035*	.07

Note. *p < .05, **p < .01, ***p < .001

Table 3.3. *Statistical results for performance in Experiment 3.1, separated by instructions*

	Emotional task instructions				Non-emotional task instructions			
Effect	*F*	*MSE*	*p*	*Partial* η^2	*F*	*MSE*	*p*	*Partial* η^2
Detection sensitivity								
Load	57.27	.01	<.001***	.54	32.79	.01	<.001***	.41
Emotion	21.17	.01	<.001***	.31	3.51	.01	.034*	.07
Age	5.12	.03	.028*	.10	10.67	.03	.002*	.18
Load × Emotion	1.00	<.01	.371	.02	.75	.01	.474	.02
Load × Age	13.88	.01	.001**	.22	1.00	.01	.323	.02
Emotion × Age	.34	.01	.714	.01	.44	.01	.644	.01
Load × Emotion × Age	.19	<.01	.830	<.01	.23	.01	.793	.01
Correct response time								
Load	47.39	34276	<.001***	.50	16.36	50130	<.001***	.25
Target type	60.83	9951	<.001***	.56	22.53	15525	<.001***	.32
Emotion	45.41	7412	<.001***	.49	1.02	5393	.363	.02
Age	59.06	189205	<.001***	.56	74.42	179730	<.001***	.61
Load × Trial type	2.00	9874	.164	.04	18.51	7197	<.001***	.28
Load × Emotion	2.61	6833	.079	.05	3.02	5665	.053	.06
Load × Age	17.51	34276	<.001***	.27	5.64	50130	.022*	.11
Trial type × Emotion	51.40	8667	<.001***	.52	.48	4443	.620	.01
Trial type × Age	1.01	9951	.320	.02	.02	15525	.880	<.01
Emotion × Age	.82	7412	.442	.02	.22	5393	.806	<.01
Load × Trial type × Emotion	1.01	9157	.393	.02	.11	5233	.464	.02
Load × Trial type × Age	.67	9874	.416	.01	.57	7197	.453	.01
Load × Emotion × Age	1.17	6833	.315	.02	.24	5665	.788	.01
Trial type × Emotion × Age	3.06	8667	.049*	.06	.95	4443	.390	.02
Load × Trial type × Emotion × Age	4.99	3724	.009**	.09	.77	5233	.464	.02

Note. *$p < .05$, **$p < .01$, ***$p < .001$

Reaction times

The five-way omnibus ANOVA revealed a task instructions × emotion interaction, which qualified the main effect of emotion. The interaction was further qualified by a task instructions × trial type × emotion interaction (see Table 3.2). These interactions were relevant for hypothesis 1, predicting a facilitating effect of task-relevant but not of task-irrelevant emotion on updating. There was no significant task instructions × emotion × age interaction, as per hypotheses 2a. and 2b. However, it was part of a five-way load × task instructions × trial type × emotion × age interaction, qualifying the task instructions × emotion and the task instructions × trial type × emotion interactions. This higher-order interaction was relevant for the hypothesis 3, according to which load would attenuate emotion × age interactions. RTs for match and non-match trials under emotional instructions in the 1-back and 2-back tasks are presented in Figure 3.3. RTs for match and non-match responses under non-emotional instructions in the 1-back and 2-back tasks are presented in Figure 3.4. There was also a main effect of age, which was driven by slower RTs in older (*M* = 1154 ms, *SD* = 121 ms) than in younger adults (*M* = 868 ms, *SD* = 121 ms).

Separate analyses for performance under emotional and non-emotional instructions were conducted to follow up the task instructions × trial type × emotion and load × task instructions × trial type × emotion × age interactions (see Table 3.3). There was a trial type × emotion interaction under emotional instructions, but not under non-emotional instructions. Separate analyses for match and non-match trials under emotional instructions revealed a main effect of emotion for match trials, $F(2, 96) = 57.18$, $MSE = 8122$, $p < .001$, partial $\eta^2 = .54$, as match responses were faster for happy faces (*M* = 880 ms, *SD* = 198 ms) than for neutral (*M* = 970 ms, *SD* = 198 ms), $t(49) =$

6.77, $p < .001$, or angry faces (M = 1047 ms, SD = 199 ms), $t(49) = 11.99$, $p < .001$. Match responses were also faster for neutral faces than for angry faces, $t(49) = 5.51$, $p < .001$. Analyses for non-match responses also revealed a main effect of emotion, $F(2, 96) = 7.36$, $MSE = 7098$, $p = .001$, partial $\eta^2 = .13$.

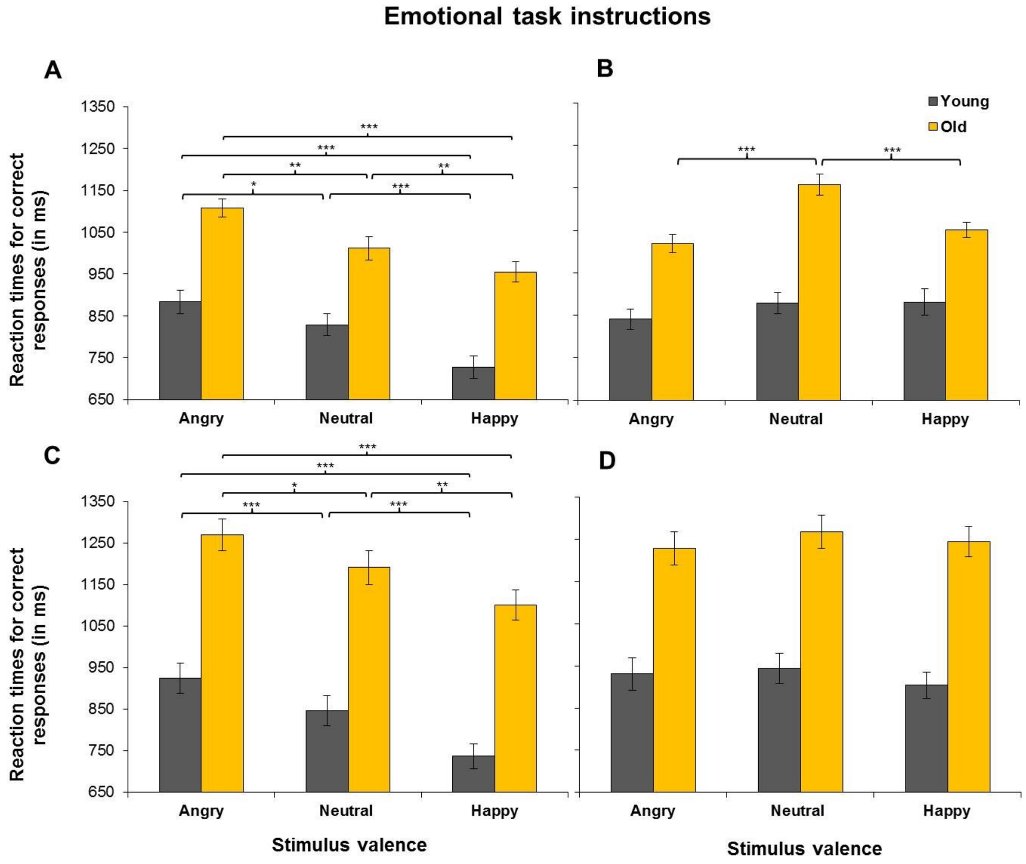

Figure 3.3. RTs for correct match responses on the left (A and C) and non-match responses on the right (B and D) in Experiment 3.1. Performance under emotional task instructions (i.e., emotion is task-relevant) is shown. RTs for the 1-back task are presented in the upper half (A and B) and RTs for the 2-back task are presented in the lower half (C and D). Error bars represent SEM.

Similarly to match trials, non-match responses were faster for happy faces (M = 1020 ms, SD = 186 ms) than for neutral faces (M = 1062 ms, SD = 206 ms), $t(49) = 3.26$, $p = .002$. However, contrary to the pattern for match responses, non-match responses to angry faces (*M* = 1005 ms, *SD* = 183 ms) were also faster than for neutral faces, *t*(49) = 4.47, *p* < .001, with no difference between angry and happy faces (*p* = .117).

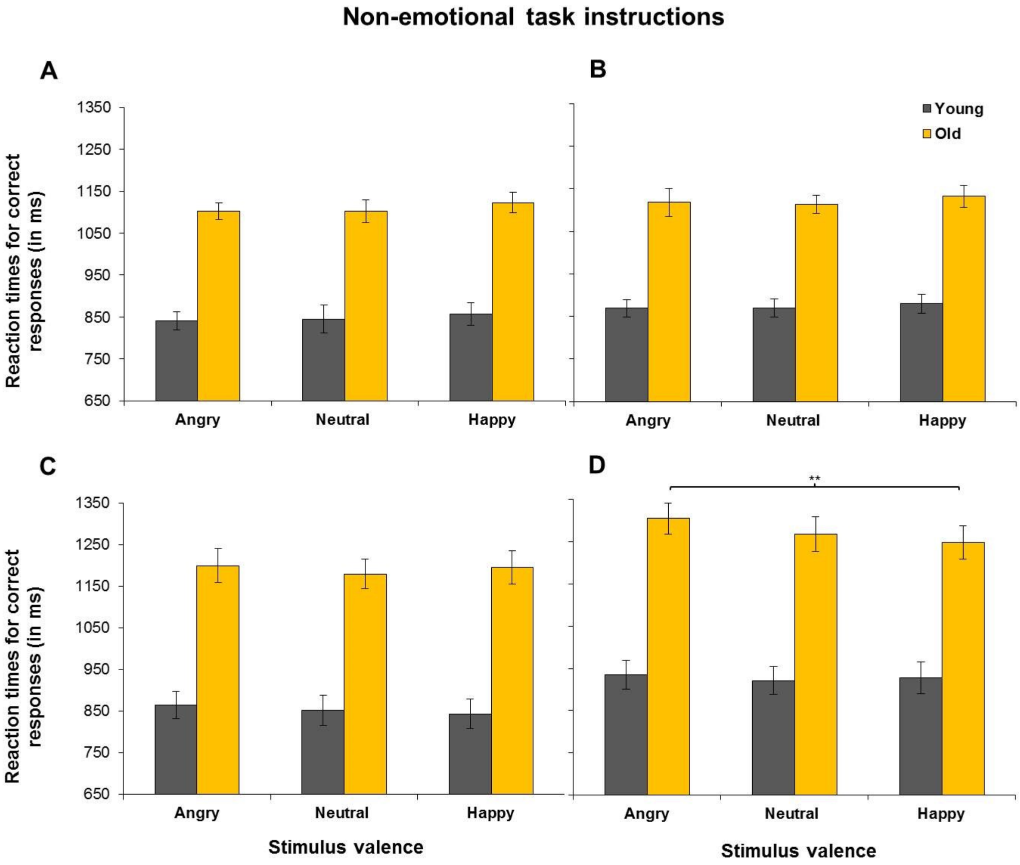

Figure 3.4. RTs for correct match responses on the left (A and C) and non-match responses on the right (B and D) in Experiment 3.1. Performance under non-emotional task instructions (i.e., emotion is task-irrelevant) is shown. RTs for the 1-back task are presented in the upper half (A and B) and RTs for the 2-back task are presented in the lower half (C and D). Error bars represent SEM.

The task instructions × trial type × emotion interaction was qualified by a load × trial type × emotion × age interaction, which was not significant (*p* = .464) under non-emotional instructions. Separate analyses for 1-back and 2-back data yielded a response × emotion × age interaction in the 1-back task, *F*(2, 96) = 7.78, *MSE* = 56666, *p* = .001, partial η^2 = .14, but not in the 2-back task (*p* = .811). As a next step, only 1-back data were analysed. Separate analyses for match and non-match trials under emotional instructions revealed an emotion × age interaction for non-match trials, $F(2, 96) = 7.34$, $MSE = 6102$, $p = .001$, partial $\eta^2 = .13$. In contrast, the interaction was non-significant match trials ($p = .336$).

For non-match trials, post-hoc t-tests revealed that older adults were faster in making non-match responses to happy ($M = 1051$ ms, $SD = 92$ ms) than to neutral faces ($M = 1157$ ms, $SD = 124$ ms), $t(24) = 4.25$, $p < .001$. They were also faster in making non-match responses to angry ($M = 1019$ ms, $SD = 108$ ms) than to neutral faces, $t(24) = 5.07$, $p < .001$, with no difference between RTs for happy and angry faces (p = .066). In younger adults, the difference between RTs for angry and neutral faces missed significance ($p = .068$). Moreover, there were no differences between RTs for happy and neutral faces ($p = .930$), or between RTs for angry and happy faces ($p = .083$). Thus, it appears that older adults' performance for non-match trials was driving the response × emotion interaction reported above.

Discussion

Experiment 3.1 demonstrated that emotion can have both enhancing and impairing effects on n-back performance. It was observed that task-relevant positive emotion facilitated performance in both age groups, with better detection sensitivity for happy compared to neutral or angry faces. In contrast, detection sensitivity for angry task-relevant faces was reduced compared to neutral or happy faces. Moreover, differential effects of emotion in the two age groups were found for RTs. Whereas all participants responded faster to task-relevant happy and slower to task-relevant angry faces on match trials, only older adults made faster non-match responses on trials with happy and angry relative to neutral probes. This speed-up effect for emotional faces in older adults was only observed under low-load conditions (1-back task) but not under high-load conditions (2-back task). In addition, it was found that task-irrelevant emotion did not impair performance in neither of the two age groups. When instructed to respond to the age of the faces, both younger and older adults showed similar performance for emotional and neutral faces (despite lower detection sensitivity for happy relative to angry faces). This suggests that both age groups were able to ignore consistently task-irrelevant emotion and that older adults were not more susceptible to interference from task-irrelevant emotion than younger adults.

Facilitating effects of task-relevant emotion on WM updating

The finding that both younger and older adults responded more accurately and faster to task-relevant happy relative to neutral or angry probes supported the prediction that positive emotion would facilitate performance. The finding of a facilitating effect of happy faces is consistent with previous findings of faster updating of positive compared to neutral or negative stimuli (Cromheeke & Mueller, 2015; Pe, Koval, et al., 2013) and with findings showing that non-depressed adults integrated and matched happy faces in WM faster than neutral or sad faces (Levens & Gotlib, 2010).

Smiling faces might improve WM updating as they are generally more quickly and accurately recognised than other expressions (Becker et al., 2011; Becker & Srinivasan, 2014; Juth et al., 2005). As reviewed by Becker and Srinivasan (2014) and discussed in Chapter 2, happy faces are believed to be prioritised in attention and memory by the perceiver due to their contribution to important social goals such as forestalling conflict. Becker and Srinivasan (2014) also suggested that the low-spatial-frequency visual properties of happy faces facilitate their efficient recognition. In the present study, the happy face advantage was observed across all loads, which supports research showing that identifying happy faces requires few cognitive resources (Becker & Srinivasan, 2014; Srivastava & Srinivasan, 2010).

An additional factor could be the rewarding value of smiling faces. Previous research has shown that happy faces were rated as being more attractive (O'Doherty et al., 2003; Otta et al., 1996), more approachable (Tsukiura & Cabeza, 2008) and were found to engage the orbitofrontal cortex, which is associated with reward (O'Doherty et al., 2003; Tsukiura & Cabeza, 2008). It is likely that the rewarding value of happy faces contributed to the happy face advantage in this study as motivational processes were found to affect key cognitive control processes such as inhibition, shifting and updating (Pessoa, 2009, 2015, 2017). According to the dual competition framework, reward modulates cognitive control by fine-tuning executive functions that are needed for the task through efficient orienting of attention (e.g., sharpening updating processes in an n-back task) and by rearranging the allocation of more general common-pool resources (Pessoa, 2009, 2015, 2017).

Thus, it is suggested that not only the perceptual features but also the rewarding nature of smiling faces facilitated fast and accurate responses in the present experiment. In contrast, participants showed lowest detection sensitivity for angry compared to neutral or happy faces and were also slowest when matching angry faces. These results are consistent with findings that threatening material can impair cognitive control (Pessoa, 2009, 2015, 2017). Although angry faces are often efficiently detected among distractors (Hansen & Hansen, 1988; Öhman et al., 2001), they were also found to be more difficult to disengage from once detected, resulting in longer dwelling times compared to non-threatening material (Fox et al., 2001).

Older adults benefit from task-relevant emotion more than younger adults

Crucially, Experiment 3.1 revealed that older adults showed greater benefits from task-relevant emotion than younger adults when responding to emotional probes in a WM updating task. Whereas both age groups made faster match responses to happy relative to neutral and angry faces, only older adults responded faster to emotional relative to neutral probes on non-match trials. This finding supports our prediction that older adults would benefit more from task-relevant positive emotion in an n-back paradigm. Additionally, it was observed that they also benefited from negative material when having to respond on non-match trials. Importantly, faster non-match responses for emotional relative to neutral trials were observed in older adults when task load was low, whereas this effect disappeared under high-load conditions.

In the present study, responses for non-match trials were found to be generally slower than for match responses, replicating previous findings (Y.-N. Chen et al., 2008; Szmalec et al., 2011; Verhaeghen & Basak, 2005). This difference in RTs for match and non-match trials suggests that additional processes were involved in non-match compared to match trials. It has previously been suggested that longer RTs in non-match trials can be attributed to replacing an old representation in WM with a new one, which is not needed on match trials (Verhaeghen & Basak, 2005). Thus, it appears that older adults benefited from task-relevant emotion when they had to perform this more complex non-match response. However, a more detailed task analysis is needed to understand which sub-processes are involved in non-match trials and which are affected by emotion in ageing. It is likely that a number of sub-processes from identifying a non-match to successfully replacing the old representation were needed. For instance, it is not clear whether a replacement has already been achieved when the response button is pressed or whether it has merely been initiated. A follow-up experiment will help to address this issue.

It is important to note that the facilitating effect of emotion on updating in older adults was only observed in the 1-back task, whereas no such facilitating effect was observed in the 2-back task. This pattern of reduced emotion effects under higher cognitive load is in line with SST (Carstensen, 1993), which suggests that older adults use cognitive resources to focus on emotional and particularly positive emotion, with load diminishing or even reversing this emotion bias (e.g., Mather & Knight, 2005). However, within this framework it could be expected that older adults place greater importance on positive emotion compared to younger adults (Carstensen, 1993; Carstensen & Mikels, 2005; Reed & Carstensen, 2012). In this study, however, the emotion benefit in older adults' updating performance was not more pronounced for positive compared to negative material. This valence-unspecific result is slightly more difficult to reconcile with the SST. Alternatively, it is possible that arousal facilitated processes involved in non-match responses to a greater extent in older than in younger adults. As it was only the case in the 1-back but not in the 2-back task, this could be linked to previous evidence that emotional responses are down-regulated when task load is high (Van Dillen et al., 2009). Future research could help to test whether the emotion benefit on non-match trials in the present experiment was in fact due to motivational processes or whether other explanations might fit the data better.

No age-related differences in the effects of task-irrelevant emotion on updating

When participants were asked to respond to the age of the faces, emotional expressions did not impair performance relative to neutral expressions in either age group. These results are similar to those by Cromheeke and Mueller (2015) who reported that adults were not affected by emotional expressions when updating the gender of faces. They are also compatible with previous studies, which found no differences in distractibility by emotional or neutral items during updating (Miendlarzewska et al., 2013; Mullin et al., 2012; Ozawa et al., 2014).

Contrary to the hypotheses, older adults were not more susceptible to distraction from task-irrelevant emotion than younger adults. This is in contrast to findings of impairments in older adults' performance in previous studies using a delayed-response WM task (Truong & Yang, 2014) or a binding short-term memory task (Borg et al., 2011) with task-irrelevant emotion. It is possible that methodological differences contributed to the conflicting results. In Truong and Yang's study (2014), participants were required to ignore distractor words that were presented intermixed with target words. Each word was presented one at a time and participants were not able to predict whether the next word would be a target or distractor, requiring them to flexibly recruit different mechanisms such as inhibition of distractors and rehearsal of targets on a trial-by-trial basis.

In contrast, in the present research, older adults were not required to ignore a stimulus but to respond to a non-emotional feature when emotion was task-irrelevant. Also, participants were asked to do so for the duration of an entire block, so they did not have to flexibly apply different strategies on different trials. Research suggests that older adults find it more difficult than younger adults to maintain two different task sets (Verhaeghen & Basak, 2005; Verhaeghen & Cerella, 2002) and to perform task switching in unpredictable designs (Kray et al., 2002). Thus, it is possible that flexibly applying different processes to distractors and targets in an unpredictable design, which was not needed in the present experiment, affected older adults' performance in Truong and Yang's study (2014). Borg et al. (2011) asked participants to bind negative and neutral pictures with their respective locations on the screen and found less accurate binding for negative compared to neutral pictures in older but not younger adults. Although binding the pictures with their respective locations was the target task in the experiment, emotion was not explicitly task-irrelevant and might have been included in the participants' goal structure, affecting their performance. This is different from the current study in which participants' attention was explicitly directed to the age of the faces and thus to the faces' non-emotional features. These task differences might explain why no impairing effect of task-irrelevant emotion was observed in the present experiment contrary to results reported in previous research.

Although there was no difference in detection sensitivity between emotional and neutral faces, discrimination sensitivity was lower when participants had to respond to the age of happy compared to angry faces. It is possible that participants attended to the rewarding but task-irrelevant facial features in order to maximise reward, making them more susceptible to mistakes. Alternatively, discrimination sensitivity for the ages of happy faces was low due to difficulties to estimate the age of smiling faces. Previous research has shown that age estimates were particularly inaccurate for smiling faces compared to other expressions (Ganel, 2015; Voelkle, Ebner, Lindenberger, & Riediger, 2012), but the reasons remain unclear. In one study, smiling faces were judged as being older than neutral faces (Ganel, 2015), which was attributed to wrinkles around the eyes and the eyes' narrowing in a smiling face. In the other study, smiling faces were judged as being younger than those with other expressions (Voelkle et al., 2012), which was attributed to the attractiveness of smiling faces and the prevailing stereotype associating youth with happiness. In the present experiment, participants were not asked to provide an age estimate. Instead they were asked to assign the face to one of three broad age groups (i.e., young, middle-aged, old), which was relatively straightforward to do. It is also important to note that, according to the evaluation data for the stimuli (see Appendix A), age estimates for neutral and emotional expressions did not vary much and were all within the age group boundaries. Thus, the task should have been manageable despite potential effects of emotional expressions on age ratings. However, it is possible that factors such as distortions through wrinkles, higher attractiveness or stereotypes associated with happiness contributed to "noise" when responding to the age of happy compared to angry faces, thereby reducing discrimination sensitivity.

To conclude, the study contributed to research differentiating between enhancing and impairing effects of emotion on WM updating in younger and older adults. When emotion was task-relevant, happy faces facilitated better performance in both age groups. Crucially, this study showed that older adults benefited more from the inclusion of emotional material in an updating task and that they were not more susceptible to distraction from task-irrelevant emotion than younger adults.

3.4. Angry lures: Auxiliary analyses of data from Experiment 3.1

One of the main results observed in Experiment 3.1 was that older adults benefited from emotion in the 1-back task, as their non-match responses were faster for emotional faces than for neutral faces. As no such effects were observed for match trials, it appears that the benefits were specific to the processes that took place during non-match trials in the 1-back task.

Research suggests that previous items can have an effect on responses to the current probe in an updating task (Kensinger & Corkin, 2003; Levens & Gotlib, 2010, 2012) and we attempted to assess how the old representation, which had to be replaced in a 1-back task, affected updating performance. To do this, we split the 1-back RT data not only by the emotion of the currently presented face (i.e., probe) but also by the emotion of the face that needed to be replaced (i.e., target). The RT data for non-match responses in the 1-back task are presented in the left panel of Figure 3.5. Only non-match responses were compared as they require an updating process whereas match trials do not (Verhaeghen & Basak, 2005). As can be seen in the left panel of Figure 3.5, RTs were slower for neutral probes with angry targets (*M* = 1059 ms, *SD* = 213 ms) than for angry probes with neutral targets (*M* = 990 ms, *SD* = 169 ms), *t*(49) = 3.36, *p* = .002. Similarly, RTs were slower for neutral probes with happy targets (*M* = 993 ms, *SD* = 197 ms) than for happy probes with neutral targets (*M* = 947 ms, *SD* = 160 ms), *t*(49) = 2.27, *p* = .028. Thus, it appears that in the 1-back task, replacing old representations with new emotional ones was faster than replacing them with neutral items. However, it should be noted that the effects of the probe and the 1-back target were conflated in this comparison. Additionally, the effects of angry and happy 1-back targets for neutral probes were compared. It was found that RTs were slower if the previous target was angry (*M* = 1075 ms, *SD* = 217 ms) rather than happy (*M* = 1008 ms, *SD* = 195 ms), *t*(49) = 2.64, *p* = .011. This suggests that replacing an angry face in WM was slower than replacing a happy face. RTs for non-match responses to neutral probes in the 1-back task are presented in Figure 3.6, left panel.

To further assess the effects of the previous emotion on WM updating, the 2-back RT data were split not only by the emotion of the currently presented face (i.e., probe) but also by the emotion of the 1-back face, which needed to be kept and manipulated in WM (i.e., lure). The RT data for match responses in the 2-back task are presented in the right panel of Figure 3.5. RTs for non-match responses in a 2-back paradigm were not compared due to the fact that no emotion was presented repeatedly in the 2-back task in Experiment 3.1. Thus, 1-back lures were always different from 2-

back targets and trials with different 1-back lures also had different 2-back targets (e.g., happy 1-back lure with angry 2-back target or angry 1-back lure with happy 2-back target for neutral non-match responses). Thus, the effects of targets and lures would have been intermixed in this type of comparison.

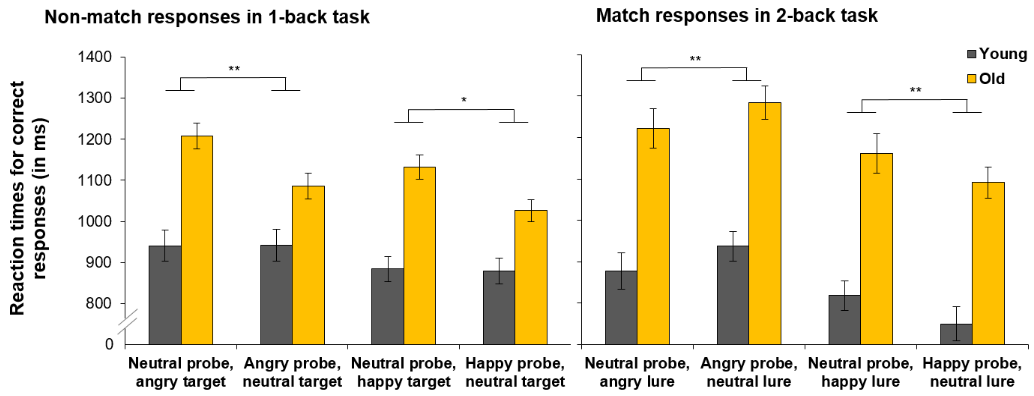

Figure 3.5. RTs for non-match responses as a function of probe and target in the 1-back task (left panel) and for match responses as a function of probe and lure in the 2-back task (right panel). Data are taken from Experiment 3.1.

As can be seen in the right panel of Figure 3.5, match responses to neutral probes with happy lures were slower (*M* = 989 ms, *SD* = 268 ms) than to happy probes with neutral lures (*M* = 920 ms, *SD* = 255 ms), *t*(49) = 3.56, *p* = .001. This suggests that neutral probes slowed responses down relative to happy probes, which is consistent with results from the 1-back task. However, this pattern of results could also indicate that neutral 2-back targets slowed responses down relative to happy 2-back targets. In contrast, match responses to neutral probes with angry lures were faster (*M* = 1050 ms, *SD* = 281 ms) than to angry probes with neutral lures (*M* = 1110 ms, *SD* = 255 ms), *t*(49) = 3.01, *p* = .004. Given that angry probes were found to speed up responses relative to neutral probes in the 1-back task (see above), this contrasting pattern of results could suggest that angry 2-back targets slowed responses down relative to neutral 2-back targets.

Again, the effects of the probe and target were conflated in this comparison and it was not possible to disentangle them at this stage.

Additionally, it is also likely that 1-back lures affected RTs in the 2-back task as well. In order to get a better understanding of the effects of 1-back lures, match responses to neutral probes with happy and angry 1-back lures were compared. It can be seen that responses were slower if the 1-back lure was angry (*M* = 1050 ms, *SD* = 281 ms) rather than happy (*M* = 989 ms, *SD* = 268 ms), *t*(49) = 2.47, *p* = .017. This suggests that having to maintain and to manipulate angry 1-back lures slowed responses down relative to happy 1-back lures. RTs for match responses to neutral probes in the 2-back task are presented in Figure 3.6, right panel.

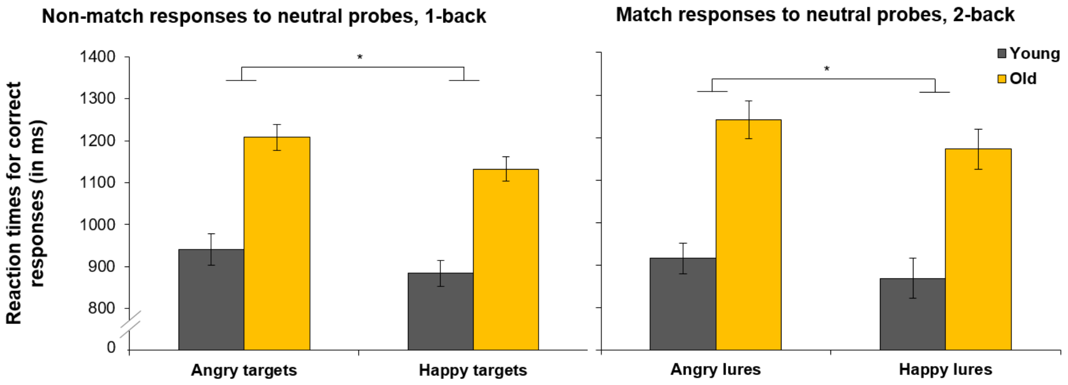

Figure 3.6. RTs for non-match responses to neutral probes in the 1-back task (left panel) and for match responses to neutral probes in the 2-back task (right panel). Data are taken from Experiment 3.1.

Taken together, the auxiliary analyses suggest that the emotion of lures and targets affected WM updating additionally to the emotion of the probe. The analyses also suggest that the effects of angry and happy faces differed and that the effects of angry faces were dependent on the face's status as the probe, lure or target: On the one hand, participants were faster to respond to angry vs. neutral probes in the 1-back task. On the other hand, participants were slower if the 1-back targets that needed to be replaced were angry rather than happy. A negative impact of angry faces was also observed in the 2-back task as participants responded slower if the 2-back targets were angry rather than neutral and if the 1-back lure was angry rather than happy. In contrast, happy faces facilitated performance independently of their status as probe, lure or target.

Due to their uniform effect on updating, happy faces will not be included in further experiments. Instead, focus will be placed on investigating the effects of angry lures and targets on WM updating in Experiment 3.2. Furthermore, due to a low number of relevant observations, it was not possible to include age as a separate factor in a formal analysis. Age-related differences in the effects of angry faces on WM will therefore be examined in the following dedicated experiment.

3.5. Experiment 3.2: The effects of angry lures in the WM buffer

The present experiment was designed to investigate the effects of angry 1-back and 3-back lures and 2-back targets on updating in a 2-back task. An additional aim was to explore whether the effects of angry faces, which have to be maintained and manipulated in WM, differed in younger and older adults.

One possible reason for why angry lures and targets might have more detrimental effects on WM performance relative to neutral lures and targets might be the greater cognitive cost associated with manipulating threatening relative to non-threatening material in WM. Successful updating relies on the ability to flexibly bind and unbind items to their contexts and participants have to find a balance between maintaining and replacing representations (Szmalec et al., 2011). It is possible that threatening material like angry faces is more difficult to bind and unbind as it tends to draw cognitive resources needed for executive control (Pessoa, 2009). Moreover, threatening stimuli such as angry faces were found to be more difficult to disengage from compared to non-threatening material (Fox et al., 2001), which could impair binding and unbinding in WM. Negative information was also found to be more complex than neutral or positive information (Bohner et al., 1988; Peeters & Czapinski, 1990), which might place greater demands on WM performance. Taken together, the manipulation of angry faces in WM could be expected to be more effortful and require more time and cognitive control relative to neutral faces.

It is possible that older adults would be affected by angry lures and targets to a greater extent than their younger counterparts due to overall reduced cognitive resources in ageing (e.g., Braver & West, 2008; L. H. Phillips & Henry, 2008; Reuter-Lorenz & Sylvester, 2005; Salthouse, 1990). Indeed, research suggests that binding processes for emotional and particularly negative items – whether they are currently task-relevant (i.e., targets) or task-irrelevant (i.e., lures) – could be impaired in ageing. For instance, Borg et al. (2011) found that when asked to bind negative or neutral pictures with their respective locations on the screen, older adults were less accurate to indicate the original location of negative but not neutral pictures, whereas younger adults showed no such difference. All emotional items were task-relevant targets in Borg et al.'s study (2011), showing that emotional items do not necessarily have to be task-irrelevant to affect cognitive performance in ageing.

Researchers have also highlighted the negative impact of task-irrelevant emotional material on binding in ageing. For instance, Pehlivanoglu et al. (2014) used an n-back paradigm with emotional faces and found age-related deficits in unbinding task-irrelevant emotional information under higher (i.e., 2-back task) cognitive load. In fact, Szmalec et al. (2011) suggested that inefficient binding and unbinding during the updating process could make participants more susceptible to interference from lures (i.e., not n-back targets but neighbouring n+1 or n-1 items). The authors highlighted that in order to reduce interference from lures, controlled recollection processes were needed. With reduced recollection in ageing (Bastin & Van der Linden, 2003; Jacoby, Bishara, Hessels, & Toth, 2005; Jennings & Jacoby, 1997), this control process can be expected to be less efficient, making the tagging of material as task-relevant and task-irrelevant difficult in older adults. Overall, these findings suggest that updating of both emotional lures and targets should be affected by ageing due to inefficient binding of emotional material.

Evidence for age-related susceptibility to cues of familiarity from lures in an n-back paradigm has been reported before (Schmiedek et al., 2009). According to the authors, older adults relied more on familiarity as a source of information on how much a probe matched a target than younger adults did. The authors suggested that this could indeed be a strategic adaptation to less efficient recollection memory in ageing. Should binding and unbinding be less efficient for angry relative to neutral faces in ageing, it can be expected that older adults will be more affected by interference from angry relative to neutral lures. Moreover, it can be expected that the interference effect will be particularly pronounced when angry probes follow angry lures, as they are likely to cue familiarity compared to neutral probes.

Further investigation of older adults' ability to bind and unbind angry faces in WM could also help interpreting the results observed in Experiment 3.1. It was found that older but not younger adults responded faster to emotional faces, including angry faces, than to neutral faces when having to give a non-match response. In contrast, match responses were slowest for angry faces in both age groups. As updating – the replacement of old representations with new ones – is only required on non-match trials, the results could indicate that older adults benefit from emotion, including angry expressions, when having to replace an old representation. However, it is not clear whether updating processes are indeed completed by the time participants make their response on non-match trials. It is also possible that other processes such as identifying a non-match in the presence of emotional faces or initiating the updating process were sensitive to emotion and age, resulting in faster non-match responses in older adults. As more detailed task analyses are not available to this date, it is not clear which of the sub-processes were sensitive to emotion and which were driving the effect. The design of the present experiment will help to assess how updating is affected in ageing by considering full sequences rather than responses to the probe only.

Thus, the present experiment was designed to follow up results from Experiment 3.1 and to assess how angry lures and targets affect updating in younger and older adults in a 2-back task. As the ability to replace old with new representations was of interest for the present experiment, RTs for non-match responses were the focus here. Based on the results of the previous experiment and the literature reviewed in this section, the following hypotheses were assessed: 1. Angry 1-back lures will slow down non-match responses relative to neutral 1-back lures to a greater extent in older than in younger adults. 2. The slow-down effect for angry 1-back lures in ageing will be more pronounced in trials with angry relative to neutral probes. To assess whether this slow-down effect of angry lures would also be observable for 3-back lures, position in the WM buffer was also included in the analysis. 3. Angry 2-back targets will slow down responses relative to neutral 2-back targets to a greater extent in older than in younger adults.

Methods

Participants

Thirty-one younger adults (18 – 40 years old) and 31 older adults (60 – 78 years old) participated in the present research (see Table 4 for participant characteristics). Younger and older adults met the same criteria as in Experiment 3.1 and were reimbursed in the same manner. None of the participants involved in Experiment 3.2 had participated in Experiment 3.1. As can be seen in Table 3.4, older adults outperformed younger adults on the NART (Nelson & Willison, 1991), suggesting better vocabulary knowledge, and scored lower on the Digit Symbol Substitution Test from the WAIS-R (Wechsler, 1955), suggesting slower processing speed. No other differences were observed. The ethics board of Birkbeck, University of London, approved the procedure prior to the start of the study and written informed consent was obtained from each individual.

Table 3.4. *Participant characteristics, Experiment 3.2*

	Younger adults		Older adults		Group difference	
Variable	*M*	*SD*	*M*	*SD*	*t*	*p*
Age (years)	25.03	5.57	68.84	4.55		
Gender (male/female)	11/20		10/21			
Education (years)	16.73	2.45	16.52	3.11	0.3	.769
NART Verbal IQ	106.82	8.05	118.81	4	-7.13	<.001***
Digit Symbol Test	73.84	8.76	52.68	9.16	9.3	<.001***
BDI II	4.65	4.92	4.23	4.21	0.36	.720
STAI Trait Anxiety	34.13	7.44	34.23	8.39	-0.05	.962
MMSE			29.4	0.72		

Note. NART = The National Adult Reading Test, BDI II = Beck Depression Inventory II, STAI = State-Trait Anxiety Inventory, MMSE = Mini-Mental State Examination; **p* < .05, ***p* < .01, ****p* < .001

Materials

The same face stimuli were used as in Experiment 3.1.

Procedure

The procedure was identical to the procedure for Experiment 3.1, with the difference that the computer task consisted of a 2-back task only. Participants were instructed to make "same" or "different" judgments based on the emotion of the current face (angry vs. neutral vs. happy), with the same trial presentation times as in Experiment 3.1. Contrary to Experiment 3.1, the emotional valence was relevant for task performance in all blocks and there was no other feature of the stimulus that participants had to respond to. Trial presentation was the same as in Experiment 3.1. Participants were instructed to to compare the current facial expression with the expression presented two trials earlier and to respond by pressing one of two labelled buttons ("S" for same, "D" for different). On the computer keyboard, the buttons "1" and "2" of the numeric keypad were used and participants were instructed to leave the index finger and middle finger on the two buttons for the duration of the task. The 2-back task consisted of 576 trials that were separated into twelve blocks of 48 items. Twenty-four practice trials were presented before the experimental blocks. All 72 stimuli were included in the 2-back task and each item was presented on average 8 times during the task. In order to assess the effects of the currently presented item, the 1-back lure and the 3-back lure, 14 different trial sequences were created (see Table 3.5). They were concatenated randomly for each participant and occurred once in each block, resulting in 12 observations for each sequence across the whole task.

To ensure that 50% of the items required a "same" response and 50% required a "different" response, filler trials were added that were not included in the analysis. In each block, 14 items were angry, 14 items were neutral and 20 items were happy. For the first two faces in each block of trials, participants viewed the faces without pressing a key; from the third face on, participants were instructed to start responding, resulting in 46 usable trials per block.

Table 3.5. *Trial sequences used in Experiment 3.2*

No	Lure 3-back	Target 2-back	Lure 1-back	Probe
1	Happy	Happy	Happy	Neutral
2	Happy	Happy	Neutral	Neutral
3	Happy	Neutral	Happy	Neutral
4	Neutral	Happy	Happy	Neutral
5	Happy	Happy	Angry	Neutral
6	Happy	Angry	Happy	Neutral
7	Angry	Happy	Happy	Neutral
8	Happy	Happy	Happy	Angry
9	Happy	Happy	Neutral	Angry
10	Happy	Neutral	Happy	Angry
11	Neutral	Happy	Happy	Angry
12	Happy	Happy	Angry	Angry
13	Happy	Angry	Happy	Angry
14	Angry	Happy	Happy	Angry

Trial types and statistical analysis

Participants' responses and RTs were recorded for each trial. For the analysis of RTs, any RTs faster than 200 ms or 2.5 standard deviations above or below the group mean were excluded, resulting in an exclusion of an average of 1.4% of trials for younger adults and 0.70% for older adults. For each condition, mean accuracy scores and median RTs for correct trials were calculated. Statistical analyses were conducted with SPSS 22 (IBM Corp., Armonk, NY). To assess the effects of angry vs. neutral probes and lures, accuracy scores and RTs for non-match responses for sequences 2, 4, 5, 7, 9, 11, 12 and 14 were submitted to a four-way mixed factors ANOVA including the within-subjects factors probe (angry vs. neutral), lure (angry vs. neutral), and position of lure (1-back vs. 3-back) as well as the between-subjects factor of age (younger vs. older adults).

Bonferroni-corrected post-hoc t-tests were performed to follow up significant main effects and all interactions. To assess the effects of angry vs. neutral targets, accuracy scores and RTs for sequences 3 and 13 (match responses) and for sequences 6 and 10 (non-match responses) were compared in two paired-samples t-tests. All tests were two-tailed with $\alpha = .05$.

Results

Angry vs. neutral probes and lures

Accuracy. Accuracy scores for probes as a function of the 1-back lure in younger and older adults are presented in Figure 3.7. The four-way omnibus ANOVA revealed a probe × age interaction, $F(1, 60) = 9.42$, $MSE = .02$, $p = .003$, partial $\eta^2 = .14$, which qualified a main effect of probe, $F(1, 60) = 12.70$, $MSE = .02$, $p = .001$, partial $\eta^2 = .18$. Separate analyses for the two age groups revealed that older adults responded overall more accurately to angry probes ($M = .84$, $SD = .11$) than to neutral probes, ($M = .76$, $SD = .14$), $t(30) = 4.15$, $p < .001$. No such difference in accuracy was observed in younger adults ($p = .683$). No main effect of lure was observed ($p = .938$), but there was a significant lure × age interaction, $F(1, 60) = 9.58$, $p = .003$, partial $\eta^2 = .14$, and a probe × lure interaction, $F(1, 60) = 20.67$, $p < .001$, partial $\eta^2 = .26$, which were both qualified by a significant probe × lure × age interaction, $F(1, 60) = 8.73$, $p = .004$, partial $\eta^2 = .13$. Separate analyses for the two age groups revealed that the probe × lure interaction was significant in older adults, $F(1, 30) = 18.90$, $p < .001$, partial $\eta^2 = .39$, whereas the interaction was non-significant in younger adults ($p = .126$). Post-hoc t-tests showed that when presented with a neutral probe, older adults responded less accurately when the lure was also neutral ($M = .71$, $SD = .18$) rather than angry ($M = .82$, $SD = .13$), $t(30) = 4.32$, $p < .001$. Similarly, when presented with an angry probe, older adults responded less accurately when the lure was also angry (*M* = .81, *SD* = .10) rather than neutral (*M* = .87, *SD* = .15), *t*(30) = 3.00, *p* = .005.

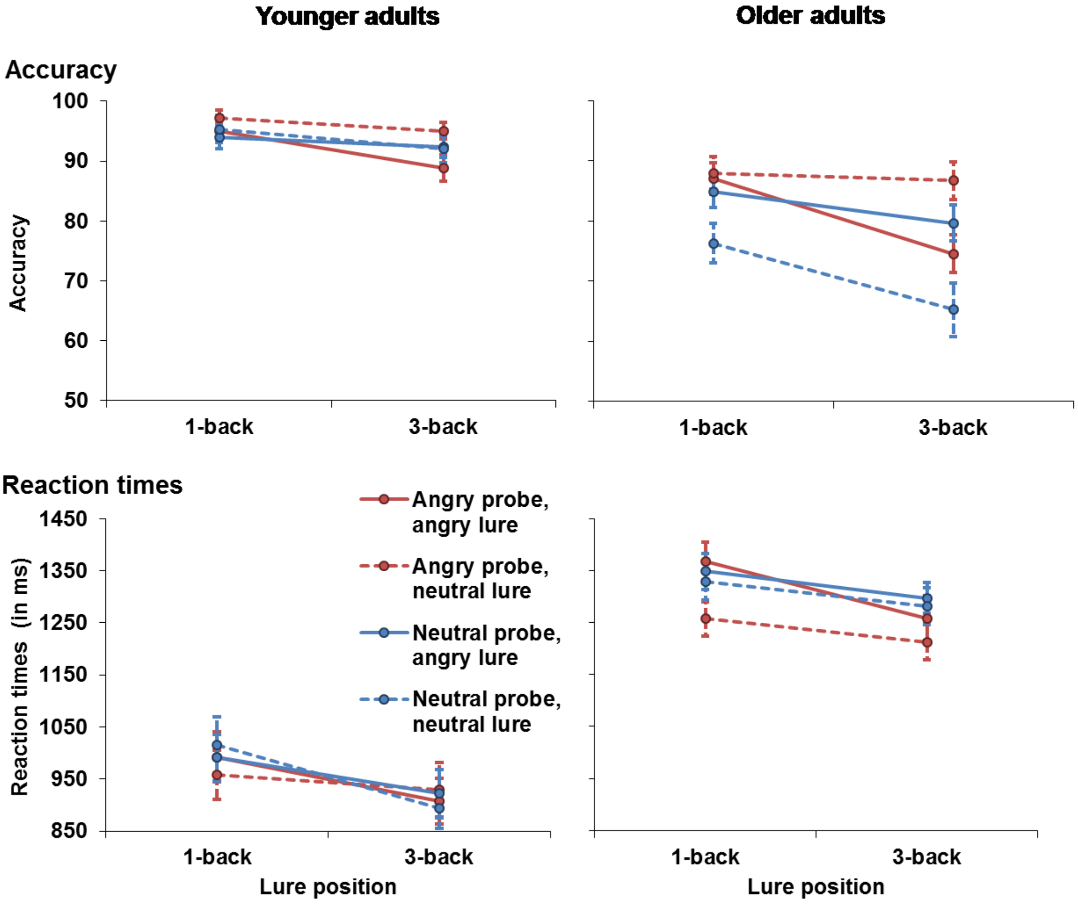

Figure 3.7. Accuracy (upper panel) and RTs (lower panel) for probes as a function of the 1-back lure in Experiment 3.2. Younger adults' data are presented on the left and older adults' data are presented on the right.

There was also a significant probe × lure × position interaction, *F*(1, 60) = 8.74, *p* = .004, partial η^2 = .13, which qualified the probe × lure interaction. Separate analyses for responses with 1-back lures and 3-back lures revealed a significant probe × lure interaction for 3-back lures, *F*(1, 61) = 21.13, *p* < .001, partial η^2 = .26. In contrast, this interaction missed significance for 1-back lures (*p* = .064). Post-hoc t-tests showed that when presented with an angry probe, responses were less accurate when the 3-back lure was also angry (*M* = .82, *SD* = .17) rather than neutral (*M* = .92, *SD* = .14), *t*(61) = 4.17, *p* < .001. Similarly, when presented with a neutral probe, responses were less accurate when the 3-back lure was also neutral (*M* = .79, *SD* = .24) rather than angry (*M* = .86, *SD* = .15), *t*(61) = 3.30, *p* = .002. Finally, there was a main effect of age, *F*(1, 60) = 30.69, *p* < .001, partial η^2 = .34, with overall lower accuracy in older adults (*M* = .80, *SD* = .11) than in younger adults (*M* = .94, *SD* = .07), *t*(60) = 5.54, *p* < .001. No further main effects or interactions were observed for accuracy scores.

Reaction times. RTs for probes as a function of the 1-back lure in younger and older adults are presented in Figure 3.7. The four-way omnibus ANOVA[1] revealed a main effect of probe, *F*(1, 59) = 4.77, *MSE* = 19160, *p* = .033, partial η^2 = .08, as RTs were faster for angry probes (*M* = 1110 ms, *SD* = 268 ms) than for neutral probes (*M* = 1135 ms, *SD* = 267 ms). Consistent with hypothesis 1 predicting that angry lures will interfere with performance in older adults, there was a lure × age interaction, *F*(1, 59) = 5.73, *p* = .020, partial η^2 = .09, qualifying the main effect of lure, *F*(1, 59) = 7.71, *MSE* = 11530, *p* = .007, partial η^2 = .12. Separate analyses for the two age groups revealed that older adults were slower when the lure was angry (*M* = 1318 ms, *SD* = 160 ms) rather than neutral, (*M* = 1271 ms, *SD* = 156 ms), *t*(29) = 3.15, *p* = .004. No such difference in RTs was observed in younger adults (*p* = .766). Moreover, a main effect of position of lure was observed, *F*(1, 59) = 31.76, *MSE* = 17639, *p* < .001, with 1-back lures being associated with slower responses (*M* = 1157 ms, *SD* = 267 ms) than 3-back lures (*M* = 1087 ms, *SD* = 267 ms). There was also a main effect of age, *F*(1, 59) = 43.45, *MSE* = 323077, *p* < .001, with slower responses in older adults (*M* = 1294 ms,

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[1] Data from one older participant were excluded from the analyses for RTs as this participant had no correct responses to one of the target sequences.

SD = 152 ms) than in younger adults (*M* = 951 ms, *SD* = 238 ms). No further main effects or interactions were observed for RTs.

Angry vs. neutral targets

Accuracy. Accuracy scores for targets in younger and older adults are presented in Figure 3.8. On match trials, participants were less accurate for angry (*M* = 88.83, *SD* = 16.93) than for neutral matches (*M* = 80.38, *SD* = 18.53), *t*(61) = 3.75, *p* < .001. Separate t-tests for younger and older adults revealed that this pattern was particularly pronounced for younger adults. Their accuracy scores were lower for angry (*M* = 84.04, *SD* = 11.85) than for neutral matches (*M* = 94.88, *SD* = 9.84), *t*(30) = 5.36, *p* < .001. In contrast, accuracy scores in older adults were not different between angry and neutral matches *p* = .395). On non-match trials, participants were less accurate when the 2-back target was angry (*M* = 80.38, *SD* = 18.53) rather than neutral (*M* = 88.83, *SD* = 16.98), *t*(61) = 2.20, *p* = .032. Separate t-tests for younger and older adults showed that older adults were driving this effect. Their accuracy was lower if the 2-back target was angry (*M* = 80.01, *SD* = 18.86) rather than neutral (*M* = 88.34, *SD* = 17.76), *t*(30) = 3.37, *p* = .002, whereas younger adults did not show this difference in accuracy (*p* = .143).

Reaction times. RTs for targets in younger and older adults are presented in Figure 3.8. On match trials, participants were slower to respond if the match was angry (*M* = 1109 ms, *SD* = 257 ms) rather than neutral (*M* = 1062 ms, *SD* = 235 ms), *t*(61) = 2.30, *p* = .025. Separate t-tests for younger and older adults revealed that this pattern for angry vs. neutral matches was found in younger (*M* = 958 ms, *SD* = 232 ms vs. *M* = 924 ms, *SD* = 207 ms) and older adults (*M* = 1261 ms, *SD* = 181 ms; *M* = 1200 ms, *SD* = 172 ms), but it was not significant in each individual age group (*p*s > .134). On non-match trials, participants were slower if the 2-back target was angry (*M* = 1170 ms, *SD* = 282 ms) rather than neutral (*M* = 1106 ms, *SD* = 241 ms), *t*(61) = 3.69, *p* < .001. Separate t-tests for younger and older adults showed that older adults were slower for angry (*M* = 1357 ms, *SD* = 174 ms) than for neutral targets (*M* = 1200 ms, *SD* = 172 ms), *t*(30) = 3.77, *p* = .001, whereas the difference in RTs was non-significant in younger adults (*p* = .094).

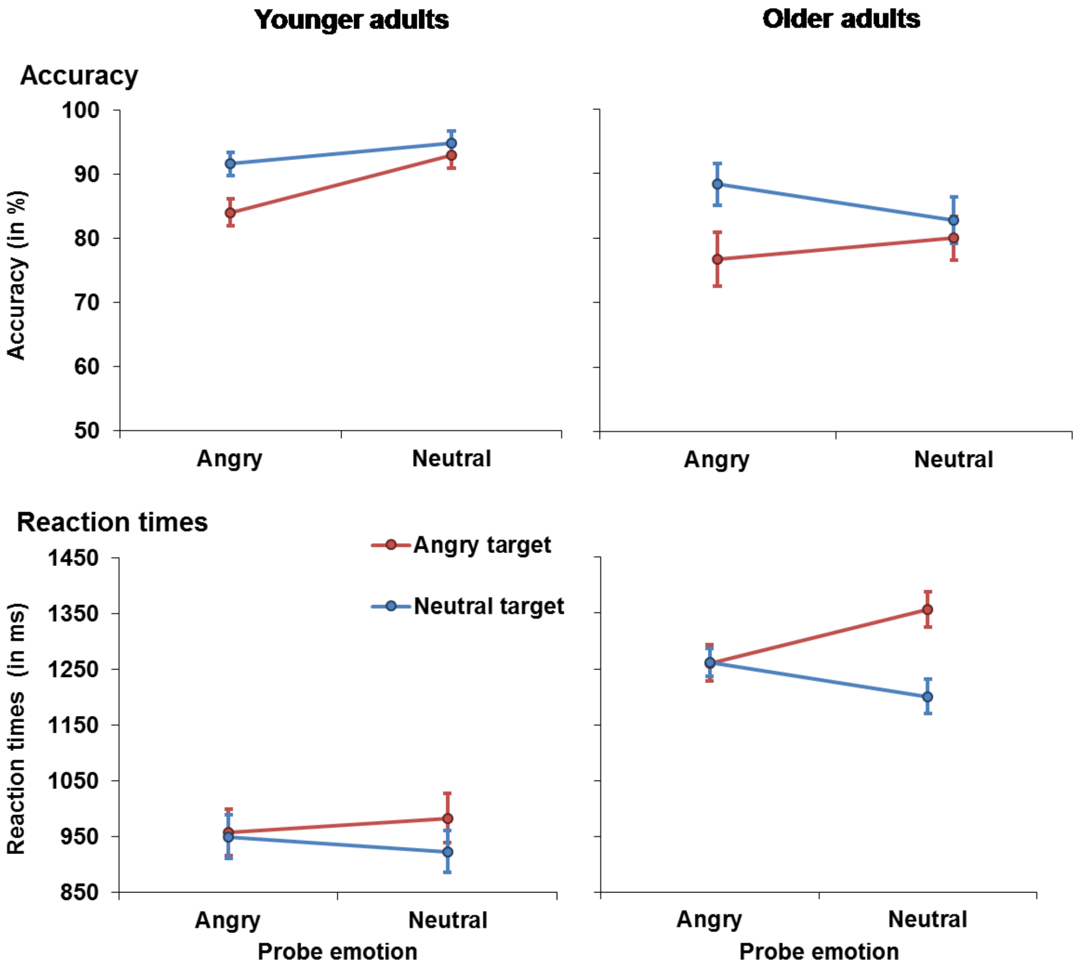

Figure 3.8. Accuracy (upper panel) and RTs (lower panel) for probes as a function of the 2-back target in Experiment 3.2. Younger adults' data are presented on the left and older adults' data are presented on the right.

Discussion

The aim of Experiment 3.2 was to assess how WM updating in a 2-back task would be affected by angry 1-back and 3-back lures as well as angry 2-back targets relative to neutral stimuli and whether the effects would vary for younger and older adults. It was found that older but not younger adults were overall slower when lures were angry rather than neutral and that they made more mistakes when lures and probes had the same emotional valence. A similar impairment was observed for angry relative to neutral 2-back targets and older adults were more affected by angry targets than younger adults when having to replace the target on non-match trials. Moreover, it was found that no-longer relevant lures affected updating in both age groups, as participants made more mistakes when 3-back lures had the same valence as the currently presented probe. Lastly, replicating results from Experiment 3.1, older adults benefited more from emotional probes than younger adults as they were not only faster to respond to angry than to neutral probes similarly to their younger counterparts, but were also more accurate. The results of the present study confirm the conclusions drawn from the auxiliary analyses on data from Experiment 3.1 that angry lures and targets slowed down responses to probes in an n-back paradigm. They also add to findings that previous items can have an effect on responses to the current probe in updating (Kensinger & Corkin, 2003; Levens & Gotlib, 2010, 2012). However, they go beyond the auxiliary analyses and extend previous research by showing that the effects of previously presented emotional items on updating differ in younger and older adults.

The results obtained for angry vs. neutral lures are in accordance with the hypothesis that older adults would be affected by negative information that needs to be maintained and manipulated in WM to a greater extent than younger adults. Older adults also made more mistakes when lures and probes had the same emotional valence, which suggests that there was stronger interference from familiar cues in older adults during updating. Together, the results obtained in this experiment suggest that binding and unbinding of negative material in WM was less successful in older adults than in younger adults.

Such an interpretation is in accordance with research showing that binding was less successful for negative than neutral pictures in ageing (Borg et al., 2011). It is also in line with findings that unbinding of task-irrelevant emotional material was impaired in older relative to younger adults in a facial 2-back task (Pehlivanoglu et al., 2014). Finally, the results are in accordance with previous research showing stronger interference through lure items in older relative to younger adults in a n-back task (Schmiedek et al., 2009), which the authors attributed to older adults' greater reliance on familiarity and gist-based processing due to less efficient recollection processes.

The results obtained for angry vs. neutral 2-back targets support the interpretation that binding and unbinding of angry relative to neutral faces is particularly affected in older adults. When analysing match responses, it was found that younger adults were less accurate if the 2-back targets were angry rather than neutral, but no other age-related differences were observed. In contrast, analyses of non-match trials revealed that older adults were less accurate and also slower if the 2-back target, which needed to be replaced, was angry rather than neutral. A similar pattern of results was found in Experiment 3.1, in which age-related differences in the effects of emotion on n-back performance was observed for non-match trials but not for match trials. The demand on binding and unbinding performance is higher in non-match trials than in match trials and appears to become more difficult in older adults if angry targets need to be replaced. The results for different targets need to be treated with caution, as not only the targets but also the probes differed in non-match responses. However, together with the results observed for angry lures, a consistent picture emerges, showing older adults' greater difficulty to maintain and replace angry items than neutral items.

It should be noted that contrary to an impairing effect on updating when presented as lures, angry faces were found to have a beneficial effect on performance when presented as probes in all participants, but particularly in older adults. All participants were faster when making non-match responses to angry probes relative to neutral probes, with older adults additionally being more accurate. This is a replication of findings from Experiment 3.1, in which better performance for angry relative to neutral probes was observed in older adults. The implications of this facilitating effect of emotion for non-match trials will be discussed together with the results for Experiment 3.1 in the general discussion of this chapter below.

Finally, it was observed that responses to probes were less accurate in both younger and older adults when the 3-back lure had the same emotionality, suggesting that representations are not discarded from WM even when they are no longer relevant. This effect was found for 3-back lures and not for 1-back lures for all participants, with no age-related differences and for both neutral and angry lures. Although it is puzzling that interference was not stronger for 1-back lures than for 3-back lures, this finding could be explained by rehearsal. In a 3-back task, Szmalec et al. (2011) reported stronger interference from an older compared to a more recent lure. The authors suggested that interference from older lures could be stronger as they have been rehearsed more often, therefore being more familiar over the course of the sequence. This could also be the case in the present task, in which the familiarity of the item that was just outside of the buffer was high through rehearsal, causing greater interference than the recently added 1-back lure.

To sum up, it was found that angry lures had an impairing effect on updating in older but not younger adults, indicating that manipulating threatening information in WM comes at a greater cost in ageing. In contrast, both age groups benefited from angry relative to neutral probes in their RTs, with older adults showing an additional benefit in accuracy, replicating results from Experiment 3.1. The implications of these findings are discussed in the general discussion section below.

3.6. Experiment 3.3: Updating of emotional words in younger adults

One of the critical findings observed in Experiment 3.1 was that both younger and older adults responded more accurately and faster when task-relevant probes were happy compared to other expressions, which supported the prediction that positive emotion would facilitate WM updating. In contrast, angry faces were found to impair detection sensitivity in both age groups to a greater extent than neutral faces. This facilitating effect on updating, however, might be restricted to happy faces and might not extend to other emotional material such as positive words. Based on the results of one single experiment, it is not clear whether the same benefits and impairments can be expected for other stimulus sets such as words.

As discussed in more detail in Chapter 2.2, it was suggested that orienting towards emotional faces and words might differ, as faces are biologically prepared, whereas words are not (Kensinger & Corkin, 2003; Kensinger & Schacter, 2006; Vuilleumier, 2005). It was also suggested that differences in extracting emotional significance from these stimuli might play a role, with the significance of words depending on semantic knowledge rather than on perceptual features as for faces (Kensinger & Schacter, 2006; Rellecke et al., 2011). Given these differences, it is possible that the effects of emotional words on updating will differ from those observed for emotional faces.

It should be noted that the effects of emotional words in an n-back task have been investigated before. It was shown that emotional words did not modulate updating, whereas faces did (Kensinger & Corkin, 2003), which was attributed to the fact that emotional words were not biologically prepared. However, only three negative and three neutral words were used in this n-back task. With such a small pool of repeating stimuli, it is possible that the effect of emotion was reduced or even completely washed out due to habituation (Breiter et al., 1996; Carretié, Hinojosa, & Mercado, 2003; Wright et al., 2001). Thus, it is suggested that the investigation of effects of emotional words in an updating task with a larger pool of emotional stimuli might help to provide new insights.

As described above, it is believed that the updating advantage of happy faces may be due to perceptual features such as low spatial frequencies and a smile that make happy faces efficiently recognisable additionally to other factors such as a smile's rewarding nature. By using verbal stimuli in a 1-back and 2-back task, the aim was to assess whether updating of emotional words would be associated with comparable effects as those observed for emotional faces. Should words produce similar effects, this would suggest that the valence of stimuli (i.e., pleasantness of happy faces and positive words) drive the effects of positive emotion on updating performances. In contrast, if differential effects of emotion were to be observed across different stimulus sets, this would suggest that the facilitating effect of happy faces is special and restricted to facial stimuli. Given previous research showing that emotional biases in processing are stronger for faces than for words (Kensinger & Corkin, 2003; Kensinger & Schacter, 2006; Vuilleumier, 2005), it was hypothesised that an attenuated effect of emotional words relative to emotional faces on updating would be observed. As both age groups showed the pronounced facilitating effect of happy faces in Experiment 3.1 with no age-related differences, it was decided that it would be sufficient to focus on the younger age group only in the present experiment.

Methods

Participants

Twenty younger adults (18 – 40 years old) participated in the present research (see Table 3.6 for participant characteristics). One participant was removed from the analysis and replaced as this person's accuracy for neutral stimuli was at chance level (50%), additionally to scoring above 19 on the BDI-II (Beck et al., 1988), indicating moderate depression. Participants in this experiment met the same criteria as the younger participants in Experiment 3.1 and were reimbursed in the same manner. None of the participants involved in Experiment 3.1 participated in the present experiment.

Materials

Stimuli consisted of 72 words from the ANEW database (Bradley & Lang, 1999), a database with affective norms for English words. The selected words were negative, positive or emotionally neutral and had been rated in a preliminary evaluation study (for evaluation details, see Appendix C). The final selection of 72 words comprised 24 words per emotional category. Valence ratings[2] for negative words were lower (*M* = 1.96, *SD* = .96) than valence ratings for neutral words (*M* = 5.47, *SD* = .74), whereas valence ratings for emotionally neutral words were lower than valence rating for

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[2] No inferential tests were conducted due to the fact that different groups of participants evaluated different sub-sets of words. Neither independent-samples nor paired-samples t-tests were appropriate to analyse mean differences for valence and arousal ratings and thus, only descriptive statistics are provided. For further details, see Appendix B.

positive words (*M* = 7.90, *SD* = .82). Moreover, arousal ratings were higher for negative words (*M* = 6.66, *SD* = 1.85) than for neutral faces (*M* = 3.73, *SD* = 2.02), but were similarly high as those for positive words (*M* = 6.77, *SD* = 1.54). Half of the negative, neutral, and positive words were included in the 1-back task, whereas the other half were used in the 2-back task. Assignment of the sets to the 1-back or 2-back task was counterbalanced.

Table 3.6. *Participant characteristics, Experiment 3.3*

Variable	*M*	*SD*
Age	26.11	7.48
Gender (male/female)	8/11	
Education (yrs)	16.78	2.80
NART Verbal IQ	109.17	6.36
Digit Symbol Test	66.00	13.72
BDI II	5.50	4.40
STAI Trait Anxiety	34.61	8.42

Note. NART = The National Adult Reading Test, BDI II = Beck Depression Inventory II, STAI = State-Trait Anxiety Inventory, MMSE = Mini-Mental State Examination

Procedure

The procedure was identical to the procedure for Experiment 3.1, with the difference that the experiment comprised two tasks only (no 0-back task was included): (i) in a 1-back task, participants compared the currently presented word with the word presented one trial earlier and (ii) in the 2-back task, participants compared the currently presented word with the word presented two trials earlier. Participants were instructed to make "same" (match) or "different" (non-match) judgments based on the emotional valence of the current word (negative vs. neutral vs. positive). Contrary to Experiment 3.1, the emotional valence was relevant for task performance in all blocks and there was no other feature of the stimulus that participants had to respond to. Trial presentation was the same as in Experiment 3.1 and participants were instructed to indicate their response by pressing one of two labelled buttons ("S" for same, "D" for different). On the computer keyboard, the buttons "1" and "2" of the numeric keypad were used and participants were instructed to leave the index finger and middle finger on the two buttons for the duration of the task. As in Experiment 3.1, the 1-back task consisted of 220 trials, which were separated into four blocks of 55 items, and 11 additional practice trials, which were not scored. The 2-back task consisted of 304 trials, which were separated into eight blocks of 38 items. Twelve additional practice trials were not scored. In each block, half of the trials required a "same" response and the other half of the trials required a "different" response.

Trial types and statistical analysis

Responses and RTs were recorded for each trial. The percentages of hits (correct match) and false positives (incorrect match) were calculated for each condition and hits and false positives were used to calculate *A'* (Grier, 1971) to obtain a corrected measure of recognition (for accuracy scores in Experiment 3.3, see Appendix D). For the analysis of RTs, any RTs faster than 200 ms or 2.5 standard deviations above or below the mean were excluded, resulting in an exclusion of 1.99% of trials from the 1-back task and 1.17% trials from the 2-back task. Statistical analyses were conducted with SPSS 22 (IBM Corp., Armonk, NY).

Detection sensitivity scores for the 1-back and 2-back tasks were submitted to a two-way ANOVA with the within-subjects factors load (1-back vs. 2-back) and emotion (angry vs. neutral vs. happy). RTs for correct responses were analysed with the same factors as above plus an additional within-subjects factor of target type (match vs. no match). Bonferroni-corrected post-hoc t-tests were performed to follow up significant main effects and interactions and all tests were two-tailed with $\alpha = .05$.

Results

Detection sensitivity

The two-way omnibus ANOVA revealed a main effect of emotion, $F(2, 38) = 26.92$, $MSE < .01$, $p < .001$, partial $\eta^2 = .59$. Post-hoc t-test revealed that detection sensitivity was greater for negative words ($M = .95$, $SD = .03$) than for neutral words, ($M = .93$, $SD = .04$), $t(19) = 5.57$, $p < .001$, or positive words ($M = .91$, $SD = .04$), $t(19) = 7.40$, $p < .001$. Sensitivity was also greater for neutral words than for positive words, $t(19) = 2.79$, $p = .012$. No further main effects or interactions were observed for detection sensitivity. Results for discrimination sensitivity are presented in Figure 3.9, panel A.

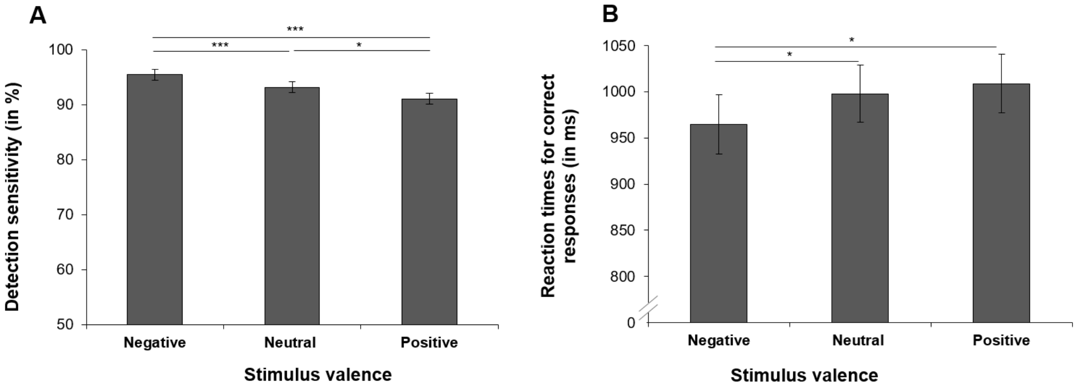

Figure 3.9. Detection sensitivity (panel A) and RTs for correct responses (panel B) in Experiment 3.3, collapsed across the 1-back and 2-back tasks.

Reaction times

The three-way omnibus ANOVA revealed a main effect of load, $F(1, 19) = 8.04$, $MSE = 30785$, $p = .011$, partial $\eta^2 = .30$, as RTs were faster in the 1-back task ($M = 954$ ms, $SD = 129$ ms) than in the 2-back task ($M = 1021$ ms, $SD = 159$ ms). There was also a main effect of trial type, $F(1, 19) = 43.49$, $MSE = 5383$, $p < .001$, partial $\eta^2 = .70$, as RTs were slower for non-match responses ($M = 1023$ ms, $SD = 131$ ms) than for match responses (*M* = 960 ms, *SD* = 148 ms). Moreover, there was a main effect of emotion, *F*(2, 38) = 3.81, *p* = .031, partial η^2 = .17 and post-hoc t-tests revealed that RTs were faster for negative words (*M* = 965 ms, *SD* = 141 ms) than for positive words (*M* = 1009 ms, *SD* = 144 ms), *t*(19) = 2.84, *p* = .011. RTs were also slightly faster for negative words than for neutral words (*M* = 998 ms, *SD* = 140 ms), *t*(19) = 2.25, *p* = .035 (trend for significance after Bonferroni correction). No difference in RTs for neutral and positive words was observed (*p* = .508). No further main effects or interactions were observed for RTs. Results for RTs are presented in Figure 3.9, panel B.

Discussion

The aim of this study was to assess updating of emotional words in younger adults. In contrast to findings of a facilitating effect of happy faces in Experiment 3.1, the present experiment showed that there was no such facilitating effect of positive words. In contrast, it was found that detection sensitivity was lowest for positive compared to neutral or negative words. Detection sensitivity was also higher for negative than for neutral words. No difference in RTs was observed between responses to neutral and positive words, whereas RTs were faster for negative words.

Contrary to the hypotheses and results reported by previous research, the present study did not show attenuated effects of emotional words compared to emotional faces. Instead, a reversed pattern of results was observed: When asked to update emotional faces in Experiment 3.1, participants showed higher detection sensitivity and faster RTs for happy compared to neutral or angry faces. In contrast, when asked to update emotional words in the present experiment, participants showed higher detection sensitivity and faster RTs for negative compared to neutral or positive words. Younger adults' RTs for match and non-match trials in Experiment 3.1 with facial stimuli and in Experiment 3.3 with verbal stimuli are presented in Figure 3.10.

As can be seen in Figure 3.10, the differences between results from Experiments 3.1 and 3.3 were particularly pronounced for match responses. Although emotion did not interact with trial type in the present experiment, which could be due to a low sample size and lack of power, Figure 3.10 shows that RTs for negative words were faster than for neutral words but only for match but not for non-match responses. In contrast, data from Experiment 3.1 show that match responses were particularly fast for happy faces compared to neutral or angry faces and that this effect was also only significant for match but not for non-match responses.[3]

One possible explanation for the improved performance for negative words in the present study might be that the mild level of threat conveyed by words was actually beneficial for task performance. Threat has been shown to impair cognitive performance through detraction of cognitive resources from the on-going task, but only when it is high (Pessoa, 2009). In contrast, the dual competition model suggests that mildly threatening stimuli are prioritised in processing and thereby can have an enhancing effect on performance. Pessoa (2009) also argued that mildly threatening stimuli are

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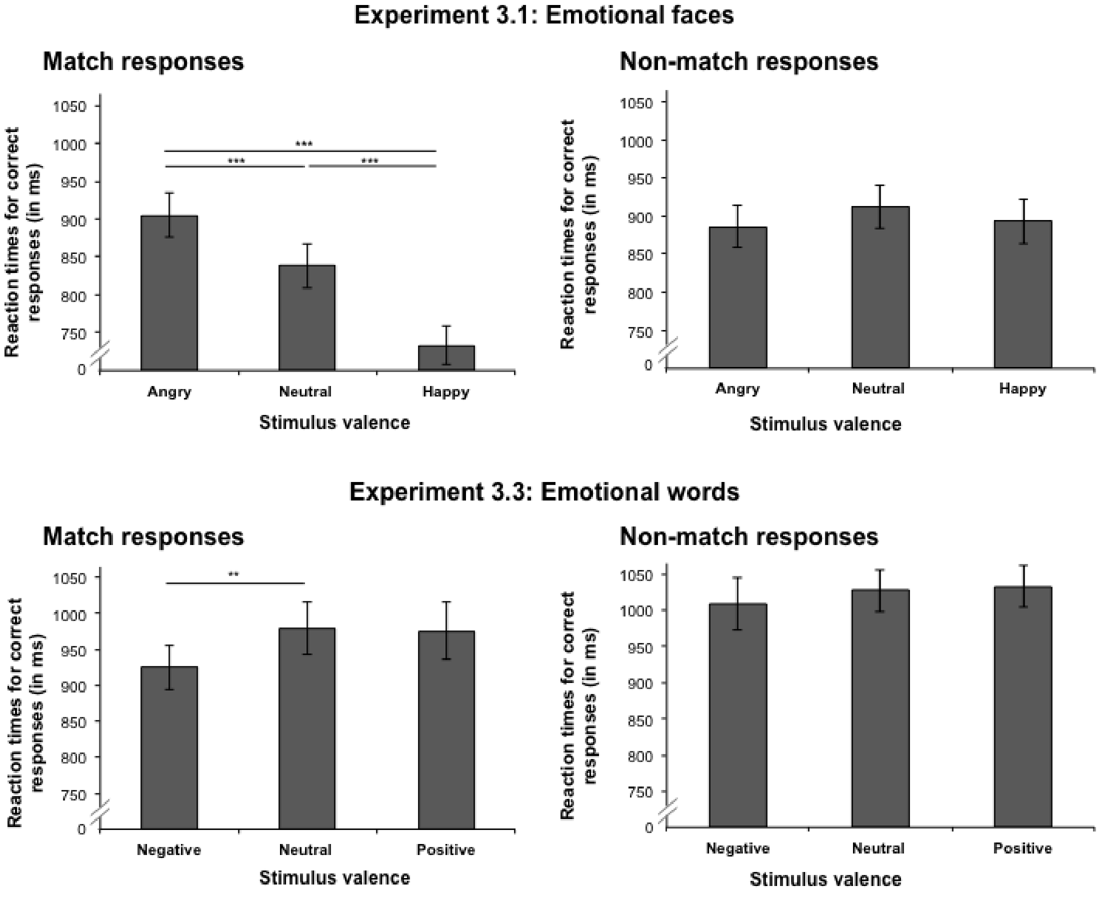
[3] To match the analysis for the present experiment, younger adults' RT data from Experiment 3.1 were analysed using a three-way ANOVA including the within-subjects factors load (1-back vs. 2-back), response (match vs. non-match) and emotion (happy vs. neutral vs. angry). There was a main effect of response, $F(1, 24) = 60.04$, $MSE = 7202$, $p < .001$, partial $\eta^2 = .72$, and a main effect of emotion, $F(2, 48) = 30.65$, $p < .001$, partial $\eta^2 = .56$. These main effects were qualified by a response × emotion interaction, $F(2, 48) = 28.55$, $p < .001$, partial $\eta^2 = .54$. Separate analyses for match and non-match responses showed no significant effect of emotion for non-match responses ($p = .212$). The main effect of emotion was significant for match responses, $F(2, 48) = 51.62$, $p < .001$, partial $\eta^2 = .68$, as RTs were slower for angry ($M = 905$ ms, $SD = 143$ ms) than for neutral faces ($M = 838$ ms, $SD = 145$ ms), $t(24) = 4.79$, $p < .001$, or happy faces ($M = 733$ ms, $SD = 132$ ms), $t(24) = 9.23$, $p < .001$. The difference in RTs between neutral and happy faces was also significant, $t(24) = 5.77$, $p < .001$.

prioritised in processing as they are often more ambiguous, requiring participants to gather more information (Whalen, 1998). Similarly, it was shown that participants were quicker to repeat words if they were perceived as more dangerous (Wurm, Vakoch, Aycock, & Childers, 2003). This suggests that factors such as perceived threat can improve semantic access. Overall, it is possible that the mild level of threat associated with negative words helped to extract lexical information more efficiently, thereby improving updating performance for negative relative to neutral or positive words.



Experiment 3.1: Emotional faces

Match responses

Non-match responses

Experiment 3.3: Emotional words

Match responses

Non-match responses

Figure 3.10. Younger adults' RTs for correct match responses (left) and non-match responses (right), collapsed across the 1-back and 2-back tasks. Data from Experiment 3.1 with facial stimuli are presented in the upper half and data from Experiment 3.3 with verbal stimuli are presented in the lower half.

It is also possible that more accurate updating performance for negative than positive words was linked with findings showing that negative words were less often used and that they had greater informational content than positive words (Dodds et al., 2015; Garcia, Garas, & Schweitzer, 2012). These characteristics might have contributed to better distinctiveness of negative words and might have facilitated better binding of words to the serial position in the sequence for negative words. In contrast, binding might have been weaker for positive words as positive information was shown to be less complex than negative information (Bohner et al., 1988; Peeters & Czapinski, 1990) and to be associated with increased familiarity (Garcia-Marques, Mackie, Claypool, & Garcia-Marques, 2004; Monin, 2003). Also, pleasant words are per definition not associated with threat, and thus, might not have benefited from the preferential processing of negative material. This might have contributed to overall slower responses to positive compared to negative words.

It should be noted that the present findings of enhanced performance for negative relative to neutral and positive words are not compatible with findings of a previous study, which found no effects of emotional words on updating (Kensinger & Corkin, 2003). As indicated previously, the contrasting findings might be rooted in the different designs of the experiments. As only three negative and three neutral words were used in Kensinger and Corkin's study (2003), it is possible that the effect of emotion was reduced due to habituation (Breiter et al., 1996; Carretié et al., 2003; Wright et al., 2001). In contrast, the present experiment comprised 36 items from three different valence categories in each task (i.e., 1-back and 2-back). Thus, habituation was probably less pronounced in the present study. The present experiment adds to research showing that the emotional effects observed with one particular stimulus set of emotional items cannot be generalised to other stimuli.

3.7. General discussion

The experiments in the present chapter were conducted to investigate WM updating of emotional items in younger and older adults. Taken together, they yielded three important findings. First, there were both enhancing and impairing effects of emotional material on updating, which were more pronounced in older adults compared to younger adults. Second, both age groups were able to ignore task-irrelevant emotion across blocks with no age-related differences. Third, it was found that the effects of emotional material on updating were domain-specific, as the effects of emotion on WM updating differed for faces and words. The implications of these results are discussed below.

Differential effects of emotion on updating in younger and older adults

Overall, the impact of emotional items on updating in older adults was found to be mixed. On the one hand, two experiments highlighted that older adults benefited from emotional relative to neutral probes. In Experiment 3.1, older but not younger adults were faster when responding to angry and happy relative to neutral non-match probes in a 1-back task. In Experiment 3.2, both age groups were faster when responding to angry relative to neutral non-match probes in a 2-back task, but only older adults were additionally more accurate. These results suggest that older adults were more efficient when responding to emotional rather than neutral probes on non-match trials. This pattern of results is in line with previous research showing that emotional material can help to improve WM performance in older adults (Mammarella, Borella, et al., 2013; Mikels et al., 2005). However, Experiment 3.2 also showed that impairing effects of emotion were more pronounced in older than in younger adults. Older but not younger adults' non-match responses were slower if angry 1-back lures or angry targets were included in the sequence and needed to be manipulated in WM in a 2-back task.

Experiment 3.2 also showed that both age groups were affected by the emotionality of the 3-back lure, which suggests that these still lingered on in WM despite being task-irrelevant when participants responded to probes.

Overall, these results suggest that older adults were more efficient to respond to emotional probes on non-match trials but that this did not entail more efficient updating of these items in WM. Although non-match trials require participants to replace old representations with new ones (Verhaeghen & Basak, 2005), it appears that this procedure was not always completed when participants made their responses. This is also highlighted by the finding that even outdated 3-back items still affected responses to the probe in the 2-back task in Experiment 3.2. Overall, it appears that other processes – potentially those that are needed in order to initiate the updating procedures on non-match trials – were facilitated by emotion in ageing.

As no detailed analysis of all sub-processes involved in n-back tasks are available to this date, it is difficult to pinpoint which of these was or were facilitated by emotion in ageing. However, this study provided encouraging evidence that emotion can facilitate older adults' performance in a WM task requiring both maintenance and manipulation of WM information, as previous research focused on tasks requiring maintenance in WM only (Mammarella, Borella, et al., 2013; Mikels et al., 2005). Given research showing that age is associated with a decline in WM performance in general (Babcock & Salthouse, 1990; Braver & West, 2008; MacPherson et al., 2002; Reuter-Lorenz & Sylvester, 2005; Zelazo et al., 2004) and in WM updating in particular (T. Chen & Li, 2007; De Beni & Palladino, 2004; Hartman et al., 2001; Salthouse et al., 2003; Van der Linden et al., 1994), the findings of the present study provide intriguing evidence that emotion can improve performance in ageing.

The impairing effects of angry faces in older adults' updating performance, however, deserve further attention. To interpret older adults' slowdown for angry 1-back lures and 2-back targets in Experiment 3.2, it is important to take into account that interference effects were not restricted to emotional lures. Besides a slowdown for angry lures in older but not younger adults, older adults also showed reduced accuracy when presented with lures that had the same emotionality as probes, whether these were neutral or angry. Thus, older adults appeared to be less efficient in tagging items as task-relevant or task-irrelevant on a trial-by-trial basis, particularly when these were threatening. As older adults appeared to be less able to ascertain whether items are currently task-relevant (i.e., n-2) or irrelevant (i.e., n-1 or n-3), this suggests that they had difficulties binding and unbinding items flexibly, which has been reported to be a core mechanism in WM updating (Oberauer, 2009; Szmalec et al., 2011). The results are in accordance with previous research showing stronger interference from lures in older relative to younger adults in an n-back task (Schmiedek et al., 2009), which the authors attributed to older adults' greater reliance on familiarity, likely due to less efficient recollection processes. In other words, a clear assignment of item to the serial position was less available to older compared to younger adults, highlighting their difficulties in manipulating information in WM. However, the results also extend previous research by showing that this is exacerbated when emotional items are used.

Mixed effects of angry faces on updating performance

Overall, these results suggest that angry faces produced a particularly complex pattern of results across the two facial n-back experiments, which was not observed for happy faces. The enhancing effect of angry faces, which was particularly pronounced in older adults, was only found for non-match but not for match trials. On match trials, participants were slowest when making match responses to angry relative to neutral or happy probes, which was possibly due to a slowdown for angry 1-back targets as shown by the auxiliary analyses for Experiment 3.2 (see Chapter 3.5. above). Thus, angry faces had both improving and impairing effects, which were highly dependent on the target trial and the face's status in the n-back sequence. Although older adults responded more efficiently to angry (and happy faces) on non-match trials, valence-specific features of angry faces had impairing effects once they had to be further manipulated in WM.

It is unlikely that a greater difficulty in manipulating (i.e., binding and unbinding items flexibly to context on a trial-by-trial basis) angry relative to neutral material was attributable to older adults' stronger focus on emotion. Such a focus would be more likely to contribute to better rather than reduced ability to manipulate emotional information, as more cognitive resources are allocated to these items. Instead, it appears that specific features of angry faces contributed to the observed problems, possibly the threat they communicate.

Threat tends to detract cognitive resources needed for WM operations (Pessoa, 2009). This is likely to have had a particularly impairing effect on older adults relative to younger adults due to overall reduced availability of cognitive resources (e.g., Braver & West, 2008; L. H. Phillips & Henry, 2008; Reuter-Lorenz & Sylvester, 2005; Salthouse, 1990). Reward, on the other hand tends to improve executive functioning by fine-tuning (e.g., sharpening updating processes in an n-back task) and by rearranging the allocation of more general "common-pool" resources to the ongoing task (Pessoa, 2009). Thus, although Experiment 3.2 did not implement happy lures and targets, no such impairing effects of happy faces was to be expected. In contrast, threatening (and rewarding) features might have helped older adults to respond quickly to emotional probes in Experiment 3.1. Threatening (and rewarding) items might have been more distinct and have signalled a non-match to a stronger degree than neutral probes. With greater availability of cognitive resources in the 1-back relative to the 2-back task, older adults had more resources to process these items in a more controlled fashion, thus benefitting from distinct emotional cues. The missing effect of emotion in the 2-back task is in line with research showing that load can downregulate responses to emotional items both on a neural level and in subjective experience (Van Dillen et al., 2009). Although the SST (Carstensen, 1993) would also predict a reduced age-related effect of emotion with increased load, it is less suitable to explain improved performance for angry relative to neutral faces on non-match trials in older adults.

Inhibition of task-irrelevant information is not impaired in ageing

Research suggests that emotional material can impair performance in cognitive tasks to a greater extent in older than in younger adults by detracting attention from non-emotional item features or from the ongoing task (Borg et al., 2011; Kensinger, 2009b; Truong & Yang, 2014; Wurm et al., 2004). However, the pattern of results obtained in this study is not fully reconcilable with this notion. Older adults were not found to be generally susceptible to interference from emotional material. Instead, interference by emotion in ageing was highly dependent on task requirements.

In Experiment 3.1, participants had to maintain focus on task-relevant features for the duration of a block, while continuously inhibiting task-irrelevant emotional content. In such a task, both age groups were able to update non-emotional features of emotional faces. In contrast, results from Experiment 3.2 showed that older adults' updating performance was slowed down by angry lures in a 2-back paradigm. In this experiment, the task required participants to flexibly bind and unbind emotional information that was – depending on its position – either task-relevant (i.e., 2-back targets) or task-irrelevant (i.e., 1-back and 3-back lures). Thus, while being able to inhibit emotional features that were consistently task-irrelevant, older adults showed impairments when having to manipulate emotional information in WM and keeping track of its relevance for the task on a trial-by-trial basis. This is in line with reviews by Verhaeghen and colleagues (Verhaeghen & Basak, 2005; Verhaeghen & Cerella, 2002), according to which older adults show impairments when maintaining distinct mental sets simultaneously, but no impairments when tasks require active selection of relevant information or the inhibition of information. In the case of the present 2-back task, the former refers to the requirement to maintain both task-relevant and task-irrelevant items at the same time, while the relevance depends on the position of the item in the sequence. The latter refers to the requirement to focus on task-relevant features while consistently ignoring other task-irrelevant features. Thus, it can be suggested that older adults show difficulties when they are required to deal with task-relevant and task-irrelevant emotional information at the same time, while the inhibition of consistently irrelevant emotional material appears relatively preserved in ageing.

Contrasting effects of emotion conveyed by faces and words

It should be noted that the results observed for emotional faces cannot be generalised to verbal stimuli. Particularly diverse patterns of results were observed for faces and words on match trials in an n-back task. Whereas angry faces were found to impair WM performance, negative words were found to improve performance. Match trials do not require replacing old representations with new ones, whereas non-match trials do. Thus, they allow observing emotion-sensitivity of processes involved in attention and detection better compared to non-match trials. On non-match trials, the effects of emotion on detection might be mixed with effects of emotion on additional processes, which are involved in updating and replacing in WM. Thus, it is possible that the particularly pronounced effects of emotion on match trials were driven by the effects that emotion has on attention and detection processes.

The results obtained in the present study also indicate that emotional faces and words modulate performance in an n-back task in specific ways. As previous research has shown that emotional biases in processing were stronger for faces than for words (Kensinger & Corkin, 2003; Kensinger & Schacter, 2006; Vuilleumier, 2005), an attenuated effect of words compared to faces was expected. However, the present research highlighted that modality-specific emotion effects not only differ in the effect size but in their qualitative pattern.

The different pattern could indeed be related to the fact that words are not as biologically prepared as faces are. The RTs for verbal stimuli in Experiment 3.3 were slower than RTs for facial stimuli in Experiment 3.1, which could reflect the need to process verbal stimuli to a higher level before a response can be made relative to facial stimuli (Kensinger & Corkin, 2003; Rellecke et al., 2011; Schacht & Sommer, 2009). This, in turn, could have contributed to the differences in effects observed for faces and words. Other or additional factors could be the informational value of negative compared to positive words and their relative novelty (see Chapter 3.6 above).

To assess whether the contrasting effects of emotion for facial and verbal stimuli can be replicated in other executive functions tasks, different stimulus sets were used in a number of Stroop experiments. These will be reported in Chapter 4 and the pattern of results observed for emotional material across multiple experiments and multiple executive functions will be discussed in detail in Chapter 6.2.

Conclusion

To conclude, the study contributed to research differentiating between enhancing and impairing effects of emotion on WM updating in younger and older adults and showed that emotion effects on updating are domain-specific. Crucially, this study was the first to show that older adults can benefit from emotion when performing a WM task that requires participants not only to maintain but also to manipulate information in WM. Moreover, it was found that older adults were not more susceptible to interference from task-irrelevant emotional information than younger adults if it was consistently task-irrelevant. However, difficulties occurred when relevance of an emotional item varied on a trial-to-trial basis and this study showed that impairing effects of negative emotion were more pronounced in older than in younger adults. Overall, this pattern indicates that flexibility in binding and unbinding of negative material is impaired in ageing. This research is important as it can inform our understanding of how the facilitating effects of emotion on cognitive performance can be harnessed. It can also highlight avenues where focus should be placed, when attempting to find ways of buffering the impairing effects of emotion on older adults' cognitive performance.

Chapter 4: Ageing and cognitive control in the presence of emotional material

4.1. Introduction

After examining the effects of emotion and ageing on WM updating in Chapter 3, this chapter will focus on the ability to prevent irrelevant information from interfering with the ongoing task. Although Miyake et al. (Miyake & Friedman, 2012; Miyake et al., 2000) used the term “inhibition”, in the literature on the Stroop task (Stroop, 1935), a slightly different terminology was often used. Researchers using this task were usually interested in the interference of task-irrelevant information and in how participants can exhibit control in order to avoid or solve interference in the Stroop task. Although inhibition will be mentioned in this chapter, the term cognitive control will be used and differences between proactive and reactive control will also be considered, a distinction of control processes that was suggested by Braver and colleagues (Braver, 2012; Braver, Gray, & Burgess, 2007).

The Stroop task (Stroop, 1935) has been widely used to assess cognitive control. In the classic colour version task, colour words are printed in a congruent or an incongruent ink colour (e.g., “red” printed in red vs. green ink) and participants have to name the colour of the ink while ignoring the colour word. Whereas word reading and colour naming produce the same response in congruent trials, word reading interferes with the correct colour-naming response for incongruent trials. It is assumed that in the presence of a word, even if it is task-irrelevant, there is a strong tendency to read the word due to life-long experience with reading (Verhaeghen & De Meersman, 1998b).

Cognitive control is thus required to selectively attend to and respond to the attribute that is weaker but task-relevant (i.e., the colour of the ink) in the presence of a strong but task-irrelevant (i.e., written colour word) attribute (Miller & Cohen, 2001). Another way of phrasing it is that participants have to inhibit the prepotent response of reading in favour of the weaker response of colour naming (Verhaeghen & De Meersman, 1998b). Typically, incongruent trials are associated with slower responses than on non-word trials, highlighting that the exertion of cognitive control requires resources and time (Lindsay & Jacoby, 1994). The slow-down effect for incongruent relative to non-word trials is known as the Stroop effect.

Stroop performance in ageing

The Stroop task has been used in a large number of studies on cognitive ageing (Ashley & Swick, 2009; Davidson, Zacks, & Williams, 2003; Hartley, 1993; Houx, Jolles, & Vreeling, 1993; Milham et al., 2002; Monti, Weintraub, & Egner, 2010; Spieler, Balota, & Faust, 1996; Uttl & Graf, 1997; West, 2004; West & Alain, 2000; West & Bell, 1997; Wurm et al., 2004). These studies usually reported an increased Stroop effect in older relative to younger adults (e.g., Davidson et al., 2003; Hartley, 1993; Houx et al., 1993; Spieler et al., 1996; West & Alain, 2000; West & Bell, 1997), which was interpreted as evidence for older adults' impaired ability to inhibit task-irrelevant information from interfering with the on-going task. Similarly, neuroimaging studies of Stroop performance in ageing reported reduced effectiveness of attentional control in older adults. This was evidenced by age-related decreases in the responsiveness of structures thought to support attentional control such as dorsolateral prefrontal and parietal cortices (Milham et al., 2002). Further support for inhibitory deficits in ageing came from studies using ERP measures (West & Alain, 2000).

However, Stroop studies also provided evidence that inhibitory processes remain largely intact in ageing. Verhaeghen and Meersman (1998b) analysed data from 20 behavioural studies in a meta-analysis and argued that the increased Stroop interference effect in ageing could be explained by general slowing rather than an age-related decline in inhibition. General slowing theories (Bunce & Macready, 2005; Cerella, 1990; Myerson, Hale, Wagstaff, Poon, & Smith, 1990; Salthouse, 1996, 2000) suggest that age differences in RTs grow larger in conditions with increasing RTs rather than staying constant across conditions (e.g., larger for incongruent than for congruent/non-word condition in the Stroop task; see also Chapter 1.2). As the age differences found for interference were not larger than predicted by general slowing, it was suggested that general slowing was a more parsimonious explanation for age-related changes in the Stroop task (Verhaeghen & De Meersman, 1998b). This was also concluded by Uttl and Graf (1997), who tested 310 adults of various ages in the colour Stroop task and found no evidence for an age-related decline beyond slowing.

As discussed in Chapter 2.2, the Stroop task has been adapted to investigate the effects of mainly task-irrelevant emotion on cognitive control, for instance, by showing emotional and neutral words or faces in different colours and asking participants to name the colour. Usually, it was found that it took participants longer to name the colour of emotional compared to neutral items (Constantine et al., 2001; Kindt & Brosschot, 1997; Williams et al., 1996). Despite evidence that ageing is associated with changes in emotional functioning (see Chapter 2.4), only a limited number of studies attempted to investigate age-related differences in an emotional Stroop task. These studies reported mixed findings regarding age-related changes.

In one study, older adults, who were stratified into low-, medium- or high-worry groups, had to indicate the ink colour of negative (threat-related), neutral and positive words (Price, Siegle, & Mohlman, 2012). It was reported that high-worry older adults were slower to respond to threatening words. In contrast, low-worry older adults were slower to respond to positive relative to neutral words, which was interpreted as an age-related “positivity bias”. However, as no younger adults were tested in the study, conclusions that could be drawn regarding age-related changes were limited. Another study tested two age groups in a Stroop task with negative and neutral words and it was found that both younger and older adults were slower to respond to the ink colour on trials with negative rather than neutral words (Ashley & Swick, 2009). However, only younger but not older adults showed a carry-over effect by responding slower to neutral words following emotional words, which was interpreted as evidence for a reduced “negativity bias” in ageing. In a third experiment (Exp. 2; Wurm et al., 2004), older adults were slower to name the ink colour of words high in arousal (including emotional and neutral words) but not low in arousal, whereas arousal did not play a role in the responses of younger adults.

It should be noted, however, that the inclusion of emotional items in a colour Stroop has been criticised. Although a general comparison between groups might be possible based on their RTs to emotional relative to neutral items, it was argued that Stroop tasks with emotional stimuli in a colour naming paradigm do not actually allow to assess the real Stroop effect (Algom, Chajut, & Lev, 2004; McKenna & Sharma, 2004). For instance, Algom, Chajut and Lev (2004) argued that the Stroop effect cannot be calculated in a Stroop task using non-colour words, picture or faces, as there is no “true” consistency for these items printed in different colours. Thus, it can be concluded that these studies do not provide insight into the attentional processes underlying true Stroop effects. Instead, they highlight the distracting effect of emotional information on colour naming.

Task conflict and proactive control in ageing

Importantly, the studies reported above have focused on conflict elicited by incongruent trials, which reflects information conflict. However, it was suggested that the Stroop paradigm produces an additional type of conflict, the task conflict, which has received little attention in ageing research so far. It refers to the conflict between word reading and colour naming in a classic colour Stroop task and contrasts with the information conflict, which refers to the conflict between the relevant colour information and the irrelevant word information in incongruent trials only (Goldfarb & Henik, 2007; Kalanthroff, Goldfarb, & Henik, 2013). Whereas trials with non-words do not trigger task-irrelevant word reading, both congruent and incongruent trials are thought to elicit task conflict due to the presence of both colour and word information (Goldfarb & Henik, 2007; Kalanthroff et al., 2013).

Evidence for task conflict in both congruent and incongruent relative to non-word trials has been provided by a number of studies (Goldfarb & Henik, 2007, 2013; Kalanthroff, Avnit, Henik, Davelaar, & Usher, 2015; for a review, see Kalanthroff, Davelaar, Henik, Goldfarb, & Usher, submitted; Kalanthroff et al., 2013). For instance, Goldfarb and Henik (2007) increased the number of non-word trials (see also Tzelgov, Henik, & Berger, 1992) and added cues that informed participants on half of trials whether the next trial would be a Stroop trial or a non-word trial. On the other half of trials, the cues were uninformative. This procedure was aimed at reducing control in participants on un-cued trials, as the majority of trials only had task-relevant colour information, and have them use the cues to recruit higher levels of control. With this procedure, it was found that on non-cued trials, RTs were longer for congruent compared to non-word trials, which was labelled reversed facilitation. Additionally, RTs were longer for non-cued congruent stimuli compared to cued stimuli. Incongruent trials were slower than non-word and congruent trials for both conditions. These results suggest that both congruent and incongruent trials elicited task conflict and that participants were less able to resolve it when engaging in low levels of control. Evidence for conflict in both congruent and incongruent Stroop trials also comes from neuroimaging studies showing increased activation of the anterior cingulate cortex (ACC), which is associated with conflict monitoring (Botvinick et al., 2001; Carter et al., 1998; Kerns et al., 2004), in congruent and incongruent relative to non-word trials (Aarts, Roelofs, & van Turennout, 2009; Bench et al., 1993; Carter, Mintun, & Cohen, 1995).

Whereas manipulating the proportion of non-word trials (Tzelgov et al., 1992) was originally used to induce an increase or decrease in control without specifying control any further, studies have attempted to explain the variable behavioural patterns under high and low expectancy conditions by linking them to the deployment of proactive control (De Pisapia & Braver, 2006; Funes, Lupiáñez, & Humphreys, 2010; Kalanthroff et al., 2015; Krug & Carter, 2012). The distinction between proactive and reactive control was proposed in the dual mechanisms of control (DMC) theory (Braver et al., 2007; Braver, Paxton, Locke, & Barch, 2009). Proactive control refers to sustained control, which is recruited before the occurrence of conflict (Braver, 2012), whereas reactive control refers to transient control processes that are recruited once conflict has been detected (Botvinick et al., 2001).

Studies using the Stroop paradigm have linked high expectancy of conflict with the recruitment of sustained, proactive control (De Pisapia & Braver, 2006; Kalanthroff et al., 2015; Krug & Carter, 2012). Neuroimaging studies also suggested that increasing the proportion of conflict (i.e., congruent and incongruent) trials in a Stroop task was associated with sustained activity in the dorsolateral prefrontal cortex (DLPFC), usually associated with deployment of cognitive control (De Pisapia & Braver, 2006; Krug & Carter, 2012). In contrast, conflict trials under conditions of low conflict expectation were associated with event-related activation of a medial and lateral prefrontal cognitive control network, including the ACC, which has been linked to conflict monitoring (De Pisapia & Braver, 2006; Krug & Carter, 2012). Thus, it appears that proactive control is needed to overcome not only information but also task conflict in the Stroop paradigm.

Ageing research indicates that the more parsimonious and less resource-demanding reactive mode of control is preserved across the adult life span (Braver, 2012; Paxton, Barch, Storandt, & Braver, 2006). In contrast, age-related differences have been reported for the efficient but more resource-demanding proactive mode of control as older adults were found to show significantly impaired goal maintenance relative to younger adults (e.g., Braver et al., 2009; Braver, Satpute, Rush, Racine, & Barch, 2005; Haarmann, Ashling, Davelaar, & Usher, 2005; Paxton, Barch, Racine, & Braver, 2008, Exp. 1). These studies have used the AX-Continuous Performance Task (AX-CPT; Rosvold, Mirsky, Sarason, Bransome Jr, & Beck, 1956), which requires participants to maintain goal-related information and to make target responses on cued trials and non-target responses on all other trials.

A different set of studies, however, reported intact proactive control in ageing (e.g., Paxton et al., 2008, Exp. 2; Staub, Doignon-Camus, Bacon, & Bonnefond, 2014). Using ERP indices of proactive and reactive control in a Go/No-Go task, Staub and colleagues (2014) showed that older adults were able to deploy proactive control and that they maintained it over a longer period of time without decrement compared to younger adults. This finding suggests that proactive control is not generally impaired in ageing and further investigation is needed to assess under which circumstances or tasks older adults show difficulties.

The present research

The aim of the present research was to investigate older and younger adults' ability to exert proactive control in the presence of neutral and emotional material. To extend previous ageing research, which has primarily focused on the AX-CPT task, the chapter will cover four experiments that used the Stroop paradigm. To manipulate the use of proactive control in participants, the proportion of conflict trials was varied in all four experiments. A high proportion of conflict trials (congruent and incongruent trials) relative to non-word trials is thought to facilitate a shift to proactive control due to high expectancy of conflict, whereas a low proportion of conflict trials is thought to induce a shift away from proactive control due to low expectancy of conflict (e.g., Entel, Tzelgov, Bereby-Meyer, & Shahar, 2014; Goldfarb & Henik, 2007, 2013). Two main indices were used to assess changes in control processes: interference, which is the difference between RTs for incongruent and non-word trials, and facilitation, which is the difference between RTs for congruent and non-word trials. Deployment of high proactive control is thought to be associated with reduced interference and facilitation, whereas no or low deployment of proactive control is thought to be associated with higher levels of interference and no or even reversed facilitation (Goldfarb & Henik, 2007; Kalanthroff et al., 2015; Kalanthroff et al., 2013; Tzelgov et al., 1992).

In Experiment 4.1, focus will be placed on examining proactive control in ageing in a classic colour Stroop paradigm. Cognitive control over emotional material will be assessed in Experiment 4.2 by presenting emotional faces as targets with words as distractors. To assess how the timing of target and distractor presentation can affect performance in an emotional Stroop task, Experiment 4.3 will use a different presentation schedule compared with the rest of the emotional Stroop tasks. In Experiment 4.4, emotional words will be presented as targets with faces as distractors to mirror the stimulus construction in Experiment 4.2.

4.2. Experiment 4.1: Stroop performance in ageing

There is mixed evidence regarding age-related decline in proactive control, with some studies providing evidence for impaired proactive control (Braver et al., 2009; Braver et al., 2005; Haarmann et al., 2005; Paxton et al., 2008, Exp. 1) and others providing evidence for intact proactive control in ageing (Paxton et al., 2008, Exp. 2; Staub et al., 2014). It should be noted that none of these previous studies have manipulated cognitive control in older adults in a Stroop task. Given the overall mixed pattern of results regarding proactive control in ageing, it was an open question whether older adults would show impairments in proactive control relative to younger adults. The aim of the present experiment was therefore to assess cognitive control in a sample of older and younger adults in a classic colour Stroop paradigm. To manipulate the use of proactive control, the proportion of non-word trials was varied, creating two levels of conflict expectancy: high expectancy (HE) and low expectancy (LE). Consistent with previous research (Goldfarb & Henik, 2007; Kalanthroff et al., 2015; Kalanthroff et al., 2013; Tzelgov et al., 1992), it was expected that behavioural signatures of high proactive control would be reduced interference and facilitation under HE conditions relative to LE conditions.

Methods

Participants

Twenty younger (20 - 38 years old) and 20 older adults (63 - 78 years old) participated in the experiment (see Table 4.1 for participant characteristics). One older participant was excluded from the analysis due to RTs that were 2.5 SDs slower than the older adults' group mean RTs. Younger adults were undergraduate and postgraduate students at Birkbeck, University of London, and received either course credits or £7.50/hour for their participation. Older adults were recruited from the University of the Third Age in London and were paid at the same rate as younger adults for their participation. Participants were community-dwelling, reported to be in good health, were pre-screened for psychiatric disorders and a history of neurological disorders and had normal or corrected-to-normal vision. Colour blindness was an exclusion criterion. Older participants had a score of 27 or above on the Mini-Mental State Examination (MMSE; Folstein et al., 1975). Subjects were tested individually.

Table 4.1. *Participant characteristics, Experiment 4.1*

	Younger adults		Older adults		Group difference	
Variable	*M*	*SD*	*M*	*SD*	*t*	*p*
Age	25.03	5.57	68.84	4.55		
Gender (male/female)	7/13		7/12			
Education (yrs)	16.73	2.45	16.52	3.11	0.3	.769
NART Verbal IQ	106.82	8.05	118.81	4.00	-7.13	<.001***
Digit Symbol Test	73.84	8.76	52.68	9.16	9.3	<.001***
BDI II	4.65	4.92	4.23	4.21	0.36	.720
STAI Trait Anxiety	34.13	7.44	34.23	8.39	-0.05	.962
MMSE			29.40	0.72		

Note. NART = The National Adult Reading Test, BDI II = Beck Depression Inventory II, STAI = State-Trait Anxiety Inventory, MMSE = Mini-Mental State Examination; **p* < .05, ***p* < .01, ****p* < .001

As can be seen in Table 4.1, older adults had better verbal knowledge than younger adults as assessed with the NART (Nelson & Willison, 1991) and scored lower on the Digit Symbol Substitution Test (Wechsler, 1955) suggesting slower processing speed than in younger adults. These results of slower processing speed (Salthouse, 1996, 2000) and better vocabulary knowledge in older than younger adults (Alwin & McCammon, 2001; Bowles, Grimm, & McArdle, 2005) are consistent with typical findings in ageing research. No other significant differences were observed. The ethics board of Birkbeck, University of London, approved the procedure prior to the start of the study and written informed consent was obtained from each individual.

Materials

Three colour words were used in this experiment: red, green and yellow. Congruent items were created by printing each of the colour names in their own colour (e.g., “red” printed in red ink) and incongruent items were created by printing each of the colour names in one of the two other colours (e.g., “red” printed in green ink). Non-word items were created by printing a string of “xxxxx” in the three different colours. The stimuli were presented centrally on black background in 42-point Courier New font.

Procedure

After giving informed consent, participants completed a demographic questionnaire and were then seated in front of a computer screen. A visual acuity test (Bach, 1996) was conducted at a distance of 65 cm to ensure that vision was in the normal range. Participants were then instructed to perform the computerized Stroop task. The task consisted of two blocks, and the order of the blocks was counterbalanced across participants. In the HE block, 75% of the trials were either congruent or incongruent

(37.5%, respectively), while 25% of the trials were non-words. In the LE block, 25% of the trials were either congruent or incongruent (12.5%, respectively) and 75% of the trials were non-words. Each block consisted of 192 trials and presentation of trials was random. The task was preceded by 24 practice items with an equal amount of congruent, incongruent and non-word items. Participants were instructed to indicate the ink colour as accurately and quickly as possible by pressing one of three colour-labelled buttons. On the computer keyboard, the buttons “1”, “2” and “3” of the numeric keypad were used. Button presses initiated the next trials and the assignment of colour labels to buttons was counterbalanced across participants. Participants were instructed to leave the fingers on the buttons for the duration of the task and were given the opportunity to have short breaks after every 48 trials (resulting in two short breaks in each block and one break in-between blocks).

After task completion, participants filled out the BDI-II (Beck et al., 1988) and the A-Trait version of the STAI (Spielberger et al., 1983). They also completed the Digit Symbol Substitution Test from the WAIS-R (Wechsler, 1955) and the NART (Nelson & Willison, 1991) as measures of fluid and verbal intelligence, respectively. Older adults were additionally administered the MMSE (Folstein et al., 1975) as a screening for cognitive impairments. The participants were debriefed at the end of the session and each session lasted approximately 1 hour to 1 hour and 15 minutes in total.

Design and statistical analysis

Responses and RTs were recorded for each trial. For the analyses, any RTs that were faster than 200 ms or 2.5 SD slower than the respective age group’s mean RTs were excluded. This resulted in an exclusion of 2.92% of data points in the younger age group and 2.57% in the older age group. Accuracy and median RTs for correct responses were then calculated. The analysis focused on interference (difference between incongruent and non-word trials) and facilitation (differences between congruent and non-word trials).

Statistical analysis of the data was conducted with SPSS 22 (IBM Corp., Armonk, NY). Accuracy and RTs were analysed by 2 × 3 × 2 mixed factors ANOVA including the within-subjects factors expectancy (LE vs. HE) and congruency (congruent vs. non-word vs. incongruent) as well as the between-subjects factor of age (younger vs. older). Post-hoc t-tests with a Bonferroni adjustment to the alpha level were performed to follow up significant main effects and interactions. All tests were two-tailed and a value of $\alpha = .05$ was used to determine statistical significance. As latencies varied considerably between younger and older adults, log-transformed data were used for the analysis of RTs.

Results

Accuracy

Accuracy scores for younger and older adults are presented in Figure 4.1. The analysis yielded a main effect of age, $F(1, 37) = 12.85$, $MSE < .001$, $p = .001$, partial $\eta^2 = .26$, as accuracy was higher in older ($M = .99$, $SD = .01$) than younger adults ($M = .96$, $SD = .03$). There was also a main effect of expectancy, $F(1, 37) = 5.09$, $MSE = .001$, $p = .030$, partial $\eta^2 = .12$, with higher accuracy in the LE ($M = .98$, $SD = .03$) than in the HE condition ($M = .97$, $SD = .03$). Moreover, there was a main effect of congruency, $F(2, 74) = 9.98$, $MSE = .001$, $p < .001$, partial $\eta^2 = .21$, as accuracy was higher for congruent trials ($M = .99$, $SD = .02$) than for non-word ($M = .98$, $SD = .02$), $t(38) = 3.25$, $p = .002$, or incongruent trials ($M = .96$, $SD = .04$), $t(38) = 3.72$, $p = .001$. Accuracy was also slightly higher for non-word compared to incongruent trials, $t(38) = 2.21$, $p = .033$

(marginally significant after Bonferroni correction). No significant interactions were observed for accuracy.

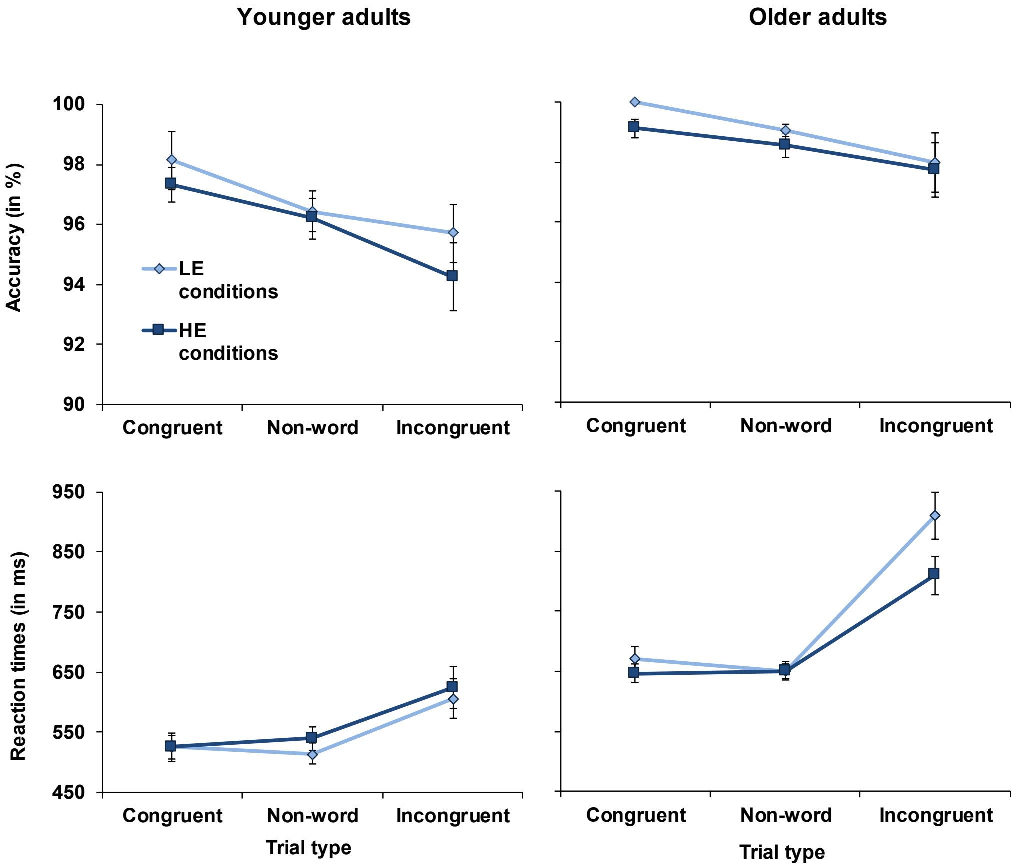


Figure 4.1. Accuracy (upper panels) and RTs for correct responses (lower panels) in younger (left panels) and older adults (right panels) in Experiment 4.1.

Reaction times

RTs for younger and older adults are shown in Figure 4.1. The analysis yielded a main effect of age, $F(1, 37) = 29.59$, $MSE = .023$, $p < .001$, partial $\eta^2 = .44$, as older adults were overall slower ($M = 723$ ms, $SD = 93$ ms) than younger adults ($M = 556$ ms, $SD = 105$ ms). There was no significant main effect of expectancy ($p = .334$), but there was a significant expectancy × age interaction, $F(1, 37) = 11.88$, $MSE = .007$, $p = .001$, partial $\eta^2 = .24$. Older adults were significantly faster under HE ($M = 702$ ms, $SD = 88$ ms) than under LE conditions (*M* = 744 ms, *SD* = 104 ms), *t*(18) = 3.27, *p* = .004, whereas the difference in RTs between HE and LE conditions was non-significant in younger adults (*p* = .109).

There was also a main effect of congruency, *F*(2, 74) = 122.17, *MSE* = .013, *p* < .001, partial η^2 = .77, with overall faster RTs for congruent (*M* = 590 ms, *SD* = 110 ms) than for incongruent trials (*M* = 734 ms, *SD* = 196 ms), *t*(38) = 11.52, *p* < .001, and with faster RTs for non-word (*M* = 587 ms, *SD* = 93 ms) than for incongruent trials, *t*(38) = 9.52, *p* < .001. No significant difference was observed between non-word and congruent trials (*p* = .871). The main effect of congruency was qualified by a congruency × age interaction, *F*(2, 74) = 10.33, *MSE* = .013, *p* =.001, partial η^2 = .22. Follow-up t tests revealed that in both age groups, RTs were slower for incongruent (younger: *M* = 615 ms, *SD* = 146 ms; older: *M* = 860 ms, *SD* = 161 ms) than for non-word trials (younger: *M* = 527 ms, *SD* = 80 ms; older: *M* = 650 ms, *SD* = .57 ms), but the effect was more pronounced in older adults, *t*(18) = 11.24, *p* < .001, than in younger adults, *t*(19) = 5.87, *p* < .001.

There was also an expectancy × congruency interaction, *F*(2, 74) = 7.80, *MSE* = .003, *p* = .002, partial η^2 = .17, which was qualified by an expectancy × congruency × age interaction, *F*(2, 74) = 5.91, *MSE* = .003, *p* = .007, partial η^2 = .14. To follow up this interaction, separate analyses were conducted for HE and LE conditions. The congruency × age interaction was significant under HE conditions, *F*(2, 74) = 4.52, *MSE* = .005, *p* = .023, partial η^2 = .11, but was more pronounced under LE conditions, *F*(2, 74) = 11.68, *MSE* = .011, *p* < .001, partial η^2 = .24. Under HE conditions, younger adults showed a trend for faster RTs for congruent (*M* = 525 ms, *SD* = 89 ms) than for non-word trials (*M* = 539 ms, *SD* = 90 ms), *t*(19) = 2.02, *p* = .058, whereas no such difference in RTs was observed in older adults (*p* = .638). Moreover, both younger and older adults showed slower RTs for incongruent (younger: *M* = 624 ms, *SD* = 153 ms; older: *M* = 810 ms, *SD* = 142 ms) than for non-word trials (younger: *M* = 539 ms, *SD* = 90 ms; older: *M* = 650 ms, *SD* = 69 ms), but the difference was more pronounced in older adults, $t(18) = 8.85$, $p < .001$, than in younger adults, $t(19) = 6.05$, $p < .001$. A similar pattern was observed for incongruent and non-word trials under LE conditions. Again, younger and older adults showed slower RTs for incongruent (*M* = 606 ms, *SD* = 147 ms) than for non-word trials (*M* = 514 ms, *SD* = 76 ms) trials, $t(19) = 4.46$, $p < .001$. In older adults, the RT difference between incongruent (*M* = 910 ms, *SD* = 193 ms) and non-word trials (*M* = 650 ms, *SD* = 53 ms) was more pronounced, $t(18) = 8.81$, $p < .001$. RT differences between congruent and non-word trials under LE conditions were non-significant in younger and older adults ($p = .556$ and $p = .078$, respectively).

Discussion

Experiment 4.1 was designed to investigate proactive control in ageing using the classic colour Stroop paradigm. The present results replicated previous findings of increased interference in older relative to younger adults. However, it was also found that both younger and older adults showed behavioural evidence of proactive control when expectancy of control was high relative to low: Older adults showed reduced interference under HE compared to LE conditions but no facilitation. In contrast, younger adults showed a trend for facilitation under HE compared to LE conditions but no reduced interference.

The present experiment showed that ageing was associated with increased interference from incongruent relative to non-word trials, which has been shown before (Davidson et al., 2003; Spieler et al., 1996; West & Alain, 2000; West & Bell, 1997) and which is in line with the inhibition account of ageing (Hasher et al., 1991; Hasher et al., 1999). However, increased Stroop interference in ageing could be due to general slowing rather than a decline in inhibition. It was suggested that age differences in RTs grow larger in conditions with increasing RTs (Bunce & Macready, 2005; Cerella, 1990; Myerson et al., 1990; Salthouse, 1996, 2000) and previous literature suggests that an increased Stroop effect in older adults can be explained by general slowing (Verhaeghen & De Meersman, 1998b). In the present experiment, older adults were indeed slower than younger adults, which could have exacerbated age-related differences in the Stroop effect. Thus, the effect of increased interference in older adults should be interpreted with caution.

Importantly, older adults were found to exhibit reduced interference from incongruent relative to non-word trials under HE compared to LE conditions, suggesting that they were able to deploy proactive control in the present paradigm. This finding is compatible with previous studies showing that proactive control is largely preserved in ageing (Paxton et al., 2008, Exp. 2; Staub et al., 2014). In contrast, these findings are not in line with evidence obtained in studies using the AX-CPT task, which highlighted age-related decline in proactive control (Braver et al., 2009; Braver et al., 2005; Haarmann et al., 2005; Paxton et al., 2008). Methodological differences between the studies, which might have contributed to the conflicting pattern of results, and possible explanations will be discussed in the general discussion of this chapter below. In contrast, no reduced interference under HE compared to LE conditions was observed in younger adults. It is unclear why this behavioural pattern of proactive control commonly found in younger adults (Goldfarb & Henik, 2007; Kalanthroff et al., 2015; Kalanthroff et al., 2013; Tzelgov et al., 1992) could not be replicated in the present experiment. One possible reason for this might be that younger adults were able to exert high levels of proactive control in both conditions. This would also suggest that they were not affected by the manipulation.

The main finding of Experiment 4.1 was that older adults were able to deploy proactive control under conditions of high conflict expectancy in a Stroop paradigm by showing reduced interference under HE relative to LE conditions. Experiments 4.2 and 4.4 were designed to investigate whether this pattern of results could be replicated. Furthermore, the results were extended by investigating the role of emotional content on the ability to exert proactive control in a Stroop paradigm in ageing.

4.3. Experiment 4.2: Ageing and cognitive control in a facial Stroop task

So far, the effect of emotion on proactive control in ageing has received little attention, despite evidence of age-related changes in how emotion can affect WM performance (as outlined in Chapter 2). On the one hand, it was reported that older adults can benefit from the inclusion of emotional and particularly positive material in WM tasks (Mammarella, Borella, et al., 2013a; 2013b; Mikels et al., 2005). On the other hand, there is evidence that emotional material can impair older adults' performance in WM tasks, particularly when it is negative (Borg et al., 2011; Svärd, Fischer, & Lundqvist, 2014; Truong & Yang, 2014; Wurm et al., 2004). The aim of the present research was therefore to investigate older and younger adults' ability to exert proactive control in an emotional Stroop paradigm.

As discussed in Chapter 2.4, two contrasting theoretical approaches have been suggested to explain how emotion and cognition might interact in ageing, namely, the SST (Carstensen, 1993) and accounts linking emotional changes with cognitive decline such as the dynamic integration theory (Labouvie-Vief, 2003, 2009b). The availability of cognitive resources plays an important role in both accounts. Thus, contrasting predictions regarding the effects of emotion on older adults' proactive control can be proposed within these accounts based on the availability of cognitive resources in the task: On the one hand, the SST suggests that older adults use cognitive resources to direct their attention to positive information as it is in accordance with their motivational goals (for reviews, see Reed & Carstensen, 2012; Scheibe & Carstensen, 2010a). On the other hand, it was suggested that the processing of complex negative information and experiences could be more difficult in ageing due to limited cognitive resources (Labouvie-Vief, 2003, 2009b). As proactive control is thought to be resource-demanding, fewer cognitive resources should be available under conditions requiring high proactive control relative to conditions requiring low proactive control. Thus, if older adults use cognitive resources in order to direct their attention to positive information, this effect should be less pronounced under conditions requiring high proactive control. In contrast, if older adults show impaired processing of negative items due to limited cognitive resources, this effect should be more pronounced under conditions requiring high proactive control.

As both theoretical approaches were suggested for task-relevant emotional material, the current study will also focus on task-relevant emotional items. Although the Stroop task has been commonly used when investigating the effects of emotion on cognitive control, it should be noted that emotion was often used as the task-irrelevant feature (see Chapter 2.2). For instance, emotional items were shown as distractors in an otherwise non-emotional Stroop task. In studies using emotional words in a colour Stroop task (Constantine et al., 2001; Kindt & Brosschot, 1997; McKenna & Sharma, 1995; Williams et al., 1996), the word's emotional content was usually irrelevant for colour naming. In other studies, participants were explicitly instructed to ignore emotional items while performing a Stroop task. For instance, Kalanthroff, Henik, Derakshan and Usher (2016) used brief emotional and neutral distractors that were presented before a target item in a classic colour Stroop paradigm.

The effects of task-relevant emotional targets, on the other hand, have received less attention in Stroop studies, despite evidence that emotion can improve cognitive performance through enhanced target processing (Pessoa, 2009). In a study by Krug and Carter (2012), participants had to respond to the emotion of neutral and fearful faces, while these were shown with congruent and incongruent emotion labels ("neutral" or "fearful"). The authors reported higher interference by an irrelevant emotional (i.e., "fearful") relative to an irrelevant neutral word distractor. However, an alternative interpretation could be that interference was actually reduced for emotional targets (fearful face with irrelevant neutral label) rather than increased for emotional distractors (neutral face with irrelevant emotional label), an option that was not explored by the authors. Also, happy faces were not included, and thus it is not clear whether the results observed for negative items would also be found for positive items.

In contrast to previous studies using primarily neutral and negative stimuli, three levels of emotion were included in the present experiment, namely happy, neutral and angry faces. Based on research showing that happy faces are detected more efficiently (Becker et al., 2011; Becker & Srinivasan, 2014; Kirita & Endo, 1995), it was predicted that both age groups would show higher accuracy and faster RTs for happy relative to neutral or angry target faces. Given the existence of two competing accounts, which could help to explain age-related differences in emotion-cognition interactions, the hypotheses were twofold: If the focus on positive material in ageing is deliberate and requires cognitive resources as suggested within the framework of the SST (Carstensen, 1993), it was hypothesised that improved performance for happy faces would be more pronounced in older adults under conditions requiring lower levels of proactive control, as more resources would be available to focus on positive information. In contrast, if the focus to positive items is due to cognitive decline in ageing, it was hypothesised that the facilitating effect of happy faces would be more pronounced in older adults under conditions requiring higher levels of proactive control, as fewer resources would be available. Similarly, the impairing effects of negative items would be more pronounced in older adults under conditions requiring higher levels of proactive control, as fewer resources would be available to process them efficiently.

Methods

Participants

Thirty younger (19 - 40 years old) and 30 older adults (62 - 85 years old) participated in the experiment (see Table 4.1 for participant characteristics). One younger and one older participant were excluded from the analysis due to RTs that were 2.5 SD slower than the respective age group's mean RTs. Younger and older adults met the same criteria as in Experiment 4.1 and were reimbursed in the same manner. None of the participants involved in Experiment 4.2 had participated in Experiment 4.1. As can be seen in Table 4.2, older adults had better verbal knowledge as assessed with the NART (Nelson & Willison, 1991) and showed slower processing speed as measured by the Digit Symbol Substitution Test (Wechsler, 1955). No further differences were observed. Older participants had a score of 27 or above on the MMSE (Folstein et al., 1975). The ethics board of Birkbeck, University of London, approved the procedure prior to the start of the study and written informed consent was obtained from each participant.

Table 4.2. *Participant characteristics, Experiment 4.2*

	Younger adults		Older adults		Group difference	
Variable	*M*	*SD*	*M*	*SD*	*t*	*p*
Age	28.14	6.99	71.34	6.75		
Gender (male/female)	8/21		8/21			
Education (yrs)	15.83	2.49	16.00	3.22	-.23	.820
NART Verbal IQ	105.69	6.56	114.46	6.04	-5.25	<.001***
Digit Symbol Test	64.17	11.90	51.69	11.83	4.01	<.001***
BDI II	5.45	5.03	4.64	4.04	.66	.509
STAI Trait Anxiety	35.66	9.64	35.32	8.50	.14	.890
MMSE			29.10	1.01		

Note. NART = The National Adult Reading Test, BDI II = Beck Depression Inventory II, STAI = State-Trait Anxiety Inventory, MMSE = Mini-Mental State Examination; **p* < .05, ***p* < .01, ****p* < .001

Materials

The stimuli were 36 faces from the FACES database (Ebner et al., 2010), a validated set of photographs of naturalistic faces of different ages in front view. Faces showed angry, neutral or happy expressions (12 items per emotion). The age group (young, middle-aged, older) and sex (male, female) of the faces were balanced in each emotion category. The faces were taken from a pool of stimuli that had been previously rated by younger and older adults and were selected based on high agreement ratings between both age groups (see Appendix A for evaluation details). Congruent items were created by printing matching emotion labels across the emotional faces (e.g., neutral face with “neutral” label). Incongruent items were created by printing non-matching emotion labels across the faces (e.g., angry face with “happy” label). Non-word items were created by printing a string of “xxxxx” across the faces. Combinations of faces and labels are summarised in Table 4.3. Face images were turned to grey-scale, whilst labels were printed in red, 38-point Courier New font, and placed between eyes and mouths of the faces. Example stimuli are presented in Figure 4.2.

Table 4.3. Combinations of facial expressions and labels that formed congruent, non-word and incongruent stimuli

	Task-relevant facial expression		
Distractor label	Angry	Neutral	Happy
Angry	congruent	incongruent	incongruent
Neutral	incongruent	congruent	incongruent
Happy	incongruent	incongruent	congruent
xxxxx	non-word	non-word	non-word

Note. Congruent stimuli are colour-coded in green, non-word stimuli in yellow and incongruent stimuli in red.

Procedure

The procedure was identical to the procedure for Experiment 4.1, as were the proportions of congruent, incongruent and non-word trials in the HE and LE blocks. There were equal numbers of angry, neutral and happy faces across congruent, non-word and incongruent trials as well as across the two blocks. Each block consisted of 288 trials and presentation of trials was random. In each trial, a fixation cross appeared for 500 ms. It was then replaced by the distractor label “angry”, “neutral”, “happy” or “xxxxx”, which was presented for 100 ms. This was done to facilitate label reading, following prior procedures by Krug and Carter (2012). The presentation of the label was followed by the simultaneous presentation of the label and the target face. Participants were instructed to indicate the emotion of the face (angry, neutral or happy) as accurately and quickly as possible by pressing one of three labelled keys. On the computer keyboard, the buttons “1”, “2” and “3” on the numeric keypad were used. Button presses initiated the presentation of a blank screen for 2000 ms, after which the next trial started. The assignment of emotion labels to buttons was counterbalanced across participants. Participants were instructed to leave the fingers on the buttons for the duration of the task. With the option to take short breaks after every 48 trials, there were five short breaks in each block and one break in-between blocks. Each session lasted approximately 1 hour and 15 minutes in total.

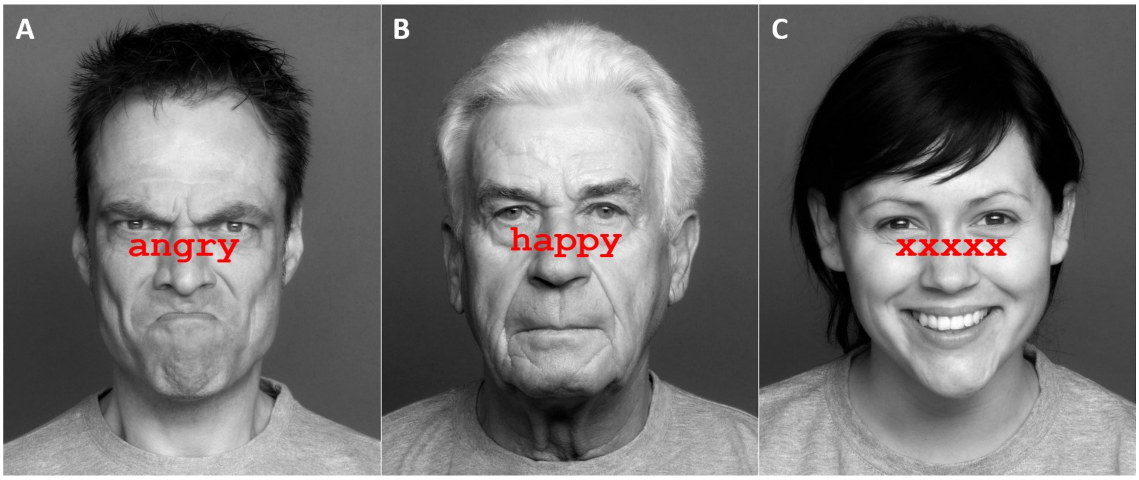


Figure 4.2. Examples of Stroop stimuli in Experiment 4.2. Picture A shows an angry face with a congruent label, picture B shows a neutral face with an incongruent label and picture C shows a happy face with a non-word label.

Design and statistical analysis

Responses and RTs were recorded for each trial. For the analyses, any RTs that were faster than 200 ms or 2.5 SD slower than the respective age group's mean RTs were excluded. This resulted in an exclusion of 2.56% of data points in the younger age group and 2.45% in the older age group. Accuracy and median RTs for correct trials were then calculated. Statistical analyses of the data were conducted with SPSS 22 (IBM Corp., Armonk, NY). Accuracy and RTs were analysed by 2 × 3 × 3 × 2 mixed factors ANOVA including the within-subjects factors expectancy (LE vs. HE), congruency (congruent vs. non-word vs. incongruent) and emotion (angry vs. neutral vs. happy) as well as the between-subjects factor of age (younger vs. older). Post-hoc t-tests with a Bonferroni adjustment to the alpha level were performed to follow up significant main effects and interactions. All tests were two-tailed and a value of $\alpha = .05$ was used to determine statistical significance. As RTs varied considerably between younger and older adults, log-transformed RTs were used for the analysis.

Results

Accuracy

Accuracy scores for younger and older adults are presented in Figure 4.3. The analysis yielded a significant main effect of congruency, $F(2, 112) = 45.89$, $MSE = .007$, $p < .001$, partial $\eta^2 = .45$, with higher accuracy for congruent ($M = 96.94$, $SD = 2.71$) compared to non-word ($M = 95.65$, $SD = 3.53$), $t(57) = 3.97$, $p < .001$, or incongruent trials ($M = 91.97$, $SD = 6.37$), $t(57) = 7.29$, $p < .001$. Accuracy was also higher for non-word than for incongruent trials, $t(57) = 6.43$, $p < .001$. There was also a main effect of emotion, $F(2, 112) = 29.25$, $MSE = .026$, $p < .001$, partial $\eta^2 = .34$, with higher accuracy for happy faces ($M = 97.74$ $SD = 3.05$) compared with neutral ($M = 96.26$, $SD = 4.22$), $t(57) = 2.89$, $p = .005$, or angry faces ($M = 90.56$, $SD = 8.49$), $t(57) = 6.51$, $p < .001$. Accuracy was also higher for neutral than for angry faces, $t(57) = 4.79$, $p < .001$. These main effects were qualified by a significant congruency × emotion interaction, $F(4, 224) = 4.25$, $MSE = .003$, $p = .008$, partial $\eta^2 = .07$. Follow-up t tests revealed that for angry faces, accuracy was higher for congruent ($M = 93.79$, $SD = 7.21$) relative to non-word trials ($M = 91.17$, $SD = 8.45$), $t(57) = 379$, $p < .001$. In contrast, the difference in accuracy between congruent and non-word trials was not significant for neutral ($p = .079$) or for happy faces ($p = .102$). Accuracy was higher for non-word than for incongruent trials for all three valences (all t values >= 4.25).

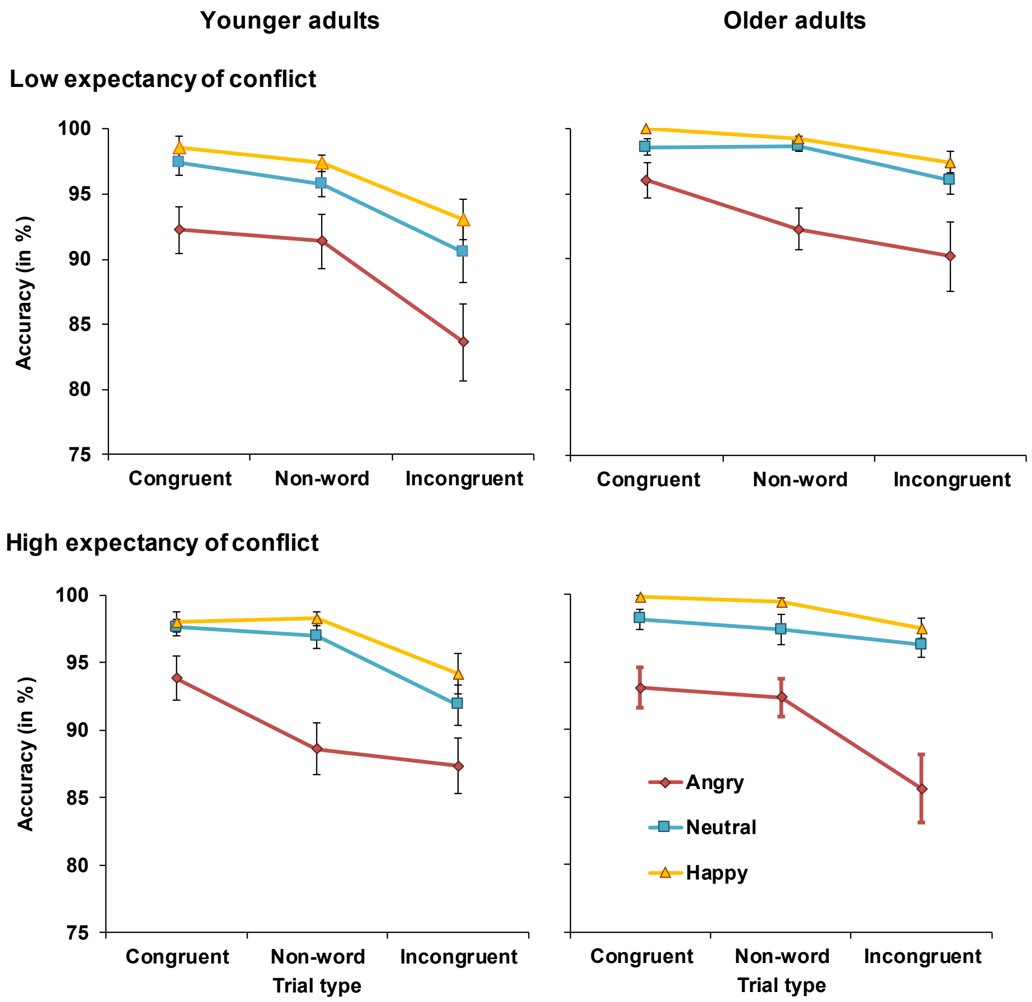


Figure 4.3. Accuracy in younger adults (left panels) and older adults (right panels) in Experiment 4.2.

There was also a significant expectancy × congruency × emotion × age interaction, *F*(4, 224) = 3.36, *MSE* = .004, *p* = .029, partial η^2 = .06. Accuracies under HE and LE conditions were analysed separately to follow up this interaction. The congruency × emotion × age interaction was not significant under LE conditions, *F*(4, 224) =.65, *MSE* = .006, *p* = .696, partial η^2 = .01, but was under HE conditions, *F*(4, 224) =7.71, *MSE* = .002, *p* = .001, η^2 = .09. Follow-up t-tests indicated that different response patterns to angry faces in younger and older adults were driving the effect: Under HE conditions, younger adults showed higher accuracy for congruent angry faces (*M* = 93.85, *SD* =

8.88) relative to non-word angry faces (*M* = 88.62, *SD* = 10.45), *t*(28) = 3.86, *p* = .001 and no difference between incongruent angry faces and non-word angry faces (*p* = .419). In contrast, older adults showed no difference (*p* = .515) in their accuracy for congruent angry relative to non-word angry faces. Instead, their accuracy was significantly lower for incongruent angry (*M* = 85.62, *SD* = 13.55) relative to non-word angry faces (*M* = 92.06, *SD* = 8.17), *t*(28) = 3.14, *p* = .004. No such contrasting patterns of results between younger and older participants were observed for neutral or happy faces.

Reaction times

RTs for younger and older adults are presented in Figure 4.4. The analysis yielded a main effect of age, *F*(1, 56) = 27.32, *MSE* = .421, *p* < .001, partial η^2 = .33, as older adults were overall slower (*M* = 853 ms, *SD* = 162 ms) than younger adults (*M* = 684 ms, *SD* = 92 ms). There was also a main effect of congruency, *F*(2, 112) = 124.06, *MSE* = .019, *p* < .001, partial η^2 = .69, with overall faster RTs for congruent (*M* = 724 ms, *SD* = 138 ms) than for non-word trials (*M* = 750 ms, *SD* = 137 ms), *t*(57) = 7.89, *p* < .001, or incongruent trials (*M* = 833 ms, *SD* = 203 ms), *t*(58) = 12.40, *p* < .001. RTs were also faster for non-word than for incongruent trials, *t*(57) = 9.86, *p* < .001. This main effect was qualified by an expectancy × congruency interaction, *F*(2, 112) = 12.25, *MSE* = .006, *p* < .001, partial η^2 = .18. To follow up on this interaction, the analysis was repeated with the factor congruency only comprising the factor levels congruent and non-word trials, which did not yield in a significant expectancy × congruency interaction (*p* = .878). In contrast, in the analysis with the factor congruency comprising the factor levels non-word and incongruent trials, there was a significant expectancy × congruency interaction, *F*(1, 57) = 15.87, *MSE* = .006, *p* < .001, partial η^2 = .22.

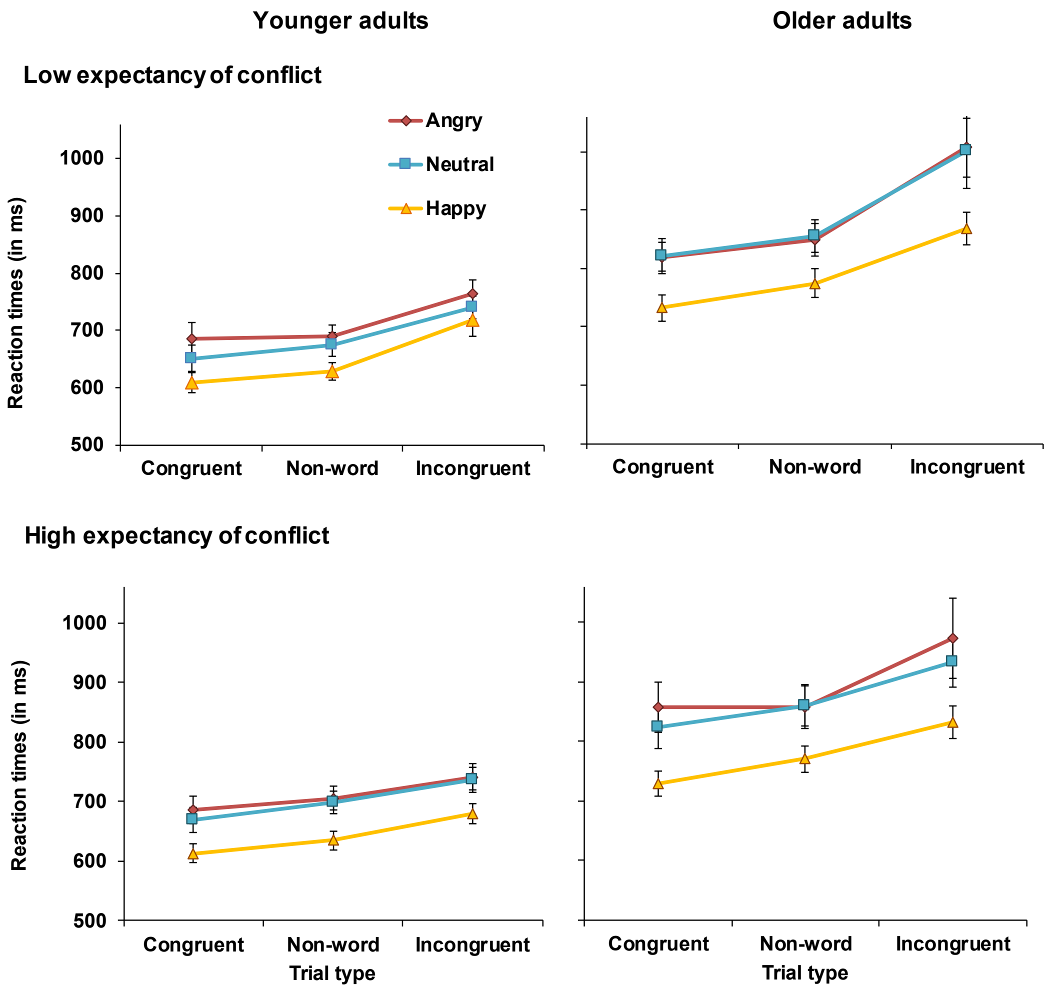


Figure 4.4. RTs for correct responses in younger adults (left panels) and older adults (right panels) in Experiment 4.2.

Follow-up t-tests revealed that under HE conditions, RTs were slower for incongruent (M = 815 ms, SD = 200 ms) than for non-word trials (M = 754 ms, SD = 146 ms), $t(57) = 8.22$, $p < .001$. Under LE conditions, the difference in RTs between incongruent (M = 850 ms, SD = 226 ms) and non-word trials (M = 745 ms, SD = 142 ms) was more pronounced, $t(57) = 9.95$, $p < .001$. Moreover, there was a significant main effect of emotion, $F(2, 112) = 50.61$, $MSE = .022$, $p < .001$, partial $\eta^2 = .48$, and follow-up analyses revealed that RTs for happy faces (M = 716 ms, SD = 124 ms) were faster than for neutral faces (M = 788 ms, SD = 177 ms), $t(57) = 7.36$, $p < .001$, or angry faces (M =

802 ms, *SD* = 181 ms), *t*(57) = 9.20, *p* < .001. The difference between RTs for neutral and angry faces was not significant (*p* = .139). No further main effects or interactions were observed for RTs.

Discussion

The aim of this experiment was to assess the effects of emotion on cognitive control in older relative to younger adults. Two critical findings were observed. First, both age groups showed reduced interference in RTs from incongruent relative to non-word trials when expectancy of conflict was high (HE conditions). This suggests that both age groups were able to increase control, which helped to prime task-relevant processing pathways before the onset of conflict-generating trials. Second, emotional faces affected cognitive control in both age groups. Happy faces were found to improve cognitive performance as evidenced by higher accuracy and faster RTs for happy compared to neutral or angry faces with no age-related differences. In contrast, accuracy was lowest and RTs were slowest for angry faces. Moreover, angry faces impaired accuracy under HE conditions, but only in older adults: Whereas younger adults were more accurate when responding to congruent relative to non-word angry faces, no such effect was observed in older adults. Moreover, older adults showed reduced accuracy for incongruent relative to non-word negative information under HE conditions, which was not observed in younger adults. Overall, these results suggest that despite no general impairment, older adults were less able to use proactive control successfully in the presence of angry faces, making them more susceptible to conflict.

Happy faces were found to improve cognitive performance as evidenced by higher accuracy and faster RTs for happy compared to neutral or angry faces. This effect was observed in both age groups and is in line with previous research showing improved WM performance for happy faces relative to other expressions (Cromheeke & Mueller, 2015; Levens & Gotlib, 2010, 2012). It is likely to be linked to a recognition advantage of happy faces, as happy expressions were found to be recognised more accurately and faster than other emotional expressions (Becker et al., 2011; Becker & Srinivasan, 2014; Juth et al., 2005). Besides the perceptual advantage it is also likely that happy faces contributed to improved performance due to the rewarding value they carry (O'Doherty et al., 2003; Tsukiura & Cabeza, 2008), which might have facilitated efficient processing of happy faces in WM.

However, the benefit of happy faces on WM performance was not more pronounced in older relative to younger adults, neither in general nor in any of the two conditions. In contrast, age-related differences in responses to emotional faces emerged for angry faces. Older adults' accuracy was not enhanced for congruent relative to non-word angry trials and older adults made more errors when angry trials were incongruent rather than showing non-words. As this was only observed when high levels of proactive control were required, it appears that older adults were less efficient in successfully resolving conflict by deploying proactive control in the presence of negative material compared to their younger counterparts.

The pattern of improved performance for happy faces in both age groups with no age-related differences on the one hand and age-related impairment in performance for angry faces under conditions requiring proactive control on the other hand is not fully reconcilable with the SST (Carstensen, 1993). According to this theory, older adults focus on positive information in order to improve wellbeing, resulting in a positivity effect in memory, attention or WM. In contrast, it is compatible with research linking ageing with changes in the processing of negative material (Grühn et al., 2007; Grühn et al., 2005; Kisley et al., 2007; Langeslag & van Strien, 2009) and suggestions that these changes might be related to cognitive decline (see Labouvie-Vief, 2003; 2009a for reviews). Research suggests that negative material elicits higher cognitive activity and leads to more complex cognitive representations than positive material (for a review, see Peeters & Czapinski, 1990) and that angry faces capture attention and are more difficult to disengage from (Fox et al., 2001; Hansen & Hansen, 1988; Öhman et al., 2001; Olofsson et al., 2008).

Given this evidence, it is possible that older adults were less efficient in resolving conflict when presented with more resource-demanding and threatening stimuli. This would also be in accordance with the dual competition model (Pessoa, 2009, 2015, 2017), according to which threatening stimuli draw common pool resources and thereby impair executive functions, which rely on these resources. Both age groups performed similarly under conditions of low expectancy in the presence of angry material, suggesting that sufficient resources were available to deal with negative material under conditions requiring low levels of proactive control in both age groups. However, age-related impairments in the presence of negative material occurred under high expectancy conditions requiring high levels of proactive control. This suggests that despite no overall impairment in proactive control in ageing, no sufficient resources were available to perform the task in the presence of threatening material, making older adults more vulnerable to distraction from conflict.

It should be noted that accuracy was not improved for congruent relative to non-word trials when neutral or happy faces were shown, whereas accuracy was impaired for incongruent relative to non-word trials for all three valences. As incongruent distractors did interfere with responses for neutral and happy faces, it appears unlikely that participants were able to ignore distractors in the face of neutral or happy faces. In contrast, it is possible that the failure to observe facilitation for neutral and happy faces was due to ceiling effects as accuracy was very high for these faces.

Facilitation in RTs, which is usually observed when target responses are faster for congruent (e.g., happy face with a "happy" label) than for non-word stimuli (e.g., happy face with non-word label "xxxxx"), was found for both age groups in both conditions. This suggests that the priming of task-relevant processing pathways improved performance for congruent relative to non-word trials irrespective of expectancy of conflict. It is believed that the distractor-first design in the experiment contributed to facilitation in RTs across both conditions. As reviewed by Roelofs (2003), facilitation is found when distractors precede target stimuli as they did in the present experiment: participants viewed the distractor label 100 ms before the target face appeared. According to Roelofs (2003), such a preview can prime a particular response, resulting in facilitation in congruent trials, and this effect is considered to be "automatic" with preview times under 250 ms. To investigate whether the pattern can be changed by showing targets and distractors simultaneously, Experiment 4.3 was conducted.

4.4. Experiment 4.3: Facial Stroop without preview of distractor

As shown in previous research (Goldfarb & Henik, 2007; Kalanthroff et al., 2015; Kalanthroff et al., 2013; Tzelgov et al., 1992), high levels of proactive control under HE conditions are associated with reduced interference and facilitation, whereas low levels of proactive control under LE conditions are associated with increased interference and no or even reversed facilitation. However, facilitation was found in both LE and HE conditions in Experiment 4.2. The aim of the present experiment was to assess cognitive control in a facial Stroop task with a simultaneous presentation of the target and the distractor. This was done to assess whether it was the distractor-first presentation in Experiment 4.2 that contributed to facilitation in RTs across both LE and HE conditions as suggested by Roelofs (2003) rather than another factor, for example the presentation of emotional targets in general or emotional faces in particular.

Again, the proportion of non-word trials was varied in the same way as in Experiments 4.1 and 4.2 and the same stimuli as in Experiment 4.2 were used. It was expected that the simultaneous presentation of targets and distractors would be associated with reduced or even reversed facilitation under conditions requiring low proactive control (LE conditions) relative to conditions requiring high proactive control (HE conditions). Similarly, it was expected that increased interference would be observed under conditions of low proactive control relative to conditions of high proactive control as observed in Experiment 4.1 and Experiment 4.2. As both age groups showed facilitation in RTs both under LE and HE conditions with no age-related differences in Experiment 4.2, only younger adults were tested in Experiment 4.3.

Methods

Participants

Twenty-three younger adults (19 - 37 years old) participated in the experiment (see Table 4.4 for participant characteristics). The participants met the same criteria as the younger adults in Experiments 4.1 and 4.2. None of the participants involved in Experiment 4.3 had previously participated in Experiment 4.2. The ethics board of Birkbeck, University of London, approved the procedure prior to the start of the study and written informed consent was obtained from each participant.

Table 4.4. *Participant characteristics, Experiment 4.3*

Variable	*M*	*SD*
Age	23.87	4.73
Gender (male/female)	9/14	
Education (yrs)	16.39	2.76
NART Verbal IQ	110.96	6.73
Digit Symbol Test	74.26	13.72
BDI II	6.00	6.44
STAI Trait Anxiety	34.91	8.69

Note. NART = The National Adult Reading Test, BDI II = Beck Depression Inventory II, STAI = State-Trait Anxiety Inventory, MMSE = Mini-Mental State Examination

Materials

The same materials as in Experiment 4.2 were used.

Procedure

The procedure was identical to the procedure for Experiment 4.2, as were the proportions of congruent, incongruent and non-word trials in the HE and LE blocks. However, rather than presenting the distracter label 100 ms before the onset of the face, the label and the target face were presented simultaneously.

Design and statistical analysis

The recording of data was identical as in Experiment 4.2. RTs that were faster than 200 ms or over 2.5 SD slower than the average RTs were removed from data analysis, resulting in an exclusion of 2.1% of the RT data. Accuracy and RTs were analysed the same way as in Experiment 4.2.

Results

Accuracy

Accuracy scores are presented in Figure 4.5. The analysis yielded a significant main effect of congruency, $F(2, 44) = 16.18$, $MSE = .009$, $p < .001$, partial $\eta^2 = .42$, as accuracy was higher for congruent ($M = 91.97$, $SD = 6.37$) than for incongruent trials ($M = 89.92$, $SD = 7.77$), $t(22) = 4.27$, $p < .001$. Accuracy was also higher for non-word trials ($M = 93.89$, $SD = 4.98$) than for incongruent trials, $t(22) = 4.25$, $p < .001$, whereas the difference between congruent and non-word trials missed significance ($p = .057$). There was also a main effect of emotion, $F(2, 44) = 14.39$, $MSE = .028$, $p < .001$, partial $\eta^2 = .40$, as accuracy was higher for happy faces ($M = 96.15$, $SD = 3.81$) than for angry faces ($M = 87.84$, $SD = 10.37$), $t(22) = 4.33$, $p < .001$. Accuracy was also higher for neutral ($M = 94.97$, $SD = 4.25$) than for angry faces, $t(22) = 3.68$, $p = .001$, whereas the difference in accuracy for happy and neutral faces was not significant ($p = .246$). These main effects were qualified by a significant congruency × emotion interaction, $F(4, 88) = 3.10$, $MSE = .004$, $p = .040$, partial $\eta^2 = .12$. Follow-up t tests revealed that for angry faces, accuracy was slightly higher for congruent ($M = 91.79$, $SD = 8.11$) relative to non-word trials ($M = 88.10$, $SD = 11.01$), $t(22) = 2.47$, $p = .027$. The differences in accuracy between congruent and non-word trials were non-significant for happy faces ($M = 97.64$, $SD = 3.41$ and $M = 97.31$, $SD = 3.02$, respectively; $p = .582$) and neutral faces ($M = 96.01$, $SD = 3.41$ and $M = 96.26$, $SD = 3.96$, respectively; $p = .703$). Accuracy was higher for non-word than for incongruent trials for all three valences (all t values >= 3.07). No further main effects or interactions were observed for accuracy.

Reaction times

RTs are shown in Figure 4.5. The analysis yielded a main effect of congruency, *F*(2, 44) = 50.52, *MSE* = .9337, *p* < .001, partial η^2 = .70, with overall faster RTs for congruent (*M* = 672 ms, *SD* = 113 ms) than for non-word trials (*M* = 696 ms, *SD* = 113 ms), *t*(22) = 3.28, *p* = .003, or incongruent trials (*M* = 767 ms, *SD* = 145 ms), *t*(22) = 7.65, *p* < .001. RTs were also faster for non-word than for incongruent trials, *t*(22) = 7.81, *p* = .001. This main effect was qualified by an expectancy × congruency interaction, *F*(2, 44) = 6.82, *MSE* = 4216, *p* < .001, partial η^2 = .24. Follow-up t-tests revealed that under HE conditions, RTs were faster for congruent (*M* = 680 ms, *SD* = 142 ms) than non-word trials (*M* = 712 ms, *SD* = 143 ms), *t*(22) = 4.48, *p* < .001. RTs were also slower for incongruent (*M* = 756 ms, *SD* = 175 ms) than non-word trials, *t*(22) = 4.85, *p* < .001. Under LE conditions, the difference in RTs between incongruent (*M* = 779 ms, *SD* = 127 ms) and non-word trials (*M* = 679 ms, *SD* = 93 ms) was even more pronounced, *t*(22) = 7.94, *p* < .001. In contrast, the difference between congruent (*M* = 664 ms, *SD* = 111 ms) and non-word trials was non-significant (*p* = .282) under LE conditions. Moreover, there was a significant main effect of emotion, *F*(2, 44) = 15.90, *MSE* = 20905, *p* < .001, partial η^2 = .42, and follow-up analyses revealed that RTs to happy faces (*M* = 656 ms, *SD* = 110 ms) were faster than to neutral faces (*M* = 731 ms, *SD* = 138 ms), *t*(22) = 4.75, *p* < .001, or angry faces (*M* = 748 ms, *SD* = 142 ms), *t*(22) = 4.74, *p* < .001. The difference between RTs to neutral and angry faces was non-significant (*p* = .337). No further main effects or interactions were observed for RTs.

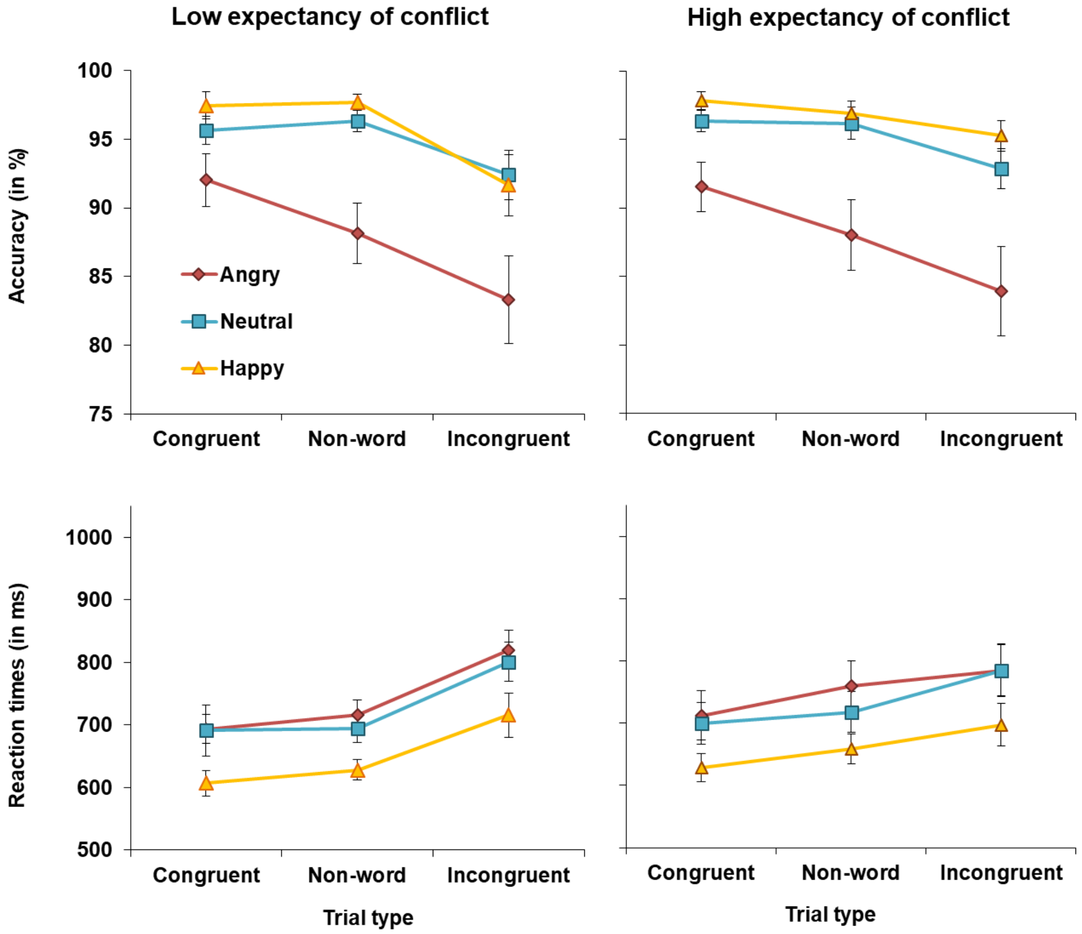


Figure 4.5. Accuracy (upper panels) and RTs for correct responses (lower panels) in younger adults in Experiment 4.3.

Discussion

The aim of this study was to assess the effects of emotion on cognitive control in an emotional Stroop paradigm, in which distractors and targets were presented at the same time. It was found that for RTs, simultaneous presentation of distractor and target resulted in facilitation and reduced interference under conditions of high proactive control (HE conditions), whereas reduced facilitation and increased interference were observed under conditions of low proactive control (LE conditions). This is consistent with the hypotheses and with previous research showing the same behavioural pattern when manipulating control by varying the proportion of non-word trials (Goldfarb & Henik, 2007; Kalanthroff et al., 2015; Kalanthroff et al., 2013; Tzelgov et al., 1992).

This pattern of results suggests that participants were able to increase proactive control when expectancy of the conflict was high, resulting in facilitation and reduced interference from distractors. Moreover, the present experiment replicated results from Experiment 4.2 by showing that emotion affected cognitive control. In both experiments, happy faces improved cognitive performance as evidenced by faster RTs for happy relative to neutral or angry faces and by higher accuracy for happy relative to angry faces. In contrast, accuracy was lowest and RTs were slowest for angry faces.

As in the previous experiment, facilitation in accuracy was found for angry faces but not for neutral or happy faces, whereas interference in accuracy was present for all three valences. It is likely that no facilitation for neutral and happy faces was observed due to ceiling effects, as accuracy was very high for neutral and happy faces. The implications of the present findings will be discussed in the general discussion of this chapter below.

4.5. Experiment 4.4: Ageing and cognitive control in a verbal Stroop task

Both Experiment 4.2 and Experiment 4.3 showed that emotional material affected cognitive performance in an emotional Stroop paradigm. More specifically, participants responded more accurately and faster when Stroop targets were happy faces, whereas accuracy was lowest and RTs were slowest for angry faces. Although the overall pattern was similar in groups of younger and older adults, Experiment 4.2 also highlighted age-related changes in cognitive control of emotional material. Reduced facilitation and increased interference in accuracy were observed for angry faces in older relative to younger adults under conditions requiring high levels of proactive control. Thus, it appears that older adults were less efficient to successfully resolve conflict by deploying proactive control in the presence of angry faces compared to their younger counterparts.

It is less clear whether the same benefits and impairments, which were observed for emotional faces, can be expected for other stimuli such as words in an emotional Stroop paradigm. As discussed in Chapter 2.2, evidence suggests that emotional biases in processing are stronger for biologically prepared stimuli such as faces compared with words (Kensinger & Corkin, 2003; Kensinger & Schacter, 2006; Rellecke et al., 2011; Vuilleumier, 2005). It was suggested that differences in extracting emotional significance from words and faces can account for these results, as words must be processed to a higher level than faces before their meaning could be assessed (Kensinger & Corkin, 2003). Their emotional significance needs to be extracted based on semantic knowledge (Rellecke et al., 2011; Schacht & Sommer, 2009), whereas the emotional significance of faces can be extracted based on perceptual features (Vuilleumier, 2005; Vuilleumier & Huang, 2009). Given these differences in the processing of emotional faces and words, it is likely that facial and verbal stimuli might have different effects on cognitive control in a Stroop paradigm.

Indeed, results from two updating experiments (see Chapter 3) showed that the facilitating effects of happy faces were not found for positive words in an n-back task. It was also found that performance was improved when participants had to respond to negative relative to neutral or positive words. It is not clear, however, whether the emotion effects that were observed for words in an n-back task can also be expected in a Stroop task, as the targeted executive functions are separable despite the unitary characteristics that they share (Miyake & Friedman, 2012; Miyake et al., 2000).

By using verbal stimuli in the same task as in Experiment 4.2, the aim was to assess whether cognitive control of emotional words would be associated with comparable effects as were observed for emotional faces. Should emotional words produce similar effects as in Experiment 4.2, this would suggest that the valence (i.e., pleasantness) of stimuli would be sufficient to affect cognition independently of their biological preparedness. In contrast, if differential effects of emotion were to be observed, this would suggest that stimulus features that are not shared by faces and words contribute to the effects of emotional items on cognitive control.

Methods

Participants

Thirty younger (20 - 38 years old) and 30 older adults (63 - 78 years old) participated in the experiment (see Table 4.5 for participant characteristics). One younger and one older adult were excluded from the analysis due to RTs that were 2.5 SD slower than the respective group's mean RTs. Additionally, one younger adult was excluded due to high BDI-II scores, indicating moderate levels of depression. The recruitment criteria were the same as in Experiments 4.1 and 4.2. None of the participants had previously participated in Experiment 4.2. As can be seen in Table 4.5, older adults had better verbal knowledge than younger adults as assessed with the NART (Nelson & Willison, 1991) and scored lower on the Digit Symbol Substitution Test (Wechsler, 1955) suggesting slower processing speed than in younger adults. Whereas these results are commonly observed in ageing research as highlighted above, it was also found that older adults reported fewer years of education than their younger counterparts. Additionally, it was found that younger adults had higher scores on the A-Trait version of the STAI (Spielberger et al., 1983), indicating higher levels of anxiety relative to older adults. No further differences were observed between the two age groups. Older participants had a score of 27 or above on the MMSE (Folstein et al., 1975). The ethics board of Birkbeck, University of London, approved the procedure prior to the start of the study and written informed consent was obtained from each participant.

Table 4.5. *Participant characteristics, Experiment 4.4*

	Younger adults		Older adults		Group difference	
Variable	*M*	*SD*	*M*	*SD*	*t*	*p*
Age (years)	26.42	6.53	72.93	5.74		
Gender (male/female)	10/18		6/23			
Education (years)	17.57	2.73	15.71	3.46	2.26	.028*
NART Verbal IQ	106.96	6.80	119.74	13.38	-4.42	<.001***
Digit Symbol Test	63.26	12.13	47.38	10.05	5.35	<.001***
BDI II	6.81	4.12	6.11	4.50	.61	.546
STAI Trait Anxiety	38.30	7.22	32.89	9.66	2.33	.024*
MMSE			29.04	.88		

Note. NART = The National Adult Reading Test, BDI II = Beck Depression Inventory II, STAI = State-Trait Anxiety Inventory, MMSE = Mini-Mental State Examination; $^{*}p < .05$, $^{**}p < .01$, $^{***}p < .001$

Materials

Stimuli consisted of a selection of 36 words from the ANEW database (Bradley & Lang, 1999), which provides normative emotional ratings for a large number of words in the English language. Words were either negative (e.g., abuse, wounds, crime), emotionally neutral (e.g., bench, board, moment) or positive (e.g., thrill, hug, love) and there were 12 words per category. The words had been rated in a preliminary evaluation study and were selected based on high agreement ratings between younger and older raters (see Appendix B for evaluation details). Congruent items were created by printing the word on emotionally matching faces that were used in Experiment 4.2 (e.g., word “thrill” with happy face). Incongruent items were created by printing a word on non-matching emotional faces (e.g., word “bench” with angry face). “Non-face” items (equivalent to non-word items used in the previous experiments) were created by printing the word on a face picture, in which the area of the face was obscured.

Combinations of words and faces are summarised in Table 4.6. Target words were printed in navy blue, 38-point Courier New font, and placed between the face's eyes and mouth. The face images were coloured photographs that appeared 100 ms before the word, in accordance with the procedures used in Experiment 4.2. Example stimuli are presented in Figure 4.6.

Table 4.6. Combinations of words and facial expressions that formed congruent, non-face and incongruent stimuli

	Task-relevant word		
Distractor face	Negative	Neutral	Positive
Angry	congruent	incongruent	incongruent
Neutral	incongruent	congruent	incongruent
Happy	incongruent	incongruent	congruent
Obscured	non-face	non-face	non-face

Note. Congruent stimuli are colour-coded in green, non-face stimuli in yellow and incongruent stimuli in red.

Procedure

The procedure for Experiment 4.4 was identical to the procedure for Experiment 4.2 as were the proportions of congruent, incongruent and non-face trials in the HE and LE blocks. There were equal numbers of negative, neutral and positive words across trials of different congruencies and across the two blocks. Each trial began with the presentation of the distractor face that was happy, neutral, angry, or obscured (100 ms), followed by the simultaneous presentation of the face and the target word. Participants were instructed to indicate the emotional valence of the word (negative, neutral or positive) as accurately and quickly as possible by pressing one of three labelled buttons. Each session lasted approximately 1 hour and 15 minutes in total.

Figure 4.6. Examples of Stroop stimuli in Experiment 4.4. Picture A shows a negative word with a congruent face, picture B shows a neutral word with an incongruent face and picture C shows a positive word with an obscured face (non-face condition).

Design and statistical analysis

The recording and exclusion of data were identical as in Experiment 4.2. In the younger age group, 2.88% of data points were excluded and in the older age group, 2.92% of data points were excluded. Accuracy and RTs were analysed by 2 × 3 × 3 × 2 mixed factors ANOVA including the within-subjects factors expectancy (LE vs. HE), congruency (congruent vs. non-face vs. incongruent) and emotion (negative vs. neutral vs. positive) as well as the between-subjects factor of age (younger vs. older). Procedures to conduct post-hoc tests and to determine significance were as described above. As latencies varied considerably between younger and older adults, log-transformed RT data were used for the analysis.

Results[4]

Accuracy

Accuracy scores for younger and older adults are shown in Figure 4.7. The analysis yielded a main effect of emotion, *F*(2, 110) = 11.78, *MSE* = .083, $p < .001$, partial η^2 = .18, as accuracy was generally higher for negative words (*M* = 97.71, *SD* = 3.78) than for neutral (*M* = 89.55, *SD* = 13.36), *t*(56) = 4.55, $p < .001$, or positive words (*M* = 91.90, *SD* = 7.49), *t*(56) = 6.38, $p < .001$. Accuracy scores for neutral and positive words were not significantly different (p = .294). There was a significant main effect of congruency, *F*(2, 110) = 6.92, *MSE* = .004, p = .002, partial η^2 = .11, as accuracy was lower for incongruent trials (*M* = 92.13, *SD* = 6.18) than for congruent (*M* = 93.63, *SD* = 5.20), *t*(56) = 2.97, p = .004, or non-face trials (*M* = 93.40, *SD* = 5.00), *t*(56) = 2.72, p = .009. There was no difference in accuracy between non-face and congruent trials (p = .518). This main effect was qualified by a marginally significant congruency × age interaction, *F*(2, 110) = 3.12, *MSE* = .004, p = .055, partial η^2 = .05, as in younger adults, accuracy was significantly higher for congruent (*M* = 93.46, *SD* = 5.72) relative to incongruent trials (*M* = 90.85, *SD* = 7.32), *t*(27) = 3.47, p = .002. In older adults, accuracy scores for congruent and incongruent trials were not significantly different (p = .504).

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[4] Due to significant differences in the two age groups' reported years of education and their anxiety scores, all analyses were repeated with years of education and anxiety included as covariates. All results with age as a factor remained qualitatively the same and significant.

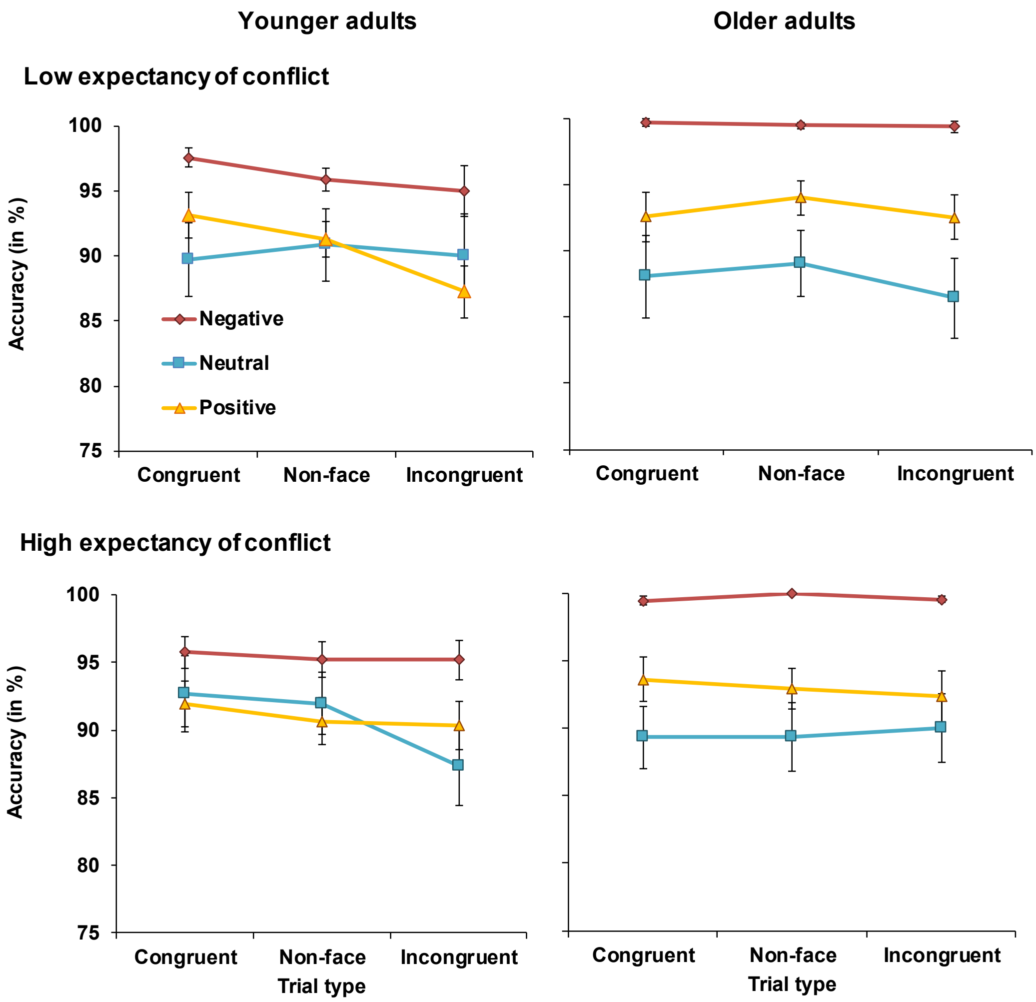

Figure 4.7. Accuracy scores in younger (left panels) and older adults (right panels) in Experiment 4.4.

There was also an expectancy × congruency × emotion × age interaction, $F(4, 220) = 3.38$, $MSE = .003$, $p = .017$, partial $\eta^2 = .06$. Accuracy scores under HE and LE conditions were analysed separately to follow up this interaction. The congruency × emotion × age interaction was not significant under LE conditions ($p = .259$), but reached significance under HE conditions, $F(4, 220) = 3.40$, $MSE = .002$, $p = .017$, $\eta^2 = .06$. Follow-up t-test indicated that different response patterns to neutral words in younger and older adults were driving the effect: Younger adults showed lower accuracy for neutral words that were incongruent ($M = 87.30$, $SD = 15.15$) rather than congruent (*M* = 92.65, *SD* = 14.86), *t*(27) = 4.65, $p < .001$, or presented with a non-face (*M* = 91.95, *SD* = 12.23), *t*(27) = 2.77, $p = .010$. There was no difference in accuracy for congruent and non-face items ($p = .700$). In older adults on the other hand, accuracy for neutral words that were incongruent did not differ from accuracy for congruent ($p = .549$) or non-face items ($p = .562$). There were no such contrasting patterns of results between younger and older adults for negative or positive words. No further main effects or interactions were observed for accuracy.

Reaction times

RTs for younger and older adults are shown in Figure 4.8. The analysis yielded a main effect of age, *F*(1, 55) = 26.46, *MSE* = .367, $p < .001$, partial $\eta^2 = .33$, as older adults were overall slower (*M* = 836 ms, *SD* = 122 ms) than younger adults (*M* = 688 ms, *SD* = 104 ms). There was also a main effect of congruency, *F*(2, 110) = 50.85, *MSE* = .005, $p < .001$, partial $\eta^2 = .48$, with overall slower RTs for incongruent (*M* = 788 ms, *SD* = 141 ms) than for non-face trials (*M* = 752 ms, *SD* = 131 ms), *t*(56) = 7.94, $p < .001$, or congruent trials (*M* = 751 ms, *SD* = 136 ms), *t*(56) = 8.89, $p < .001$. There was no significant difference in RTs for non-face compared to congruent trials ($p = .428$).

This main effect was qualified by a significant expectancy × congruency interaction, *F*(2, 110) = 6.24, *MSE* = .004, $p = .003$, partial $\eta^2 = .10$. To follow up this interaction, the analysis was repeated with the factor congruency only comprising the factor levels congruent and non-face trials, which resulted in a significant expectancy × congruency interaction, *F*(1, 56) = 6.92, *MSE* = .004, $p = .011$, partial $\eta^2 = .11$. The analysis with the factor congruency comprising the factor levels non-face and incongruent trials also resulted in a significant expectancy × congruency interaction, which was more pronounced, *F*(1, 56) = 10.81, *MSE* = .005, $p = .002$, partial $\eta^2 = .16$.

Follow-up t-tests revealed that under HE conditions, RTs were slower for incongruent (*M* = 777 ms, *SD* = 149 ms) than for non-face trials (*M* = 757 ms, *SD* = 146 ms), *t*(56) = 3.96, *p* < .001. Under LE conditions, the difference in RTs between incongruent (*M* = 798 ms, *SD* = 153 ms) and non-face trials (*M* = 747 ms, *SD* = 133 ms) was, however, more pronounced, *t*(56) = 7.35, *p* < .001. Moreover, under HE conditions, RTs to congruent trials (*M* = 745 ms, *SD* = 149 ms) were faster than to non-face trials (*M* = 757 ms, *SD* = 146 ms), *t*(56) = 2.51, *p* = .015, whereas the comparison between congruent and non-face trials was non-significant under LE conditions (*p* = .209).

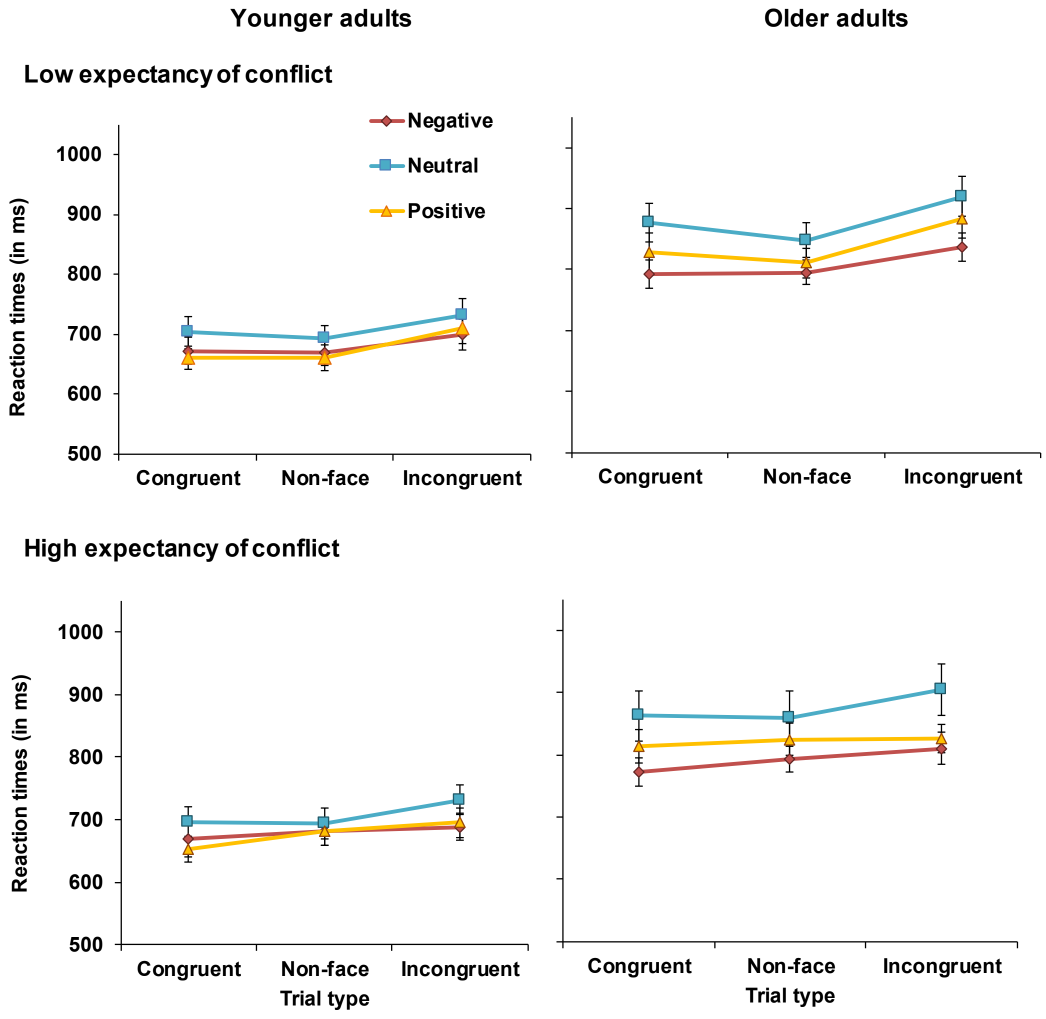

Figure 4.8. RTs for correct responses in younger (left panels) and older adults (right panels) in Experiment 4.4.

Additionally, there was a significant main effect of emotion, $F(2, 110) = 14.00$, $MSE = .025$, $p < .001$, partial $\eta^2 = .20$, and follow-up analyses revealed that RTs for negative words ($M = 6.59$ ms, $SD = .17$ ms) were faster than for neutral words ($M = 6.65$ ms, $SD = .20$ ms), $t(56) = 4.94$, $p < .001$. RTs for positive words ($M = 6.61$ ms, $SD = .18$ ms) were also faster than for neutral words, $t(56) = 3.67$, $p = .001$, with no significant difference between RTs for positive and negative words ($p = .169$). No further main effects or interactions were found for RTs.

Discussion

The study was designed to investigate the effects of emotional target words on cognitive control in a Stroop paradigm. It was found that both younger and older adults showed reduced interference and facilitation in RTs under HE compared to LE conditions, suggesting that they engaged in proactive control when the proportion of conflict-generating trials was high. It was also found that emotion facilitated task performance in both younger and older adults to a similar extent, with more accurate responses to negative relative to neutral or positive words. Responses were faster for both negative and positive words relative to neutral words in younger and older adults. Age-related differences emerged for accuracy under HE conditions: When neutral words were the targets, younger adults showed lower accuracy for incongruent relative to non-face or congruent trials, whereas older adults did not show differences in accuracy between congruent, non-face or incongruent trials.

The enhancing effect of emotion on cognitive control in an emotional Stroop task was observed for both positive and negative words, as participants responded faster when presented with emotional rather than neutral words. This could be due to enhanced sensory processing of emotional material including words (Phelps & LeDoux, 2005; Phelps et al., 2006; Vuilleumier, 2005; Vuilleumier & Huang, 2009). It should be noted, however, that the enhancing effect was particularly pronounced for negative words, as accuracy was higher for negative relative to neutral or positive words. This is similar to the results observed in Chapter 3.3, which showed that updating performance was facilitated by negative words. Differences in the effects of words and faces on Stroop performance will be discussed in the general discussion of this chapter below.

When responding to neutral words, younger adults showed lower accuracy for incongruent relative to congruent or non-face trials under HE conditions in the present experiment. In contrast, older adults did not show differences in accuracy between congruent, non-face or incongruent trials. On the one hand, this seems to suggest that older adults did not rely on external cues when responding to neutral targets under conditions requiring proactive control. On the other hand, it is also possible that the task conflict created by target words and distractor faces was not high enough under conditions requiring proactive control to affect accuracy in older adults. It is not possible to disentangle these two explanations in the present paradigm. However, it appears that older adults were more successful in responding to neutral words without being affected by distractors under conditions requiring proactive control than their younger counterparts. Although the exact reason for this remains unclear, it highlights that older adults do not show impairments under conditions requiring proactive control relative to younger adults and that they can even outperform them.

4.6. General discussion

This set of Stroop experiments was conducted to assess cognitive control in younger and older adults. In all four presented experiments, deployment of proactive control was manipulated by varying the expectancy of congruent and incongruent trials relative to trials without conflict (i.e., non-words and non-face items). Besides addressing age-related changes in cognitive control, these experiments also explored the effects of emotions on cognitive control and whether these differed for faces and words. Additionally, this chapter explored how the timing of target and distractor presentation affected facilitation in an emotional Stroop task.

These experiments revealed three critical findings. First, older adults were found to successfully deploy proactive control in three experiments as shown by behavioural patterns of proactive control under HE conditions. Second, it was found that besides common effects of emotion on cognitive control in both age groups, there were age-related differences in emotion-cognition interactions. Third, the effects of emotion on cognitive control were not uniform across different sets of emotional stimuli such as faces and words. In the following, the implications of findings of intact proactive control in ageing will be discussed, followed by a discussion of both general and age-specific effects of emotion on cognitive control in emotional Stroop tasks. This chapter will finish with a discussion of how the timing of target and distractor presentation can affect performance in an emotional Stroop task.

No age-related differences in ability to exert proactive control in Stroop tasks

The present findings extend the empirical evidence obtained in studies using the AX-CPT task (Rosvold et al., 1956) and provide support for the notion that older adults can deploy proactive control when needed. Across three experiments using the Stroop paradigm, older adults showed reduced interference from incongruent relative to non-word/non-face trials when expectancy of conflict was high. Although they did not show facilitation under HE conditions in Experiment 4.1, this effect was also not reliably found in younger adults. In contrast, both age groups showed facilitation across both HE and LE conditions in Experiment 4.2 and under HE conditions in Experiment 4.4, with no age-related differences. These results suggest that older adults were able to deploy proactive control to overcome task conflict in the Stroop paradigm, which is in accordance with prior evidence of intact proactive control in ageing, either without training (Paxton et al., 2008, Exp. 2; Staub et al., 2014) or following task-strategy training (Braver et al., 2009; Paxton et al., 2006).

In contrast, these results deviate from findings suggesting that older adults have difficulties using the context for a target response compared to their younger counterparts in AX-CPT tasks, which was viewed as evidence for age-related decline in proactive control (e.g., Braver et al., 2009; Braver et al., 2005; Haarmann et al., 2005; Paxton et al., 2008, Exp. 1). The contrasting pattern of results suggests that ageing is not associated with a general impairment in proactive control but that older adults' ability to deploy it successfully might depend on the task at hand. The AX-CPT task can be used to assess proactive control "locally" at the level of trials, whereas the present study used a global approach to manipulate cognitive control across an entire block of trials in a Stroop paradigm. Older adults were outperformed by younger adults in the former but not in the latter task, suggesting that, although it might be more difficult for them to use proactive control flexibly on a trial-to-trial basis, they can adapt their performance to task conflict and deploy proactive control over a period of time.

Another possible reason for contrasting evidence obtained in prior experiments using the AX-CPT task and the present study might be differences in task difficulty. In an AX-CPT task, participants have to remember a set of rules and keep track of preceding items in order to make correct target and non-target responses to an X. In the present Stroop study, participants had to respond to one stimulus while ignoring the other without the need to adjust their response based on the preceding item, which might have been less resource-demanding for older adults. Thus, more resources might have been available to implement proactive control in the present study compared to studies using the more difficult AX-CPT paradigm, which also requires WM updating. As shown in Chapter 3, older adults have difficulties when having to update information in WM. Moreover, participants were not informed about changes in the proportion of conflict-inducing items relative to non-conflict items across blocks in the present experiment and adjustment in the use of proactive control was thought to be unintentional. Again, this might have been less taxing, as no additional resources were required to monitor any changes in the task.

It should be noted that older adults showed higher interference from incongruent relative to non-word trials than younger adults, which could provide support for the inhibition account of ageing (Hasher et al., 1991; Hasher et al., 1999). However, as outlined above, it is possible that this effect was due to general slowing (see section 4.1 of this chapter). Moreover, an age-related increase in interference was only found in one of three experiments. Thus, it appears that the finding of an age-related increase in interference is not robust and that inhibition is not generally impaired in ageing.

Differential effects of emotional faces on cognitive control in ageing

Two experiments were conducted to assess the effects emotion on cognitive control in younger and older adults by using an emotional Stroop paradigm. In Experiment 4.2, emotional faces were used as targets and happy faces were found to improve both accuracy and RTs in younger and older adults with no age-related differences. This finding is in line with previous literature showing improved performance for happy faces relative to other expressions in WM tasks with facial stimuli (Cromheeke & Mueller, 2015; Levens & Gotlib, 2010, 2012). It is likely due to a recognition advantage of happy faces on the one hand (Becker et al., 2011; Becker & Srinivasan, 2014; Juth et al., 2005) and their rewarding effect on the other hand (O'Doherty et al., 2003; Tsukiura & Cabeza, 2008) as discussed above (see Chapter 3.2).

Importantly, the facilitating effects of emotion did not differ in the two age groups and there was no evidence for an increased positivity effect in ageing. This finding is not fully compatible with SST (Carstensen, 1993), according to which older adults focus on positive information in order to improve wellbeing. However, it has been argued that the positivity effect emerges under instructions encouraging participants to process material freely (for a review, see Reed & Carstensen, 2012). In the present experiments, participants received specific instructions how to respond to stimuli, giving less freedom to older adults to process material the way they wanted. Thus, it is possible that the chronically active bias to focus on positive material was overridden by specific task requirements in the present experiments.

However, the SST does not lend itself to explain impaired performance for angry faces under HE conditions in Experiment 4.2. Older adults did not show better accuracy for congruent relative to non-word trials with angry targets and they showed an increased error rate for incongruent relative to non-word trials with angry targets. In contrast, younger adults showed the reverse pattern with increased accuracy for congruent relative to non-word trials with angry targets and no impairment in accuracy for incongruent angry targets. The impairing effect of angry faces on older adults' accuracy was observed under HE conditions, suggesting that proactive control was less effective in the presence of angry faces in older adults.

This pattern of findings is compatible with the suggestion that age-related changes in the processing of negative material might be related to cognitive decline (see Labouvie-Vief, 2003; 2009a for reviews). It is also in line with suggestions that older adults show changes in the processing of negative material by exhibiting a reduced negativity effect rather than an increased positivity effect (Grühn et al., 2007; Grühn et al., 2005; Kisley et al., 2007; Langeslag & van Strien, 2009). However, the impairing effect of angry faces on older adults' performance was only observed for accuracy and not for RTs. This suggests that the two dependent measures, accuracy and RTs, have picked up different effects of emotion on performance. At this point it is not clear how these different effects can be explained, which could be subject of future research.

Effects of emotional faces and words on cognitive control

The age-related impairment observed for angry faces in Experiment 4.2 was not found for negative words in Experiment 4.4. Thus, it appears that negative material is not associated with impairments in general but that they are specific to angry faces, which is possibly linked to the threat angry faces communicate. This is in line with results observed in Chapter 3.5. Older adults showed difficulties when having to bind and unbind angry faces in WM, whereas this was not observed in younger adults.

Research has shown that angry faces capture attention (Hansen & Hansen, 1988; Öhman et al., 2001; Olofsson et al., 2008) and that they are more difficult to disengage from compared to non-threatening information as they hold visual attention (Fox et al., 2001). According to the dual competition model (Pessoa, 2009, 2015, 2017), threatening stimuli can draw resources shared by executive functions and thereby impair functions relying on them. Given that fewer cognitive resources are available to older relative to younger adults (e.g., Braver & West, 2008; L. H. Phillips & Henry, 2008; Reuter-Lorenz & Sylvester, 2005; Salthouse, 1990), it is likely that threat disrupted cognitive control, particularly when effortful proactive control was required.

In contrast, both age groups responded more accurately and faster to negative compared to neutral or positive words. Importantly, this effect was observed across all conditions and trial types without having a modulatory effect on the deployment of proactive control. Responses were not only faster for negative compared to neutral words but accuracy was also highest for negative relative to neutral or positive words. This is similar to results observed in Experiment 3.3 reported in Chapter 3: younger adults showed greater discrimination sensitivity for negative than for neutral or positive words and also faster RTs for negative than for neutral words in an n-back task. The present research extends these findings by showing that these enhancing effects are also found for cognitive control in a Stroop task and also in older adults. With this pattern observed in an updating and an inhibition task, it appears that negative words have a beneficial effect on executive functions.

As was suggested in Chapter 3, it is believed that differences in the effects of emotional faces and words are associated with the fact that emotional words do not fall into the same category of evolutionary prepared stimuli as faces: words must be processed to a higher level before their emotional significance needs to be extracted based on semantic knowledge (Kensinger & Corkin, 2003; Rellecke et al., 2011; Schacht & Sommer, 2009), whereas the emotional significance of faces can be extracted based on perceptual features (Vuilleumier, 2005; Vuilleumier & Huang, 2009). Other factors that have likely played a role are the informational value of negative compared to positive words and their relative novelty (see Chapter 3). Additionally, the conceptual size of the stimulus sets could also be of relevance. Faces form a small pool of very similar stimuli, whereas words form a larger pool of dissimilar stimuli. A future study could use images instead of words to address the verbal/visual dimension. In Chapter 6 of this dissertation, the domain-specific effects of facial and verbal emotional material on performance in updating and inhibition tasks will be discussed in more detail.

The role of presentation timing on facilitation in Stroop paradigms

Facilitation in RTs (i.e., faster RTs for congruent relative to non-word trials) was found for both age groups across both conditions in Experiment 4.2, in which distractors were presented 100 ms before the targets. In contrast, facilitation was reduced when the same paradigm was used with a simultaneous presentation of face target and label distractor (Experiment 4.3). This pattern suggests that facilitation across both HE and LE conditions in Experiment 4.2 was due to its distractor-first design, which is consistent with Roelofs' (2003) suggestion that preceding distractors prime a particular response. However, despite a reduced facilitation effect with a simultaneous presentation of the target face and distractor label in Experiment 4.3, no reversed facilitation (i.e., slower RTs for congruent relative to non-word trials) was observed under LE conditions either.

It is possible that reversed facilitation does not occur with target faces but only with target words. Previous research reporting reversed facilitation under LE conditions has used verbal material only (Goldfarb & Henik, 2007; Kalanthroff et al., 2015; Kalanthroff et al., 2013; Tzelgov et al., 1992). Thus, it might be a phenomenon that is not observed across different stimulus sets. It is also possible that the non-word condition took too long for a reversed facilitation effect to occur in a facial Stroop task, which might be due to different modalities of target faces and distractor labels, even for non-word distractors. In non-word trials in the classic colour Stroop paradigm, the target (ink colour) and distractor (non-word) are presented in one single stimulus, which does not require participants to process multiple stimuli across different modalities (e.g., faces and symbol/word labels). The processing of two stimuli from different stimulus modalities might generally take longer than word/colour processing in the classic colour Stroop paradigm, increasing the RTs for non-word trials and thus making it less likely to observe a reversed facilitation effect.

An alternative explanation might be that target faces with congruent distractor labels did not create enough task conflict to observe reversed facilitation. Results from Experiment 4.4, in which emotional faces were shown as distractors 100 ms before the target word, might help to elucidate the issue further. Here, the same distractor-first paradigm was used as in Experiment 4.2 and target words and distractor faces were from different modalities. In fact, this approach mirrored the one used in Experiment 4.2 with target faces and distractor labels. Despite these parallels, reduced facilitation was observed under LE relative to HE conditions in Experiment 4.4, whereas facilitation was found under HE and LE conditions in Experiment 4.2. It appears that sufficient task conflict could be created for congruent words and faces in Experiment 4.4 despite a distractor-first presentation and different modalities between target and distractor in non-face trials, which have presumably contributed to prolonged RTs. In contrast, this was not the case for face targets and distractor labels in Experiment 4.2.

Another reason for varying results in Experiment 4.2 and 4.4 despite the same presentation regime could lie in differences in distractor priming. In Experiment 4.2, irrelevant labels were presented 100 ms before the target face, whereas in Experiment 4.4, irrelevant faces were presented 100 ms before the target word. It is possible that priming was more effective for label than for face distractors for a number of reasons. Firstly, the verbal modality of label distractors was congruent with the modality of responses in Experiment 4.2, as participants were required to respond to faces by using labels (“happy”, “neutral” or “angry”). In contrast, there was no modality congruency between face distractors and target responses using labels (“positive”, “neutral” or “negative”) in Experiment 4.4. A second and related possible reason is that in Experiment 4.2, distractor labels and target responses were the same, whereas in Experiment 4.4, the emotional expressions of face distractors and “positive”, “neutral” and “negative” target responses were not. Thirdly, it is likely that priming of words was particularly efficient in Experiment 4.2, as participants’ attention was already directed to the word by the previously presented fixation cross. In contrast, the area of the face that the participants’ attention was directed to by the fixation cross was unlikely the most diagnostic one as it was in the centre of the face, rather than in the eye or mouth region. Thus, participants would have needed to saccade to the eye or mouth region to assess the expression in a short period of time. Taken together, it appears that despite using the same distractor-first design in both experiments, distractor-first priming was more efficient in Experiment 4.2 (with target faces and distractor labels) than in Experiment 4.4 (with target words and distractor faces).

Conclusion

In conclusion, the present study contributed to research on proactive control in ageing and its effectiveness in the presence of emotional material. Although there was no indication that ageing was associated with an overall impairment in proactive control, the present research showed that older but not younger adults were less able to resolve conflict when presented with angry faces under conditions requiring proactive control. In contrast, facilitating effects on task performance were found for negative words in both age groups. These results suggest that age-related differences in emotion processing depend on the stimulus domain and that threatening items such as angry faces are associated with cognitive costs that are more difficult to meet in ageing.

Chapter 5: The effects of emotion and ageing on task switching

5.1. Introduction

The previous two chapters dealt with the two executive functions of updating and inhibition. This chapter will address how emotion affects the third executive function of Miyake et al.'s model (Miyake & Friedman, 2012; Miyake et al., 2000) in younger and older adults, namely shifting.

Switching back and forth between different tasks is so common in everyday life that often, we are not even aware that we perform these switches. For example, cooking from a recipe requires switching between reading up the next step in the process and performing this step. Although switching between tasks seems to be relatively easy in everyday life, the difficulty of switching becomes more apparent when the tasks involved are more demanding, for instance when air traffic controllers have to switch continuously in their communication between different pilots and other controllers. Research suggests that switching between tasks is more difficult than repeating a task, even if each individual task is simple, and this chapter will focus on the effects of age and emotion on this ability.

Switching from a task to another is usually associated with slower RTs and with more errors compared to repeating a task. This reduction in performance is commonly referred to as the switch cost (Kiesel et al., 2010; Mayr & Kliegl, 2000; Meiran, Chorev,

& Sapir, 2000; Monsell, 2003; Rogers & Monsell, 1995; Wylie & Allport, 2000). Although preparation for a switch (e.g., through predictable switching cues or through time given between an unexpected cue to switch and the actual stimulus) can reduce the switch cost, research suggests that it does not eliminate the switch cost fully. Instead, a residual switch cost is observed even if plenty of time is given to prepare (De Jong, 2000; Kimberg, Aguirre, & D'Esposito, 2000; Rogers & Monsell, 1995; Sohn, Ursu, Anderson, Stenger, & Carter, 2000).

Different accounts have been offered to explain why switching between tasks comes at a cost. On the one hand, it has been suggested that switching requires a "task-set reconfiguration" (Monsell, 2003, p. 135; Rogers & Monsell, 1995), which could involve shifting attention to a different item feature, activating all the task parameters (Logan & Gordon, 2001) or by retrieving the relevant task set from long-term memory (Mayr & Kliegl, 2000). Thus, switch costs are believed to reflect the time that is needed to engage with the new task. On the other hand, it has been suggested that task-switching costs arise through proactive interference from the no longer relevant task on switch trials (Allport, Styles, & Hsieh, 1994; Wylie & Allport, 2000). Thus, switch costs are assumed to reflect the time it takes to disengage from the previous task.

In fact, many commonly observed effects in task-switching studies can be explained by either of these two accounts. For instance, the reconfiguration view suggests that a reduction in switch cost through preparation is achieved through reconfiguration of the relevant task set during the preparation period. However, the residual switch cost that is observed even after a prolonged preparation period can be accounted for by both accounts. From the point of view of the interference account, one could argue that the residual switch cost is due to proactive interference from the non-relevant task. In contrast, the reconfiguration account suggests that preparation cannot be fully accomplished through endogenous processes alone. Instead, completion of the reconfiguration process relies on exogenous cues from the stimulus. Although the debate regarding these two contrasting views still continues, it has been suggested that both factors, task reconfiguration and proactive interference, are involved in task switching (Goschke, 2000; Hsieh & Cheng, 2006; Hyafil, Summerfield, & Koechlin, 2009; Paulitzki et al., 2008; Vandierendonck, Liefooghe, & Verbruggen, 2010).

Studies have also shown that switch costs in task-switching paradigms might change in size or severity depending on the requirements or characteristics of the specific tasks. One common observation was that switching to a less dominant task was associated with reduced cost relative to switching to a more dominant task (Allport et al., 1994, Exp. 5; Meuter & Allport, 1999; Monsell, Yeung, & Azuma, 2000; Reeck & Egner, 2015; Wylie & Allport, 2000). For instance, Allport et al. (1994) used colour/word Stroop stimuli (e.g., the word “red” printed in green ink) and asked participants to switch between the more dominant word reading and the less dominant colour naming task. It was observed that the switch cost associated with word reading was larger than the switch cost associated with colour naming. Similarly, in a study by Meuter and Allport (1999), bilinguals switched between naming numerals in their dominant or their less dominant language and results showed that switch costs were larger for the dominant compared to the less dominant language.

Such asymmetrical switch costs were usually attributed to stronger inhibition of the dominant task set (i.e., word reading or naming numeral in dominant language) in order to facilitate performance of the less dominant task set (i.e., colour naming or naming numeral in weaker language). However, Monsell et al. (2000) assessed the generality of the asymmetrical switch cost and found that it was not consistently observed in paradigms with presumably more dominant and weaker tasks. The authors suggested that the difference in dominance between the two tasks needs to be above a certain threshold to give rise to an asymmetrical switch cost. Moreover, the authors argued that asymmetrical switch costs might also be reconcilable with the reconfiguration account as the inhibition of the dominant task might either prolong the control processes needed for reconfiguration or activate control processes that are needed to override inhibition. Overall, these findings suggest that task requirements play an important role for the observation of task-switching costs.

Task switching with emotional tasks

Studies have also investigated the effects of emotion on task switching (Aboulafia-Brakha et al., 2016; de Vries & Geurts, 2012; Gul & Khan, 2014; Johnson, 2009; Paulitzki et al., 2008; Piguet et al., 2016; Piguet et al., 2013; Reeck & Egner, 2015). One focus of these studies has been to assess the ability to switch between an emotional and a non-emotional task in clinical populations such as children with autism spectrum disorders (ASD; de Vries & Geurts, 2012) or patients with bipolar disorder (Gul & Khan, 2014). These studies typically showed that clinical populations but not healthy controls showed greater switch costs when switching from the emotional to the non-emotional task than vice versa, which was interpreted as evidence for their greater difficulty to disengage from an emotion task (de Vries & Geurts, 2012; Gul & Khan, 2014).

A second group of studies focused on the link between the ability to switch between emotional and non-emotional tasks and the ability to regulate emotions (De Lissnyder et al., 2012; Genet & Siemer, 2011; Gul & Khan, 2014; Johnson, 2009). Studies that calculated overall switch costs in a task with emotional and non-emotional task sets (rather than calculating differences in switching between those) showed that emotion regulation strategies were a significant predictor of switch costs (Gul & Khan, 2014) and that lower switch costs were associated with trait resilience (Genet & Siemer, 2011). Others looked at differences between switching to and away from an emotional task set and found that greater trait anxiety was associated with longer switches from a neutral to an emotional task set (Johnson, 2009). This was interpreted as a reduced tendency of anxious individuals to engage with emotional material.

However, despite the fact that a large number of studies have investigated switching between emotional and non-emotional task sets in different populations, results are still equivocal whether switching between these task sets comes at different costs in healthy adults. On the one hand, it was shown that switching away from an emotional task set to a neutral task set took longer than switching away from a neutral task set to an emotional task set (Johnson, 2009; Paulitzki et al., 2008). This suggests that disengaging from an emotional task set is more difficult than from a neutral task or/and that engaging with an emotional task set is less difficult than with a neutral task set. On the other hand, studies have shown that participants are slower to switch away from a neutral task set to an emotional task set than vice versa (Reeck & Egner, 2015). The authors interpreted this finding within the inhibition account of task switching as evidence for the dominance of the emotional task set. Accordingly, it was suggested that the emotional task set has to be inhibited to a stronger degree to facilitate performance in the non-emotional task set. In a third set of studies, no differences in switch costs between emotional and non-emotional task sets were found (Gul & Khan, 2014).

The discrepancies in findings relating to switching between emotional and non-emotional task sets could be due to methodological differences between these studies. For instance, two previous studies reporting higher costs for switches from emotional to neutral task sets than vice versa (Johnson, 2009; Paulitzki et al., 2008) have used stimuli with different perceptual requirements in the neutral and emotional task sets. For instance, Johnson (2009) asked participants to identify the emotional expression of faces in the emotional task set. In the neutral task set, a small shape was placed between the face's eyes and participants had to identify the type of shape. Similarly, in Paulitzki et al.'s study (2008), participants responded to photographs of spiders in the emotional task set and to small numbers placed over the spiders' backs in the neutral task. Given that in both studies, the emotional features of the stimuli were perceptually more salient relative to the non-emotional features simply due to their size, it is likely that directing attention away from these features was more effortful, resulting in greater switch costs from emotional to neutral task sets than vice versa. Additionally, a confound was introduced as there were three times more repetition trials for the emotion task (60 trials) compared to the non-emotional task (20 trials) in Johnson's study (2009). This might have affected participants' ability to disengage from the emotional task set and/or to reconfigure the non-emotional task set and thus might have biased the results.

The role of repeat trials in the calculation of the switch cost, which is used as a measure to assess the ability to switch between tasks, does indeed deserve further attention. It should be noted that most of the previous studies reported above have used switch cost as the main dependent variable. However, subtracting the latencies of repeat trials from those for switch trials makes it impossible to disentangle whether the effects observed based on these difference scores are mainly driven by the time it takes to switch or by the time it takes to repeat. In many of the studies mentioned above, the experimental design allowed for a repetition of the same response on repeat trials. Thus, it is possible that response repetition in repeat trials contributed to reduced latencies for repeat trials and thereby to increased switch costs. Furthermore, as processing efficiency is known to be particularly efficient for emotional items, it is likely that the speed-up effect for repeat trials is more pronounced when participants have to respond to emotional features (e.g., expression of a face) rather than non-emotional features (e.g., gender of a face). Thus, it is possible that in tasks requiring switching between emotional and non-emotional tasks sets, switch costs were different for those task sets due to differences in repeat trials rather than differences in switch trials.

Importantly, none of the studies reported above have attempted to compare the effects of different valences on the ability to switch between emotional and non-emotional task sets. In the majority of studies, affective stimuli were presented on each trial (Aboulafia-Brakha et al., 2016; Paulitzki et al., 2008; Reeck & Egner, 2015), while participants were required to respond according to an emotional or neutral task set. In other studies, both emotional and neutral items were included (e.g., emotional and neutral facial expressions), but the different valences were not included in the analyses (Gul & Khan, 2014; Johnson, 2009). While these approaches allowed assessing the time it took participants to switch between emotional and non-emotional task sets, a comparison between valences would allow investigating the effects of valence vs. arousal on task switching abilities. Furthermore, considering the valence of the stimulus participants have to switch to as well as the one they have to switch away from could help to disentangle the mechanisms affected by emotion in task switching. Given that both the reconfiguration of the new task set and the interference of the previous task set are thought to contribute to switch costs, it is not clear whether or how these mechanisms contribute to differences in switching between emotional and non-emotional task sets. By taking into account the characteristics of the item participants have to switch away from, this might help to assess the role that disengagement might play in switching to the new task set.

5.2. Experiment 5.1: Switching between emotional and non-emotional tasks

Switching between emotional and non-emotional task sets in ageing has not been investigated so far, despite evidence that emotion affects WM performance differently in younger and older adults (see Chapter 2.4). Although previous research suggests that local task switching is less age-sensitive than global task switching (see Chapter 2.3), there is also evidence that age-related changes in local task switching can emerge under particular task requirements. For instance, age-related impairments were observed when an unpredictable task switching design was used (Kray et al., 2002). The aim of the present research was to assess whether emotion would affect local task switching to a different extent in younger and older adults. In order to focus on emotion effects a predictable design was used, as an unpredictable design would not allow disentangling whether any differences in the two age groups were due to the inclusion of emotion or due to the use of an unpredictable design.

According to previous research, older adults tend to direct their attention to positive and away from negative material (for reviews, see Reed & Carstensen, 2012; Scheibe & Carstensen, 2010a) and this bias could affect their ability to engage with or disengage from emotional items during task switching. In contrast, younger adults tend to favour negative over positive information (Baumeister, Bratslavsky, Finkenauer, & Vohs, 2001; Taylor, 1991; Wood & Kisley, 2006). As discussed in Chapter 2.4, the reasons for this positivity effect in ageing are still being debated. According to the SST (Carstensen, 1993), it is due to older adults' motivation to regulate their emotion. Others, including proponents of the dynamic integration theory, link it with age-related cognitive decline by stating that older adults tend to avoid negative affect, as it is cognitively more demanding (see Labouvie-Vief, 2003; 2009a for reviews). However, despite the fact that different theoretical frameworks suggest different underlying mechanisms for the positivity effect in ageing, both would predict that older adults would more readily engage with positive than with negative material and disengage from negative than from positive material. This, in turn, could result in age-related differences in ability to switch to or away from positive and negative material despite no general task switching impairments in ageing.

The aim of the present experiment was to investigate how emotion affects task switching in older relative to younger adults. In order to assess how engagement with the new task and disengagement from the previous task were affected by emotion, both the emotion of the item participants had to switch to and the one they had to switch away from were considered in the present experiment. As both the SST and the dynamic integration theory would make similar predictions regarding the engagement with and the disengagement from positive and negative material in ageing, the following hypotheses can be suggested:

Configuration account. If emotion affects the engagement with the new task during task switching, target emotion is expected to have an effect. As happy faces are usually faster and more accurately recognised than other expressions, it is possible that a facilitating effect will be observed for happy relative to neutral targets. Given older adults' preference for positive material, the facilitating effect of happy faces relative to neutral faces should be more pronounced in older than in younger adults. In contrast, given that older adults tend to direct their attention away from negative material, no facilitating effects are expected for negative faces in older adults. Younger adults might engage more efficiently with negative relative to neutral material, as they tend to favour negative information.

Interference account. If emotion affects the disengagement from the previous task in task switching, previous emotion is expected to have an effect. Given that emotional material is more salient than neutral material, it is possible that emotional items will be more difficult to disengage from relative to neutral items. However, as valence has not been investigated in previous task switching paradigms yet, it is possible that differential effects between happy and angry faces will emerge. Disengaging from a previous task should be more difficult for older adults, if they have to disengage from a positive rather than neutral item. In contrast, disengaging should be easier from a negative rather than neutral item for older adults.

Emotional vs. non-emotional task sets. Given that switching between an emotional and a non-emotional task set entails switching between tasks, in which emotion is task-relevant or task-irrelevant, it is an open question whether the effects outlined above will vary with the relevance of emotion for the task. Three options are possible: First, if the effects of emotion are only observed for the emotional but not for the non-emotional task set, this suggests that emotion needs to be task-relevant to affect task switching. Second, if the effects of emotion are only observed in the non-emotional but not in the emotional task set, this suggests that task-irrelevant emotion affects task-switching. Third, if the effects of emotion are observed across both task sets, this suggests that emotion affects task switching irrespective of its relevance for the current task set. To investigate the effect of target (i.e., current item) and previous emotion on task switching in younger and older adults, the present experiment focused on switching between an emotional task set (i.e., identifying the emotion of faces) and a non-emotional task set (i.e., identifying the age of faces).

Methods

Participants

Thirty-two younger (18 - 38 years old) and 32 older adults (61 - 80 years old) took part in the experiment (see Table 5.1 for participant characteristics). Three younger adults were excluded from the analysis due to failure to follow instructions, resulting in a final sample of 29 younger and 32 older adults. Younger adults were undergraduate and postgraduate students at Birkbeck, University of London, and received £8.00 per hour for participating. Older adults were community-dwelling volunteers, who were recruited from the University of the Third Age in London and who were paid at the same rate for their participation as the younger adults. Participants reported to be in good health, had normal or corrected-to-normal vision and hearing and were pre-screened for psychiatric disorders and a history of neurological disorders. Older participants had a score of 27 or above on the MMSE (Folstein et al., 1975).

As can be seen in Table 5.1, older adults had better verbal knowledge than younger adults as assessed with the NART (Nelson & Willison, 1991) and scored lower on the Digit Symbol Substitution Test (Wechsler, 1955) suggesting slower processing speed than in younger adults. These results of slower processing speed (Salthouse, 1996, 2000) and better vocabulary knowledge in older than younger adults (Alwin & McCammon, 2001; Bowles et al., 2005) are consistent with typical findings in ageing research. No further differences were observed between the two age groups. The ethics board of Birkbeck, University of London, approved the procedure prior to the start of the study and written informed consent was obtained from each individual.

Materials

Stimuli consisted of 48 faces from the FACES database (Ebner et al., 2010). Angry, neutral and happy expressions were chosen for the experiment (16 faces per emotion category). The age group (younger, older) and sex (male, female) of the faces were balanced equally in each emotion category. The stimuli were taken from a pool of faces, which had previously been rated by younger and older adults and were selected based on high agreement ratings between younger and older raters (see Appendix A for evaluation details). For counterbalancing purposes, two subsets were created by assigning half of the faces to subset A and the other half to subset B.

Table 5.1. *Participant characteristics, Experiments 5.1 and 5.2*

	Younger adults		Older adults		Group difference	
Variable	*M*	*SD*	*M*	*SD*	*t*	*p*
Age	25.34	5.86	70.93	5.25		
Gender (male/female)	14/15		9/23			
Education (yrs)	16.86	3.16	15.73	2.94	1.42	.160
NART Verbal IQ	106.48	7.74	117.30	5.45	-6.80	<.001***
Digit Symbol Test	70.52	12.80	52.63	12.72	5.38	<.001***
BDI II	4.96	5.32	4.00	4.14	.77	.446
STAI Trait Anxiety	37.82	11.78	32.87	8.61	1.84	.072
MMSE			29.17	.91		

Note. NART = The National Adult Reading Test, BDI II = Beck Depression Inventory II, STAI = State-Trait Anxiety Inventory, MMSE = Mini-Mental State Examination
*$p < .05$, **$p < .01$, ***$p < .001$

Procedure

After giving informed consent, participants completed a demographic questionnaire and were seated in front of a computer screen. A visual acuity test (Bach, 1996) was conducted at a distance of 65 cm to ensure that vision was in the normal range. Participants were then instructed to perform the computerised task. To allow for binary responses, the task consisted of two blocks, with one mixing younger and older faces displaying neutral and happy expressions and the other one mixing younger and older faces displaying neutral and angry expressions. The block order was counterbalanced across participants.

In each block, participants viewed a face at a time that was presented in the left top quarter, the right top quarter, the bottom right quarter or the bottom left quarter of the screen. A horizontal line separated the top and bottom of the screen and was consistently visible for the duration of the whole block. Face presentation, which was preceded by a fixation cross for 500 ms in the relevant location, always started in the left top quarter and continued clockwise before starting again in the left top quarter. Participants were instructed to respond to the age of the face by pressing one of two buttons ("young" vs. "old") when the face was presented above (or below) the horizontal line and to the emotion of the face by pressing one of two buttons ("neutral" vs. "emotional") when the face was presented below (or above) a horizontal line. Button presses initiated the next trial after the presentation of a blank screen (with the horizontal line) for 200 ms. Task assignment to the top or bottom half of the screen was counterbalanced across participants, as was the labelling of the keys. Responses to the task on the top half of the screen were assigned to the left hand, whereas responses to the task on the bottom half of the screen were assigned to the right hand. On the computer keyboard, the buttons "s" and "d" as well as "k" and "l" were used and different hands were assigned to different tasks to avoid conflict at the response level.

In each block, 160 faces were presented in a random order: 40 were young and neutral, 40 were young and emotional, 40 were old and neutral and 40 were old and emotional. Participants had the option to take short breaks every 40 trials, resulting in three breaks per block and a short break in between blocks. In each block, faces from different subsets (A or B) were presented to ensure that neutral faces, which were included in both blocks, were not the same across blocks. Thus, each face was viewed approximately 10 times per block. The task was preceded by 16 practice trials, which were not scored. An example of a trial sequence is presented in Figure 5.1.

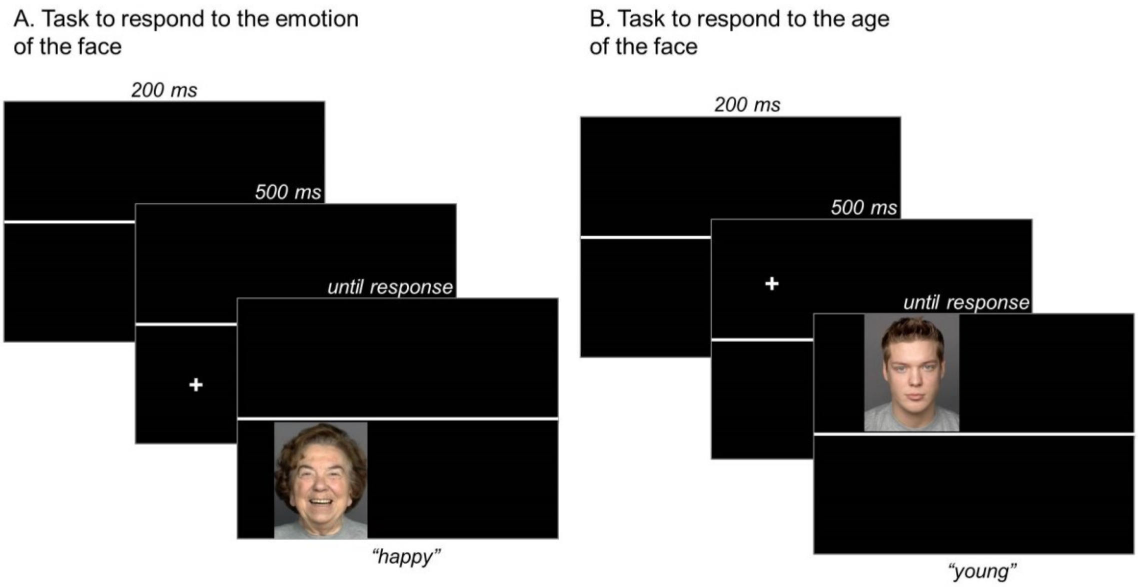

Figure 5.1. Examples of trials with the instructions to respond to the emotion of the face if it is presented below the horizontal line (A) or to the age of the face if it is presented above the horizontal line (B) in Experiment 5.1. As faces were presented clockwise, the examples show a repeat trial in the emotion condition and a switch trial in the age condition.

After completing the computer task, participants were administered the NART (Nelson & Willison, 1991) and the Digit Symbol Substitution Test (Wechsler, 1955) as measures of fluid and verbal intelligence, respectively. Participants then filled out the BDI-II (Beck et al., 1988) and the A-Trait version of the STAI (Spielberger et al., 1983). Older adults were additionally administered the MMSE (Folstein et al., 1975) as a screening for cognitive impairments. All participants were debriefed at the end of the session, with each session lasting approximately 1 hour to 1 hour and 15 min in total.

Design and statistical analysis

Responses and RTs were recorded for each trial. For the analyses of RTs, any RTs faster than 200 ms or 2.5 standard deviations above or below the age group's mean RTs were excluded, resulting in an exclusion of an average of 2.86% of trials for younger adults and 2.51% for older adults. Accuracy and median RTs for correct trials were then calculated for each condition. As explained in the introduction, the hypotheses related to the effects of emotion and age on switch trials and thus, only analyses for switch trials are reported below. Separate analyses for repeat trials are reported in Appendix E.

Statistical analysis of the data was conducted with SPSS 22 (IBM Corp., Armonk, NY). Accuracy and RTs for switch trials were analysed separately for the happy vs. neutral and the angry vs. neutral blocks. Data were analysed by a 2 × 2 × 2 × 2 mixed factors ANOVA including the within-subjects factors task (age vs. emotion), target emotion (happy/angry vs. neutral) and previous emotion (happy/angry vs. neutral) as well as the between-subjects factor of age (younger vs. older). Post-hoc t-tests with a Bonferroni adjustment to the alpha level were performed to follow up significant interactions. All tests were two-tailed with $\alpha = .05$.

Results

Happy vs. neutral faces

Accuracy. Accuracy for performance in the happy versus neutral task block in younger and older adults is presented in Figure 5.2. The four-way omnibus ANOVA revealed a task × target emotion × previous emotion × age interaction. Accuracy scores from the age task and the emotion task were analysed separately to follow-up on this interaction.

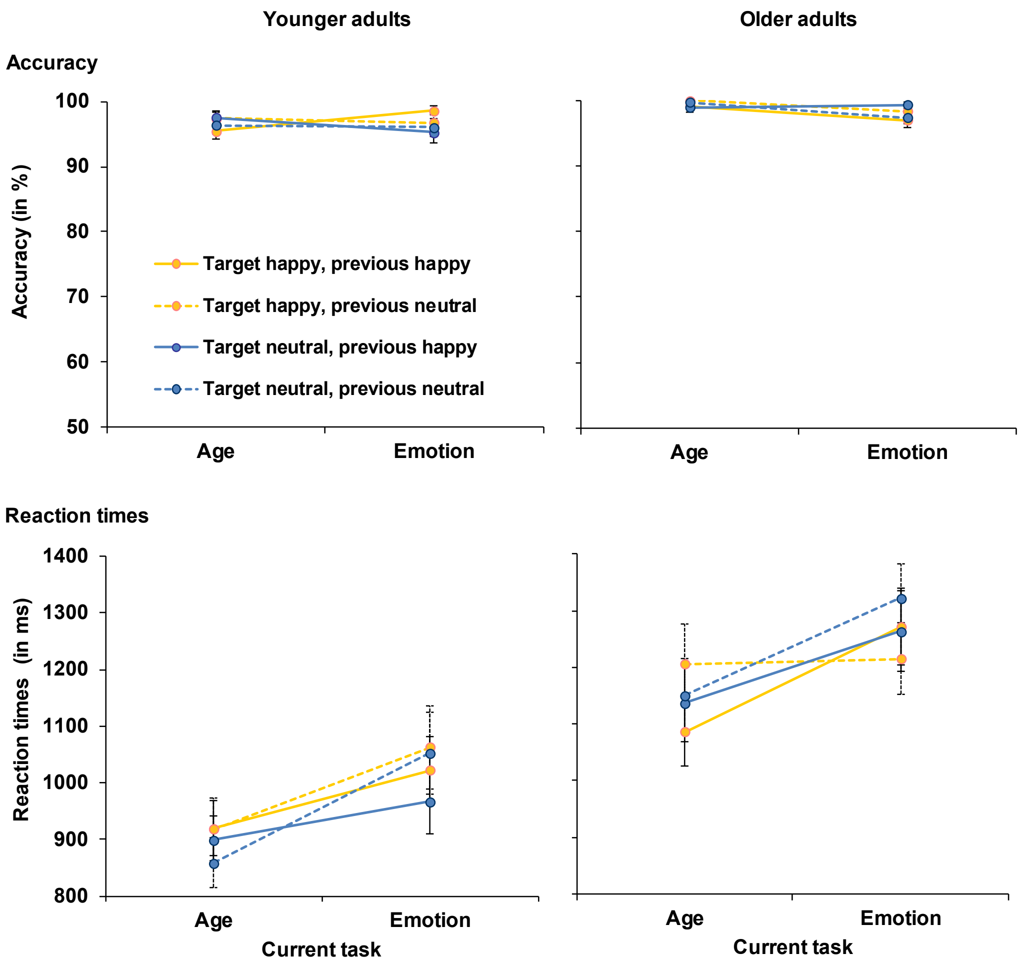

Figure 5.2. Accuracy (upper panel) and RTs for correct responses (lower panel) in younger (left-hand panel) and older adults (right-hand panel) as a function of target and previous emotion in Experiment 5.1. Participants had to switch between the age task (with task-irrelevant emotion) and the emotion task (with task-relevant emotion). This figure shows data from the happy vs. neutral task block. Only switch trials are presented in this figure.

The target emotion × previous emotion × age interaction was significant in the emotion task, $F(1, 59) = 5.13$, $MSE = .003$, $p = .027$, partial $\eta^2 = .08$, but not in the age task ($p = .117$). Data from the emotion task were analysed separately for older and younger adults to follow up this interaction. In older adults, the target emotion × previous emotion was significant, $F(1, 31) = 5.89$, $MSE = .002$, $p = .021$, partial $\eta^2 = .16$, whereas it was not significant in younger adults ($p = .263$). In older adults, accuracy was slightly lower for neutral targets if the previous emotion was also neutral (*M* = 97.35, *SD* = 5.47) rather than happy (*M* = 99.34, *SD* = 2.60), *t*(31) = 2.15, *p* = .039, but this difference was not significant after Bonferroni correction. Previous emotion did not play such a role for happy targets (*p* = .156). There was also a main effect of age, *F*(1, 59) = 11.12, *MSE* = .005, *p* = .001, partial η^2 = .16, as older adults were more accurate (*M* = 98.97, *SD* = 1.39) than younger adults (*M* = 96.93, *SD* = 2.33). No further main effects or interaction were observed for accuracy scores for happy vs. neutral faces.

Reaction times. RTs for performance in the happy versus neutral task block in younger and older adults are presented in Figure 5.2. The four-way omnibus ANOVA yielded a main effect of task, *F*(1, 59) = 17.40, *MSE* = 89530, *p* < .001, partial η^2 = .23, with overall slower RTs in the emotion task (*M* = 1153 ms, *SD* = 343 ms) compared to the age task (*M* = 1041 ms, *SD* = 323 ms). This main effect was qualified by a task × target emotion interaction, *F*(1, 59) = 4.14, *MSE* = 21865, *p* = .046, partial η^2 = .07. Follow-up t-tests revealed that in the age task, RTs were slower for happy targets (*M* = 1064 ms, *SD* = 329 ms) than for neutral targets (*M* = 1018 ms, *SD* = 332 ms), *t*(60) = 2.50, *p* = .015. In the emotion task, there was no significant difference between RTs for neutral or happy targets (*p* = .650). Finally, there was also a main effect of age, *F*(1, 59) = 11.81, *MSE* = 676967, *p* = .001, partial η^2 = .17, as older adults were overall slower (*M* = 1057 ms, *SD* = 261 ms) than younger adults (*M* = 828 ms, *SD* = 191 ms). No further main effects or interactions were observed for RTs to happy vs. neutral faces.

Angry vs. neutral faces

Accuracy. Accuracy scores for performance in the angry versus neutral task block in younger and older adults are presented in Figure 5.3. The four-way omnibus ANOVA yielded a main effect of task, *F*(1, 59) = 14.99, *MSE* = .007, *p* < .001, partial η^2 = .20, as accuracy scores were higher in the age task (*M* = 98.03, *SD* = 3.04) than in the emotion task (*M* = 95.03, *SD* = 5.83). There was also a main effect of target emotion, *F*(1, 59) = 7.58, *MSE* = .006, *p* = .008, partial η^2 = .11, with lower accuracy scores for angry targets (*M* = 95.50, *SD* = 5.59) than for neutral targets (*M* = 97.56, *SD* = 3.22). This main effect was qualified by a task × target emotion interaction, *F*(1, 59) = 7.58, *MSE* = .006, *p* = .008, partial η^2 = .11. Follow-up t-tests revealed that in the emotion task, accuracy was lower for angry targets (*M* = 93.02, *SD* = 9.73) than for neutral targets (*M* = 97.04, *SD* = 4.29), *t*(60) = 3.32, *p* = .002, whereas accuracy scores for neutral and angry targets were not different in the age task (*p* = .909). There was a trend for a main effect of age, *F*(1, 59) = 3.10, *MSE* = .010, *p* = .083, partial η^2 = .05, as older adults were slightly more accurate (*M* = 97.68, *SD* = 2.48) than younger adults (*M* = 95.38, *SD* = 2.98). No further main effects or interaction were observed for accuracy scores for angry vs. neutral faces.

Reaction times. RTs for performance in the angry versus neutral task block in younger and older adults are presented in Figure 5.3. The four-way omnibus ANOVA yielded a main effect of task, *F*(1, 59) = 50.09, *MSE* = 49662, *p* < .001, partial η^2 = .46, as participants were slower in the emotion task (*M* = 1188 ms, *SD* = 315 ms) than in the age task (*M* = 1044 ms, *SD* = 287 ms). There was also a main effect of target emotion, *F*(1, 59) = 8.15, *MSE* = 38061, *p* = .006, partial η^2 = .12, with slower RTs for angry targets (*M* = 1141 ms, *SD* = 291 ms) relative to neutral targets (*M* = 1091 ms, *SD* = 307 ms). This main effect was qualified by a task × target emotion interaction, *F*(1, 59) = 4.18, *MSE* = 32855, *p* = .045, partial η^2 = .07. Separate analyses for the age task and the emotion task revealed that in the age task, RTs were slower for angry targets (*M* = 1087 ms, *SD* = 314 ms) than for neutral targets (*M* = 1002 ms, *SD* = 283 ms), *t*(60) = 4.08, *p*

< .001. In contrast, there was no significant difference in RTs for neutral and angry targets in the emotion task (p = .567). There was also a main effect of age, *F*(1, 59) = 8.43, *MSE* = 601596, *p* = .005, partial η^2 = .13, as older adults were overall slower (*M* = 1071 ms, *SD* = 276 ms) than younger adults (*M* = 865 ms, *SD* = 156 ms). No further main effects or interactions were observed for RTs for angry vs. neutral faces.

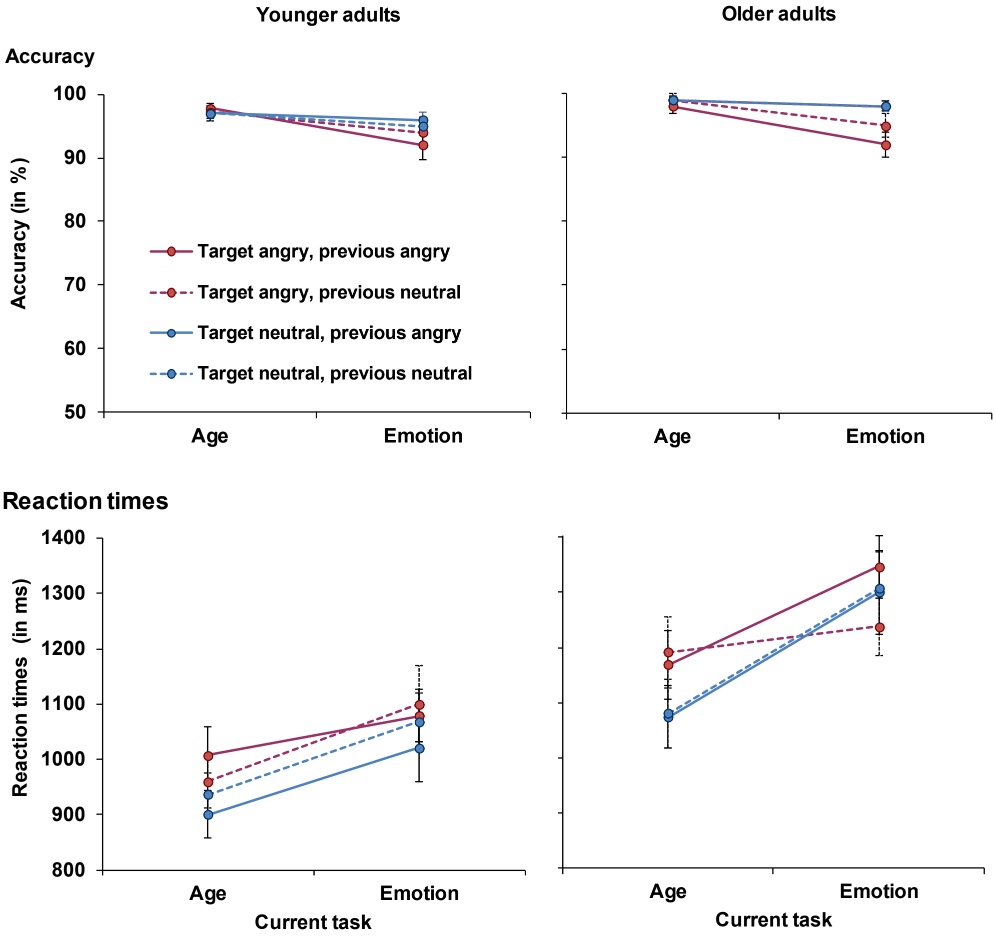

Figure 5.3. Accuracy (upper panel) and RTs for correct responses (lower panel) in younger (left-hand panel) and older adults (right-hand panel) as a function of target and previous emotion in Experiment 5.1. Participants had to switch between the age task (with task-irrelevant emotion) and the emotion task (with task-relevant emotion). This figure shows data from the angry vs. neutral task block. Only switch trials are presented in this figure.

Discussion

The aim of the present experiment was to investigate the effects of emotion on task switching in younger and older adults. The main results were as follows: While no differences in RTs were observed for switches to neutral and emotional faces in the emotion task, both age groups were slower when switching to emotional rather than neutral faces in the age task. Moreover, the experiment revealed that while the emotion of the target they had to switch to modulated responses in both age groups, the emotion of the item that they had to switch away from did not. Lastly, there were no age-related differences in switching performance besides a speed-accuracy trade-off (i.e., slower but more accurate performance) in older adults.

The finding that participants were slower when having to switch to an emotional face in the age task suggests that task-irrelevant emotion was processed and that it impaired performance in both age groups. Previous research showed slower switching from the non-emotional to the emotional task set than vice versa (Reeck & Egner, 2015), even if there were no RT differences in pure task blocks (i.e., similar mean RTs for naming the emotion of the face and naming the gender of the face as assessed in separate blocks). The authors interpreted these findings as evidence for the dominance of the emotional task set, which needed to be inhibited in order to facilitate performance on a non-emotional task (Reeck & Egner, 2015). This interpretation was in line with the interference account of task switching (Allport et al., 1994; Wylie & Allport, 2000). The results from the present experiment also showed slower switches from the age task to the emotion task than vice versa. However, as no baseline measures of performance in each task were included, this result should be interpreted cautiously. It could be due to differences in the time needed to perform each task.

Despite the longer RTs for switches to the emotion task relative to switches to the age task, the results of the present experiment are not consistent with an interpretation favouring the interference account of task switching. If participants inhibited the presumably more “dominant” emotional task set when performing the less dominant, non-emotional task, no effect of emotional material on responses in the non-emotional task set should be observed. However, this effect was observed in the present study, suggesting that emotional processing was not inhibited at all or at least not successfully. In contrast, the finding of a slowdown in responses to emotional items in the non-emotional task is more compatible with the reconfiguration account, which highlights the importance of configuring the current task set through both endogenous and exogenous factors (Monsell, 2003; Rogers & Monsell, 1995). In the current experiment, a predictable switching paradigm was used and participants were aware that they had to switch to the age task every two trials. Thus, it is expected that they were able to initiate measures to prepare for the switch (i.e., endogenous factors). However, their preparation was either incomplete or they had to overcome the task-irrelevant, emotional signal when presented with emotional stimuli in the age task, which highlights the importance of external (i.e., exogenous) factors.

Further evidence favouring the reconfiguration account comes from the finding that only the emotion of the target item affected task switching in the present paradigm. Given that inhibition is thought to be necessary to disengage from the previous task set, the previous emotion could be expected to play a role in task switching. However, no effects of previous emotion were observed in the present experiment. Given this pattern of results, no strong argument for the interference account can be made and instead, the data appear to support the reconfiguration account of task switching. As the effects of target emotion were similar in blocks with happy vs. neutral and angry vs. neutral faces, it can be concluded that the effects of emotion on task switching were driven by arousal rather than valence.

It should also be noted that despite a speed-accuracy trade-off in older adults (Salthouse, 1979), no further age-related changes in task switching between emotional and non-emotional task sets were observed. Overall, this is compatible with results from previous studies showing no age-related decline in local task switching (for a meta-analysis, see Wasylyshyn et al., 2011). Additionally, emotion modified task-switching performance similarly in both age groups, with no age-related differences. Thus, the age-specific hypotheses in the current experiment were not confirmed. Implications of these results will be discussed in the general discussion of this chapter below.

Although the present study provided clear evidence that emotion affected task-switching performance when it was task-irrelevant, the mechanisms that were driving the effect are not clear. There are multiple accounts that could be put forward to explain the pattern of results observed in this experiment. One explanation could be that having just processed and responded to emotional information in the emotional task made it difficult for participants to switch to the non-emotional task (option 1). This would be in accordance with the inhibition account. Another explanation (option 2) could be that it simply took participants longer to identify a face’s age if the face is emotional rather than neutral, as evidence suggests that emotional expressions can affect age ratings (Ganel, 2015; Voelkle et al., 2012). Alternatively, it is possible that emotional items triggered task-irrelevant emotional processing either in an automatic fashion (option 3) or due to the fact that emotion was part of the competing emotional task set (option 4). The mechanism underlying option 4 could be the reactivation of the competing task set through external cues. Research suggests that exogenous factors play an important part in task switching through cueing of task sets (Kiesel et al., 2010; Rogers & Monsell, 1995; Rubin & Koch, 2006). Thus, it is possible that emotional items slowed down responses in the non-emotional task set as they cued the currently irrelevant emotional task set.

In an attempt to rule out possibly irrelevant explanations, repeat trials were also analysed (see Appendix E). The analysis showed that RTs were slower for emotional compared to neutral targets for repeat trials in the age task just as it was the case for switch trials. Although this does not allow evaluating the validity of options 2 to 4, it helps to eliminate option 1, according to which RTs for emotional trials were slower relative to neutral trials due to the difficulty to disengage from the emotion task of the previous trial. Given that RTs for repeat trials were faster than for switch trials (see Appendix E), it can be assumed that participants were able (at least to some degree) to reconfigure the new non-emotional task set. Thus, it seems unlikely that the difficulty to disengage from the previously performed emotion task was responsible for the similar pattern of longer RTs for emotional relative to neutral trials in the age task in both switch and repeat trials. Instead, it appears that emotion cues were still effective in the age task even on repeat trials. To further explore the remaining explanations for a slowdown in responses to emotional items in the non-emotional task set, Experiment 5.2 was conducted.

5.3. Experiment 5.2: Switching between non-emotional tasks

In Experiment 5.1, participants had to switch constantly between an emotional and a non-emotional task set. As emotion was relevant for one of the competing task sets, it is possible that it affected task performance in the non-emotional task due to its relevance for the task block (which included both the emotional and the non-emotional task sets).

Alternatively, emotion might have affected task performance in the non-emotional task set in an automatic way due to salience of emotion or the effects were simply due to the difficulties of identifying an emotional face's age (Ganel, 2015; Voelkle et al., 2012).

Although task switching between emotional and non-emotional task sets has been investigated previously (Aboulafia-Brakha et al., 2016; de Vries & Geurts, 2012; Gul & Khan, 2014; Johnson, 2009; Paulitzki et al., 2008; Piguet et al., 2016; Piguet et al., 2013; Reeck & Egner, 2015), none of the studies has assessed the effect of task-irrelevant emotion on performance in a non-emotional task set so far. It has neither been investigated whether emotion has to be relevant for at least one task set in order to affect switching or whether it does so even if it is completely irrelevant for all competing task sets. The present experiment set out to close this empirical gap by investigating how switching between two non-emotional task sets is affected by task-irrelevant emotion.

As discussed in Chapter 2.2, enhanced processing of emotional material was found not only for task-relevant but also for task-irrelevant emotional items, suggesting that it is automatic (Öhman, 2002; Vuilleumier, 2005; Vuilleumier et al., 2001; Whalen et al., 1998). However, evidence regarding the effects of task-irrelevant emotion on WM performance has been mixed. On the one hand, it has been shown that task-irrelevant emotion can impair WM performance (Dolcos et al., 2013; Dolcos & McCarthy, 2006; Hart et al., 2012; Iordan et al., 2013). On the other hand, studies have shown that emotional material did not affect WM performance to a greater extent than non-emotional distractors (Miendlarzewska et al., 2013; Mullin et al., 2012; Ozawa et al., 2014). For instance, Experiment 3.1 (see Chapter 3.3) showed that emotional information did not interfere with updating in younger or older adults to a greater extent than neutral information if it was completely irrelevant for the task. Overall, these results do not provide a clear picture whether task-irrelevant emotion can be expected to affect task switching in an automatic fashion.

To assess the impact of task-irrelevant emotion on task switching, Experiment 5.2 was conducted. Besides identifying the face's age as in the previous experiment, the second task participants had to perform in the present experiment was identifying the face's gender. Thus, participants had to switch between two non-emotional task sets in the presence of happy, neutral and angry faces. By introducing two non-emotional task sets with task-irrelevant emotion, this experiment will help to distinguish between the following explanations for longer RTs in response to emotional items in the non-emotional task set in Experiment 5.1: If longer RTs for emotional rather than neutral stimuli in the age task were due to difficulties to identify the face's age in emotional faces, we would expect to find this pattern for the age but not the gender task in the present experiment. Alternatively, if emotion affected task switching irrespective of its relevance for the non-emotional task set in an automatic way, we would expect to find longer RTs for emotional than neutral faces in both the age and in the gender task. However, if emotion affected performance in the non-emotional task set in the previous experiment due to reactivation of the competing emotional task set through emotional cues, we would not expect to find an effect of emotion on task switching performance in the age task in the present experiment, as emotional cues will be irrelevant throughout the task.

Methods

Participants

The same participants, who participated in Experiment 5.1, took part in the present experiment during the same session (see Table 5.1 for participant characteristics). Half of participants started with the task in Experiment 5.1, whereas the other half started with the task in Experiment 5.2.

Materials

The same stimuli as in Experiment 5.1 were used.

Procedure

The procedure and counterbalancing were identical to the procedure for Experiment 5.1. The only difference was that participants were instructed to respond to the age of the face by pressing one of two buttons ("young" vs. "old") when the face was presented above (or below) the horizontal line and to the gender of the face by pressing one of two buttons ("male" vs. "female") when the face was presented below (or above) the horizontal line.

Design and statistical analysis

Responses and RTs were recorded for each trial and the same exclusion criteria were applied as in Experiment 5.1, resulting in an exclusion of 2.28% of data points in the younger age group and 2.65% in the older age group. Accuracy and median RTs for correct trials were then calculated. As in Experiment 5.1, only analyses for switch trials are reported below. Separate analyses for repeat trials are reported in Appendix F. Statistical analysis of the data was conducted with SPSS 22 (IBM Corp., Armonk, NY).

As in Experiment 5.1, accuracy and RTs for switch trials were analysed separately for the happy vs. neutral and the angry vs. neutral task blocks. Accuracy and RTs were analysed by 2 × 2 × 2 × 2 mixed factors ANOVA including the within-subjects factors task (age vs. gender), target emotion (happy/angry vs. neutral) and previous emotion (happy/angry vs. neutral) as well as the between-subjects factor of age (younger vs. older). Post-hoc t-tests with a Bonferroni adjustment to the alpha level were performed to follow up significant interactions. All tests were two-tailed with α = .05.

Results

Happy vs. neutral faces

Accuracy. Accuracy scores for performance in the happy vs. neutral task block in younger and older adults are presented in Figure 5.4. The analysis of accuracy scores yielded a significant main effect of target emotion, *F*(1, 59) = 4.67, *MSE* = .003, *p* = .035, partial η^2 = .07, as accuracy was higher for happy (*M* = 97.41, *SD* = 3.41) than for neutral trials (*M* = 96.36, *SD* = 4.68). This main effect was qualified by a target emotion × age interaction, *F*(1, 59) = 6.51, *MSE* = .002, *p* = .013, partial η^2 = .10. Follow-up t-tests revealed that in younger adults, accuracy was higher for trials with happy faces (*M* = 96.55, *SD* = 4.28) than with neutral faces (*M* = 94.13, *SD* = 5.36), *t*(28) = 2.64, *p* = .013, whereas in older adults, there was no difference in accuracy for trials with happy and neutral faces (*p* = .699). There was also a main effect of age, *F*(1, 59) = 12.82, *MSE* = .004, *p* = .001, partial η^2 = .18, as accuracy was higher in older adults (*M* = 98.29, *SD* = 1.98) than in younger adults (*M* = 95.34, *SD* = 4.17). No further main effects or interactions were observed for accuracy scores for happy vs. neutral faces.

Reaction times. RTs for performance in the happy vs. neutral task block in younger and older adults are presented in Figure 5.4. The analysis revealed a main effect of task, *F*(1, 59) = 4.49, *MSE* = 38279, *p* = .038, partial η^2 = .07, as RTs were longer in the age task (*M* = 1047 ms, *SD* = 321 ms) than in the gender task (*M* = 1011 ms, *SD* = 286 ms).

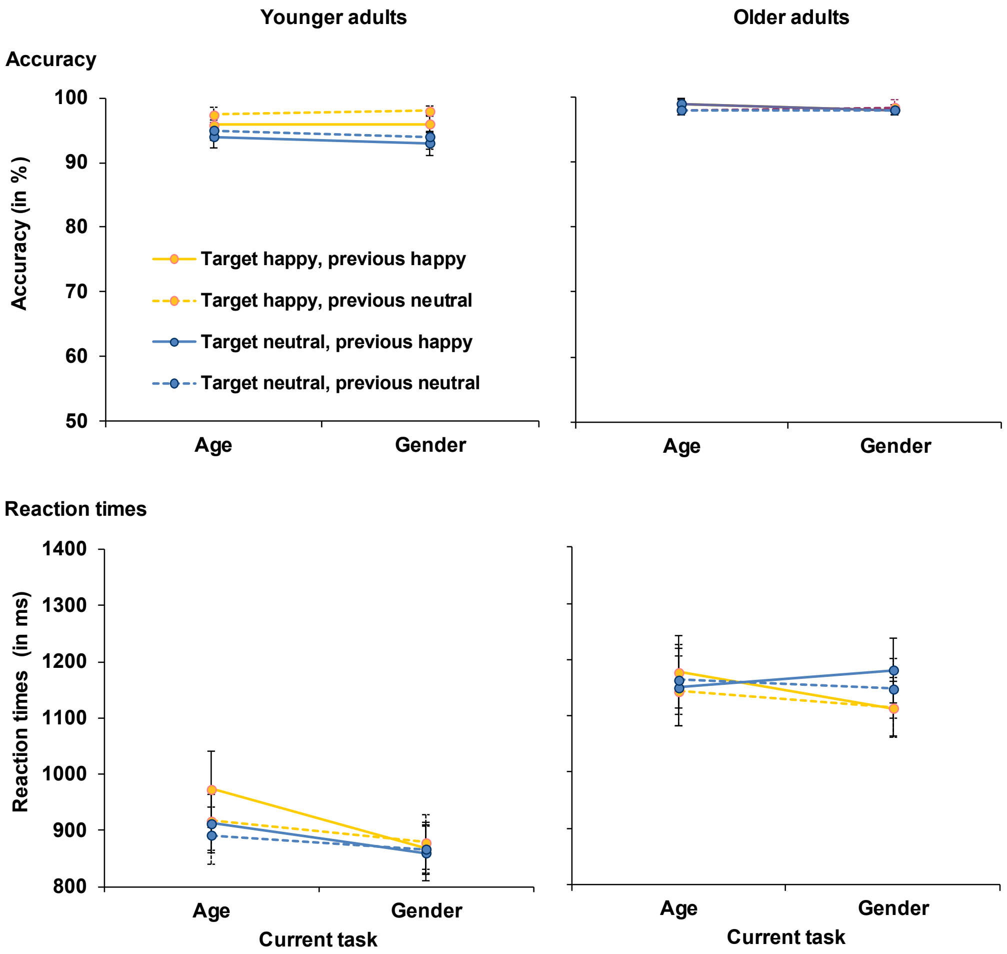

Figure 5.4. Accuracy (upper panel) and RTs for correct responses (lower panel) in younger (left-hand panel) and older adults (right-hand panel) as a function of target and previous emotion in Experiment 5.2. Participants had to switch between the age and the gender tasks with task-irrelevant emotion. This figure shows data from the happy vs. neutral task block. Only switch trials are presented.

There was also a target emotion × age interaction, *F*(1, 59) = 4.59, *MSE* = 17279, *p* = .036, partial η^2 = .07. Follow-up t-tests revealed that in younger adults, RTs were slightly higher for targets with happy faces (*M* = 910 ms, *SD* = 238 ms) than with neutral faces (*M* = 882 ms, *SD* = 232 ms), but this difference in RTs was non-significant (*p* = .122). In older adults, the pattern was reversed as RTs were slightly higher for targets with neutral faces (*M* = 1161 ms, *SD* = 317 ms) than with happy faces (*M* = 1137 ms, *SD* = 290 ms), but this difference in RTs was not significant either (*p* = .161).

There was also a main effect of age, *F*(1, 59) = 13.42, *MSE* = 581514, *p* = .001, partial η^2 = .19, as older adults were overall slower (*M* = 1115 ms, *SD* = 286 ms) than younger adults (*M* = 866 ms, *SD* = 217 ms). No further main effects or interactions were observed for RTs for happy vs. neutral faces.

Angry vs. neutral faces

Accuracy. Accuracy scores for performance in the angry vs. neutral task block in younger and older adults are presented in Figure 5.5. The analysis of accuracy scores yielded a main effect of age, *F*(1, 59) = 6.72, *MSE* = .017, *p* = .012, partial η^2 = .10, as older adults were more accurate (*M* = 97.78, *SD* = 2.45) than younger adults (*M* = 94.70, *SD* = 6.21). No further main effects or interactions were observed for accuracy for angry vs. neutral faces.

Reaction times. RTs for performance in the angry vs. neutral task block in younger and older adults are presented in Figure 5.5. The analysis yielded a task × target emotion × age interaction, *F*(1, 59) = 6.40, *MSE* = 22532, *p* = .014, partial η^2 = .10. Separate analyses for younger and older adults revealed a task × target emotion in older adults, *F*(1, 31) = 4.90, *MSE* = 17622, *p* = .034, partial η^2 = .14, which was not significant in younger adults (*p* = .155). In the age task, older adults were slower when the target emotion was angry (*M* = 1186 ms, *SD* = 352 ms) rather than neutral (*M* = 1116 ms, *SD* = 335 ms), *t*(31) = 2.56, *p* = .016. In the gender task, older adults' RTs were not different for neutral or angry faces (*p* = .851). There was also a main effect of age, *F*(1, 59) =9.13, *MSE* = 594156, *p* = .004, partial η^2 = .13, as older adults were slower (*M* = 1142 ms, *SD* = 307 ms) than younger adults (*M* = 930 ms, *SD* = 229 ms). No further main effects or interactions were observed for RTs for angry vs. neutral faces.

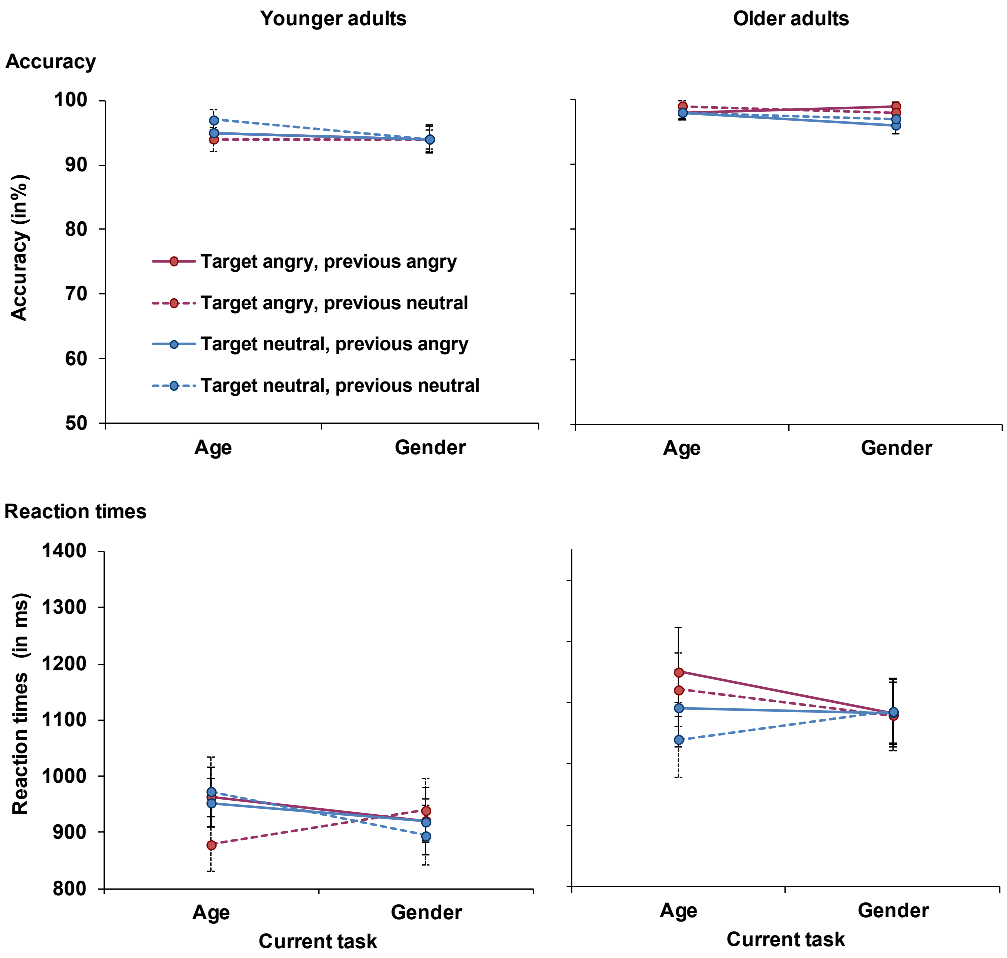

Figure 5.5. Accuracy (upper panel) and RTs for correct responses (lower panel) in younger (left-hand panel) and older adults (right-hand panel) as a function of target and previous emotion in Experiment 5.2. Participants had to switch between the age and the gender tasks with task-irrelevant emotion. This figure shows data from the angry vs. neutral task block. Only switch trials are presented.

Discussion

The aim of this experiment was to assess switching between two non-emotional task sets in the presence of task-irrelevant emotional material in two age groups. Younger and older adults had to switch between identifying the age and the gender of happy, neutral or angry faces. The results revealed that there was no overall effect of target emotion on performance in any of the two non-emotional tasks. Older adults continued to show slower responses to angry relative to neutral faces in the age task. However, this slowdown was only observed for angry and not for happy faces and no such effect was found in the gender task.

The results of the present study can help to interpret the pattern of results observed in Experiment 5.1, in which both age groups showed a slowdown for emotional rather than neutral items when switching away from an emotional to a non-emotional task set. Given that the overall effect of target emotion was not observed when participants had to switch between two non-emotional task sets in the present experiment, it appears that emotion had to be task-relevant for at least one of the competing task sets in order to affect performance in the non-emotional task set. This is in accordance with research showing that task-irrelevant emotional stimuli do not affect WM performance to a greater extent than non-emotional stimuli (Miendlarzewska et al., 2013; Mullin et al., 2012; Ozawa et al., 2014). The present findings also provide strong evidence against the assumption that participants were slower to perform the age task in the presence of emotional rather than neutral faces in the previous experiment due to difficulties to identify the age of an emotional face. No such slowdown for identifying the face's age was observed in the present experiment despite the fact that emotional expressions were shown. Further implications of the results will be discussed in the general discussion section below.

It should be noted that older adults showed a slowdown when responding to angry faces in the age task of the present experiment, whereas younger adults did not. This effect was limited to angry faces and was only observed in the age but not in the gender task. This finding could indicate that older adults processed negative information even if it was irrelevant for both task sets, which slowed down their switch responses. However, the task × target emotion × age interaction should be treated with caution as no such interaction was observed in the previous experiment: Both younger and older adults were affected equally by non-relevant emotional material when switching to a non-emotional task set, with no age-related differences. Also, the effect of task-irrelevant negative emotion was limited to the age task and was not found in the gender task. Thus, the effect does not appear to generalise to all non-emotional tasks and future studies should examine whether and under which circumstances older adults are affected to a greater extent by task-irrelevant negative material in task switching relative to younger adults.

5.4. General discussion

The two experiments presented in this chapter were conducted to assess the effects of emotion on task switching in younger and older adults. In Experiment 5.1, participants had to switch between an emotional (i.e., identifying the emotion of the face) and a non-emotional (i.e., identifying the age of the face) task set, whereas in Experiment 5.2, participants had to switch between two non-emotional (i.e., identifying the age or the gender of the face) task sets. The experiments yielded the following main findings: First, when switching between emotional and non-emotional task sets, participants showed slower switch responses for emotional rather than neutral faces in the non-emotional task set. This result was observed for younger and older adults, with no age-related differences. Second, when switching between two non-emotional task sets, there was no such slowdown in switch responses for emotional compared to neutral trials. Overall, these results suggest that the impairing effect of task-irrelevant emotion on switching is restricted to cases in which emotion is relevant for one of the competing task sets.

Impairing effects of (currently) task irrelevant emotion on task switching

The present study is the first to show that task-irrelevant emotion can contribute to slower switches compared to neutral material when it is relevant for one of the competing task sets. In contrast, task-irrelevant emotion does not affect switching performance if it is not relevant for either of the competing task sets. Importantly, the impairment through currently irrelevant emotion emerged for the comparison between emotional and neutral items in the non-emotional task set, despite the fact that switches to the non-emotional task set were faster than to the emotional task set. This pattern of results might help to explain the inconsistent findings of previous studies, which have exclusively focused on switches between emotional and non-emotional task sets without taking into account the emotionality of the individual items (Aboulafia-Brakha et al., 2016; Gul & Khan, 2014; Johnson, 2009; Paulitzki et al., 2008; Reeck & Egner, 2015).

On the one hand, studies found that switching from an emotional to a non-emotional task set comes at a greater cost than vice versa (Johnson, 2009; Paulitzki et al., 2008). This finding was usually interpreted as evidence that disengaging from an emotional task set was more difficult than from a neutral task and/or that engaging with an emotional task set was less difficult than with a neutral task set. As the present study did not find slower switches from the emotional to the non-emotional task set than vice versa, the data do not fully support this interpretation. It should be noted, however, that those studies used emotional items on every trial (Paulitzki et al., 2008), or that they used both emotional and neutral items without distinguishing between them in the analyses (Johnson, 2009). Thus, it is possible that switch costs from the emotional to the non-emotional task set were exacerbated by the fact that all items were emotional. Additionally, the emotional features of the stimuli were perceptually more salient relative to the non-emotional ones due to their size in both studies. Thus, it is also possible that it was more effortful to direct attention away from emotional than from neutral features, which affected switch costs. Due to these limitations, the results of these studies and any parallels with the present data need to be treated with caution.

On the other hand, there is evidence that costs are greater for switches to an emotional from a non-emotional task set than vice versa (Reeck & Egner, 2015) even if both tasks were similar in perceptual demand and in difficulty. The authors interpreted this as evidence that emotional task sets are more dominant and have to be inhibited to facilitate performance in less dominant, non-emotional task sets. Again, no neutral items were used in the study by Reeck and Egner (2015), which did not allow them to assess whether emotion is indeed inhibited by comparing switch responses to neutral and emotional items in the non-emotional data set. It should be noted that in the present study, switch costs were greater when participants had to switch from a non-emotional to an emotional task set, which is similar to the results reported by Reeck and Egner (2015). However, the authors' interpretation that slower switches to an emotional task set were due to the inhibition of emotional processing is not supported by the results of the present experiment. In the present experiment, emotional faces slowed down switches to a non-emotional task, which suggests that there was no or at least no successful inhibition of emotion when participants had to switch between emotional and non-emotional task sets.

Overall, by relating the results of the present research back to previous studies on emotion and task switching, it appears that without distinguishing responses to neutral and to emotional items, the interpretation of the effects of emotion on task switching can only be inconsistent or incomplete at best.

The effects of emotion on task set reconfiguration vs. task set interference

Taking into account the stimulus valence in a task-switching paradigm can help disentangling which sub-mechanisms involved in task switching are affected by emotion. The literature suggests that both the reconfiguration of the new task set and the interference of the previous task set make switching between tasks more difficult than repeating the same task. Whereas an effect of target emotion on switching was predicted based on assumptions of the reconfiguration account of task switching, an effect of previous emotion on switching was predicted based on the interference account of task switching. To assess whether emotion affected task switching through effects on task reconfiguration or on interference of task sets, both the emotion participants had to switch to and the emotion they had to switch away from were considered in the analyses.

Experiment 5.1 revealed that the emotion participants had to switch to affected performance, whereas the emotion they had to switch away from did not. Although interference might have played a role during task switching in Experiment 5.1, it was not affected by emotion, whereas task reconfiguration was. Both happy and angry targets slowed down responses when participants switched to the age task, in which emotion was irrelevant. As mentioned earlier, this is not compatible with conclusions by Reeck and Egner (2015), who suggested that emotional processing is suppressed when participants have to switch between emotional and non-emotional task sets.

Instead, it appears that reconfiguration of a non-emotional task set was less efficient in the presence of an emotional relative to a neutral stimulus. This impairment was only observed in Experiment 5.1 and not in Experiment 5.2, which suggests that emotional processing did not affect the configuration of a non-emotional task set in an automatic way, but only when it was relevant for at least one of the competing task sets. As the slowdown in task switching was observed for emotional relative to neutral items, it is likely that they triggered the competing emotional task, whereas neutral items did not or did to a smaller extent.

Taken together, the results suggest that emotional items contributed to a reactivation of the competing emotional task set, whereas neutral items did not or did to a smaller degree. This reactivation of the emotional task set in turn interfered with the reconfiguration of the non-emotional but relevant task set. It also appears that reactivation can be triggered by both happy and angry faces without any valence-related differences. These results are in accordance with the suggestion that exogenous factors play an important role in task switching through cueing of task sets (Kiesel et al., 2010; Rogers & Monsell, 1995; Rubin & Koch, 2006). As reviewed by Kiesel et al. (2010), stimulus-based task activation can happen at the level of the response set (i.e., items are processed according to the stimulus-response mapping of the alternative task) or at the level of the abstract task set. Given that in the present research, responses to each of the two tasks were assigned to different hands, it is unlikely that reactivation of the emotion task happened at the response level in the non-emotional task. Instead, it appears that it happened at the level of the abstract task set.

As mentioned above, the data suggested that the reactivation of the competing task set not only affected switch trials from the emotional to the non-emotional age task set but also repeat trials in the age task. It is not clear whether the effect observed for repeat trials was only a short-term “spill-over” from switch trials or whether it reflected a longer-lasting reactivation effect. In the present study, only one repeat trial per task was included, as participants had to switch every two trials. Thus, it is difficult to evaluate the durability of the effect. Future studies could test whether the reactivation of the competing task set diminishes with an increasing number of repeat trials or not (e.g., when participants have to switch every four vs. every two trials). The former would speak in favour of a short-term effect, whereas the latter would suggest that there is sustained reactivation of the competing task set. It should also be noted that despite the present study's focus on the effects of emotion on performance in different task sets, it is possible that the stimuli always triggered the competing task set (e.g., faces triggered age processing in the emotion task in Experiment 5.1 and gender processing in the age task in Experiment 5.2). However, since it was not the goal of the present study to compare the effects of emotion with effects of other stimulus features (e.g., age, gender etc.) and their ability to trigger competing task sets, no conclusions regarding this can be made. This topic could be further assessed in future research.

No age-related differences in the effects of task-irrelevant emotion on task switching

This research was the first to examine the effects of emotion on task switching in ageing and the findings suggest that the engagement and reconfiguration of a non-emotional task set in the presence of emotional items was similarly affected in older and younger adults. There was no evidence that emotional and particularly happy faces facilitated engagement and reconfiguration of a relevant task set in older adults relative to younger adults. Similarly, there was no evidence that disengagement from a currently irrelevant task set was affected by emotion in any of the two age groups. Overall, this research showed that age-related differences in the effects of emotion on cognitive performance did not extend to local task switching. The study also showed that age-related differences in local task switching were restricted to a speed-accuracy trade-off in older relative to younger adults.

Two theoretical approaches are usually considered when evaluating the presence or absence of age-related differences in the effects of emotion on cognition as discussed in Chapter 2.4. On the one hand, the SST (Carstensen, 1993) suggests that older adults use cognitive resources to focus on emotional and particularly positive information in order to enhance their emotional wellbeing. On the other hand, there are approaches linking older adults' preference for positive emotion with age-related cognitive decline such as the dynamic integration theory (Labouvie-Vief, 2003, 2009b; Labouvie-Vief & González, 2004). The data obtained in the present research suggest that both age groups were able to perform the task and that older adults were slower but also more accurate than younger adults. The older adults' very high accuracy rates in the two experiments in fact suggest that they were not functioning at the limit of their cognitive capacity and that additional cognitive resources might have been available.

Despite this availability of cognitive resources, emotion did not affect older and younger adults differently, which does not directly support SST. However, the results are still reconcilable with this theoretical framework as, according to the SST, emotional biases are usually observed when there are no constraints on the participants' processing (Reed & Carstensen, 2012). In the present study, specific instructions were used to direct the participants' attention to particular item features (i.e., emotion, age or gender of faces). Thus, it is possible that no emotional biases in older adults' task switching performance were observed as their goal to regulate their emotions was supplanted by the task instructions.

In contrast, the data are fully compatible with theories linking emotional biases with cognitive decline in ageing. As the task was not too difficult for older adults, it is likely that no compensation for insufficient cognitive resources through biased processing of emotional material was needed. However, as it is difficult to draw substantiated conclusions on the basis of null findings, future studies should explore whether changes in the effects of emotion on task-switching performance in ageing can be found with higher levels of task difficulty.

Overall, the results are in line with research showing that local task switching is largely unaffected in ageing (for a meta-analysis, see Wasylyshyn et al., 2011). Given previous research showing that age-related deficits in local task switching can be observed under certain circumstances (Kray et al., 2002; Meiran et al., 2001; Reimers & Maylor, 2005), it is possible that the current paradigm was not sensitive enough to reveal these age-related changes. For instance, Kray and colleagues (2002) found age-related changes in local task switching when the number of relevant task sets was increased and when task cues were unpredictable. This suggests that age-related differences in local task switching vary as a function of cognitive load and task uncertainty. Further studies could help to elucidate whether task-relevant and task-irrelevant emotion can affect local task switching in younger and older adults differently under conditions of greater cognitive load or under conditions of uncertainty.

Conclusion

To conclude, the experiments presented in this chapter contributed to research on the effects of task-relevant and task-irrelevant emotion on task switching in ageing. The study revealed that task-irrelevant emotion impaired the configuration of a non-emotional task set in both age groups. This was only observed when participants had to switch between an emotional and a non-emotional task set. This suggests that the impairment through task-irrelevant emotion in the non-emotional task was due to the reactivation of the competing emotional task set. In contrast, emotion did not affect task set reconfiguration if it was completely irrelevant for both task sets, with no age-related differences. The results of the present research suggest that local task switching is preserved in ageing and that older adults are not more susceptible to impairments through task-irrelevant emotion than younger adults.

Chapter 6: General discussion

The work presented in this dissertation was carried out to examine how emotional information affects performance in tasks tapping into different executive functions and how these emotion-cognition interactions change with age. The goal of this chapter is to present the main findings and to consider the results' implications for current research and our understanding of cognition-emotion interactions in ageing. To achieve this goal, a summary of the most important findings will be provided in section 6.1, followed by a discussion of the present research's contributions in section 6.2. In section 6.3, the implications of the present results will be considered by discussing how they can inform existing theories on cognitive ageing, emotional aging and the interplay between cognition and emotion. In section 6.4, limitations of the present research will be considered and directions for future research will be suggested. The chapter will close with a final conclusion in section 6.5.

6.1. Summary of the main results

The present research focused on updating, inhibition, and task switching in younger and older adults and it was observed that the effects of age and emotion varied across these three executive functions. An overview of the most important findings is presented in Table 6.1.

One important finding was that the effects of ageing were not uniform across the three examined executive functions. Updating was the only function that was generally affected by ageing. Two n-back experiments (Experiments 3.1 and 3.2) showed that older adults were both slower and less accurate when updating information in WM than younger adults. It was also found that their performance was disproportionally affected by increased WM load compared to younger adults (Experiment 3.1). Moreover, task-irrelevant lures had a more detrimental effect on updating in older compared to younger adults (Experiment 3.2), which suggests that older adults were less able to flexibly bind and unbind information in WM, relying to a greater extent on familiarity relative to younger adults.

On the other hand, other executive functions showed less pronounced age-related changes and there was no general impairment in older relative to younger adults. Across three Stroop experiments, which examined age-related changes in inhibition and proactive control, it was observed that both younger and older adults were able to adjust to task demands and to deploy proactive control if needed. The patterns of accuracy and RT performance across three experiments revealed that older adults were overall slower but that they were either equally accurate (Experiments 4.2 and 4.4) or even more accurate (Experiment 4.1) than younger adults. It was also found that older adults were not more susceptible to interference than younger adults in general. However, older adults were more affected by interference when angry targets were presented under conditions requiring high levels of proactive control (Experiment 4.2). This suggests that despite no overall decline in proactive control, they deployed proactive control less efficiently in the presence of resource-demanding material than younger adults. Lastly, local task switching was found to be unaffected by ageing: In two task-switching experiments (Experiments 5.1 and 5.2), older and younger adults showed similar performance despite evidence of a speed-accuracy trade-off in older adults.

Table 6.1. *Summary of results reported in this thesis*

Executive function	Age-related effects	Emotion-related effects	Age × emotion interaction
Updating			
Experiment 3.1: N-back task with task-relevant or task-irrelevant emotional faces	Detection sensitivity: YA > OA; RTs: YA < OA	Task-relevant emotion: Detection sensitivity: happy > neutral > angry; RTs: happy < neutral < angry for matches and happy < neutral > angry for non-matches	Task-relevant emotion: RTs in 1-back task: happy < neutral > angry for non-match trials in OA but not in YA
		Task-irrelevant emotion: Detection sensitivity: happy = neutral = angry; RTs: happy = neutral = angry for matches and non-matches	Task-irrelevant emotion: No age × emotion interaction
Experiment 3.2: N-back task with angry and neutral face lures	ACC: YA > OA; RTs: YA < OA	ACC: lower for probe if 3-back lure had same emotional valence RTs: negative < neutral probes	ACC: angry > neutral probes in OA but not in YA; ACC lower for probes if lures had same emotional valence in OA but not in YA; RTs slower if lures were angry rather than neutral in OA but not in YA; ACC lower and RTs slower for angry 2-back targets in OA but not in YA
Experiment 3.3: N-back task with task-relevant emotional words	N/A	ACC: negative > neutral > positive RTs: negative < neutral = positive	N/A

Inhibition			
Experiment 4.1: Neutral colour-word Stroop	ACC: YA < OA; RTs: YA < OA Proactive control in YA and OA	N/A	N/A
Experiment 4.2: Emotional Stroop with target faces	ACC: YA = OA RTs: YA < OA Proactive control in YA and OA	ACC: happy > neutral > angry RTs: happy < neutral = angry	ACC under conditions of high proactive control: YA but not OA showed facilitation for congruent angry faces; OA but not YA showed interference from incongruent angry faces
Experiment 4.3: Emotional Stroop with target faces (no preview)	N/A	ACC: happy = neutral > angry RTs: happy < neutral = angry	N/A
Experiment 4.4: Emotional Stroop with target words	ACC: YA = OA; RTs: YA < OA Proactive control in YA and OA	ACC: negative > neutral = positive	ACC under conditions of high proactive control: YA but not OA showed interference from incongruent neutral faces
Task switching			
Experiment 5.1: Switching between emotional and non-emotional task sets	ACC: YA < OA; RTs: YA < OA	RTs for switches to the non-emotional task set were slower when the target was emotional compared to a neutral target	No age × emotion interaction
Experiment 5.2: Switching between non-emotional task sets with task-irrelevant emotion	ACC: YA < OA; RTs: YA < OA	No emotion effects	No age × emotion interaction

Note. ACC = accuracy, YA = younger adults, OA = older adults

Taken together, these results suggest that the often-postulated executive functions updating, inhibition, and task switching do not undergo the same age-related changes. Whereas updating showed pronounced age-related changes, proactive control and switching between two tasks were not generally impaired in ageing, but age-related differences in the ability to override irrelevant information emerged under particular task demands.

Another important finding was that emotion affected performance across all the tasks in the present research, but that the effects of emotion were not uniform. Moreover, despite some common effects in both age groups, emotion affected performance in younger and older adults differently on a majority of the tasks used. It was found that happy faces facilitated performance in an n-back task (Experiment 3.1) and in a Stroop task (Experiment 4.2) in both age groups: Younger and older adults were faster and more accurate when they responded to happy faces relative to neutral or angry expressions. In contrast, a more complex picture emerged for angry faces: On the one hand, there were facilitating effects of angry faces, as older adults were faster to replace old representations with angry (as well as happy) relative to neutral faces in a 1-back task (Experiment 3.1). Younger adults did not show this benefit. On the other hand, impairing effects were also observed in a 2-back task, as older but not younger adults were overall slower when lures or 2-back targets were angry rather than neutral (Experiment 3.2). It was also found that older adults deployed proactive control less successfully in the presence of angry targets, whereas younger adults did not show this impairing effect (Experiment 4.1).

In contrast, no age-related differences in the effects of emotion were found for task switching. When participants had to switch from an emotional to a non-emotional task set in Experiment 5.1, it took both younger and older adults longer to perform the switch in the presence of emotional relative to neutral items. Overall, it appears that tasks tapping into executive functions are sensitive to the facilitating and impairing effects of emotion and that these effects are not uniform in younger and older adults.

In sum, the studies presented in this dissertation revealed that the effects of age and emotion vary for the three executive functions and that these two factors can also interact in unique ways. In the next section, the contribution of the present research to the understanding of how executive functions interact with emotion and ageing will be discussed in more detail.

6.2. Contributions of the present research

As highlighted in Chapter 2.2, the effects of emotion on executive functions have received limited attention to this date. Studies have focused primarily on how emotion affected the ability to maintain rather than manipulate information in WM and were mainly concerned with the impairing effects of negative and task-irrelevant emotional material (for reviews, see Dolcos & Denkova, 2015; Dolcos et al., 2011; Dolcos & McCarthy, 2006; Dolcos et al., 2014; Iordan et al., 2013). In contrast, the present research systematically examined the effects of emotion on updating, inhibition, and task switching in two age groups. It also investigated how the task relevance, valence or arousal and the stimulus domain of emotional material affected cognitive performance in two age groups. This research contributed to the following insights.

Task relevance modulates the effects of emotion on executive functions

The present research showed that emotion has to be part of the task goal to affect executive functions. In contrast, no difference between the effects of emotional and neutral information on performance was observed when emotion was not part of the task goal. For instance, when participants had to respond to the emotional expressions in an n-back task in Experiment 3.1, it was found that happy expressions improved updating in both younger and older adults. In contrast, the same experiment revealed that when participants had to respond to the age of the faces, performance was unaffected by the task-irrelevant expressions, including happy expressions. Similarly, it was found that emotion affected task switching in both younger and older adults when it was part of the two relevant task sets participants had to switch between (Experiment 5.1). In contrast, consistently task-irrelevant emotion did not affect switching between non-emotional task sets in any of the two age groups (Experiment 5.2).

The results are in accordance with theories linking emotional functioning with executive functioning such as the dual competition model by Pessoa (2009, 2015, 2017) or the extension of Baddeley and Hitch's WM model by a hedonic detector (Baddeley, 2007; Baddeley et al., 2012). Whereas the latter does not specify the exact interaction, the dual competition model (Pessoa, 2009, 2015, 2017) suggests that task-relevant emotion can help to improve performance through the recruitment of additional processing resources. However, the suggestion that task-irrelevant information can impair executive functions through detraction of resources (Pessoa, 2009, 2015, 2017) was not supported by the data without further qualification. Participants' performance was in fact unaffected by consistently task-irrelevant emotional information in an n-back task (Experiment 3.1) and in a task-switching paradigm (Experiment 5.2). Despite evidence that emotional processing is automatic (Öhman, 2002; Pessoa & Ungerleider, 2004a; Vuilleumier, 2005; Vuilleumier et al., 2001; Whalen et al., 1998), it appears that emotion did not "automatically" affect or impair executive functions. Instead, some level of intentional processing was needed in order to observe emotion-cognition interactions, which will be explained in the following.

The evidence obtained in this research indicates that task-irrelevant emotion impaired executive functions only when the status of emotional content oscillated between being task-relevant and task-irrelevant on a trial-by-trial basis. In a 2-back updating task in Experiment 3.2, there was a slowdown in older but not in younger adults' responses when angry lures were part of the sequence they had to respond to. Although the lures were currently irrelevant for the response, they had either been relevant in the previous trial (i.e., 3-back lures) or would be relevant in the subsequent trial (i.e., 1-back lures). Participants' attention was also directed to the items' emotional features (i.e., the emotional expression) in the 2-back task and thus, they could not simply ignore them.

A similar pattern was observed for task switching in Experiment 5.1, when participants had to switch between responding to the emotional and non-emotional item features. Task-irrelevant emotion affected performance in both age groups, but only when emotion was relevant for one of the tasks in the block. In contrast, task-irrelevant emotion did not have such an effect when it was consistently irrelevant for all tasks in a block (Experiment 5.2). Overall, these results suggest that task-irrelevant emotion can impair executive functions when emotion is part of the overall task goal. If consistently irrelevant, the participants' ability to shield task performance does not seem to depend on the emotionality of the distractor. This needs to be taken into account when further investigating the effects of emotion on executive functioning in future research.

It should be noted that the relevance of emotion for the task was not systematically varied in the Stroop experiments presented in the present dissertation. Instead, emphasis was placed on task-relevant emotional material in the present research. Although this does not allow comparing the effects of task-relevant and task-irrelevant emotional material, the Stroop results confirmed that task-relevant emotional material facilitated executive functioning (Experiments 4.2 to 4.4). However, impairing effects of task-relevant emotional information were found for older adults, which will be discussed in more detail below.

Age modulates the effects of emotional valence on executive functions

The present research used positive and negative stimuli that were balanced in arousal, which allowed the independent assessment of the effects of arousal and valence on executive functions. The dual competition model suggests that arousal plays an important role in the modification of executive functions (Pessoa, 2009, 2015, 2017) and the results of the present research partly supported this claim: It was found that both younger and older adults were slower to switch to a non-emotional task set when the new stimulus was emotional rather than neutral. This result was observed for both angry and happy faces (Experiment 5.1). It should be noted, however, that the majority of results obtained for inhibition and updating hinted at an effect of valence rather than arousal on executive functions.

Differential effects of positive and negative stimuli were particularly apparent when emotional faces were used, as the facilitating effects of happy faces were not found for neutral or angry faces. When participants had to respond to the expression of emotional faces in an updating task in Experiment 3.1, both younger and older adults showed greater detection sensitivity and faster RTs for happy compared to neutral or angry faces. In contrast, detection sensitivity was lowest and match RTs were slowest for angry faces (although it should be noted that a less straightforward pattern for RTs was observed for non-match responses across different WM loads, see Chapter 3.3). A similar pattern of results emerged in studies using emotional Stroop tasks, as younger (Experiments 4.2 and 4.3) and older adults (Experiment 4.2) were more accurate and faster when they had to respond to happy compared to neutral or angry targets. In contrast, all three experiments showed that accuracy was particularly low for angry faces, whereas RTs did not differ between responses to angry and neutral faces. These results suggest that happy faces facilitated performance, whereas angry faces impaired performance. More generally speaking, when emotional faces were used, the pattern of results pointed to an effect of valence rather than arousal.

The effects of happy and angry faces deserve further attention as they not only highlighted the differential effects of emotional expressions on cognitive performance in younger and older adults but also the differential effects of emotional faces on different dependent measures of executive functions (i.e., accuracy and RTs). Happy faces facilitated performance in the n-back task (Experiment 3.1) and in the Stroop task (Experiment 4.2) in both age groups across both dependent measures: participants were more accurate and faster when they responded to happy compared to neutral or angry faces. The auxiliary analyses of data from Experiment 3.1 (see Chapter 3.4) also suggested that replacing happy faces in WM was less effortful than replacing angry faces. This facilitating "happy face advantage" is consistent with findings that happy faces are more quickly and accurately recognised compared to other expressions (Becker et al., 2011; Becker & Srinivasan, 2014; Juth et al., 2005). They also link well with research showing that smiling faces are perceived as rewarding (O'Doherty et al., 2003; Otta et al., 1996; Tsukiura & Cabeza, 2008). Given evidence that reward can improve executive functioning through efficient orienting of attention and the allocation of additional resources (Pessoa, 2009, 2015, 2017), it appears that efficient perceptual processing and the rewarding nature of happy faces helped to improve executive functions.

In contrast, the present research showed that angry faces had a far more mixed pattern of effects on executive functions, and these mixed effects were particularly pronounced in older relative to younger adults. On the one hand, it was found that angry faces impaired performance: When participants had to update information in an n-back task, the lowest detection sensitivity and slowest match responses were found for angry faces in both age groups (Experiment 3.1). It was also found that older adults were slower to respond when angry lures were part of a sequence in a 2-back task, whereas no such effect was found in younger adults (Experiment 3.2). On the other hand, it was found that angry faces facilitated some aspects of performance: Participants made faster non-match responses to angry than to neutral faces and older adults showed this effect consistently (Experiments 3.1 and 3.2; younger adults showed this speed-up effect in Experiment 3.2).

Thus, it appears that angry expressions can have both beneficial and impairing effects on executive functions. Moreover, the effects of angry faces on task performance varied for the two dependent measures (i.e., accuracy and RTs). Angry faces tended to reduce accuracy compared to neutral or happy faces across a number of experiments (see Experiments 3.1, 4.2, 4.3), whereas there was no difference in RTs between neutral and angry faces (see Experiments 4.2, 4.3). These contrasting effects of angry faces on accuracy and RTs were observed in both age groups, with the impairment in accuracy being particularly pronounced for older adults (Experiment 4.2).

Overall, it appears that task-relevant happy faces facilitated executive functioning in a consistent manner, whereas the effects for angry faces varied with task requirements. Facilitating effects of angry faces were only observed when participants responded to non-match trials in two n-back tasks (Experiments 3.1 and 3.2), suggesting that the identification of a non-match was more readily achieved for emotional items. This might be related to findings that the detection of emotional faces among distractors is particularly efficient for angry faces, which has been interpreted as an evolutionary benefit of detecting threat (Hansen & Hansen, 1988; Öhman et al., 2001). In contrast, it appears that further manipulation, including binding and unbinding of information in WM or shielding WM performance from interference of task-irrelevant material, was impaired in the presence of threatening material in older adults. This is possibly due to the fact that threat detracts cognitive resources needed for WM operations (Pessoa, 2009), and this might have greater detrimental effects in older relative to younger adults due to their overall reduced availability of cognitive resources (e.g., Braver & West, 2008; L. H. Phillips & Henry, 2008; Reuter-Lorenz & Sylvester, 2005; Salthouse, 1990). It is also possible that the differential pattern of results for accuracy and RTs in the presence of angry faces were due to this dichotomy: angry faces were detected efficiently, granting relatively fast responses, but resources were detracted from the ongoing task in their presence, making participants more prone to errors. Overall, these results suggest that valence needs to be taken into account when assessing the effects of emotion on executive functions, particularly when age-related changes are of interest.

The effects of emotion on executive functions are modality-specific

The majority of experiments presented in this dissertation used emotional faces as experimental stimuli. These experiments showed that happy faces facilitated performance (Experiments 3.1 and 4.1), whereas angry faces had a mixed effect on performance, with more prevalent impairing effects (Experiments 3.1, 3.2, 4.2, 4.3). In contrast, the effects of emotional words on performance were found to be reversed: In an n-back task with negative target words, younger adults showed greater detection sensitivity and faster RTs when responding to negative relative to neutral and positive words (Experiment 3.3). In a Stroop experiment with emotional target words, both younger and older adults responded more accurately to negative relative to neutral and positive words, whereas RTs for negative and positive words did not differ (Experiment

4.4). In sum, facilitating effects were consistently observed for happy faces, whereas the pattern was reversed in experiments with verbal stimuli, as negative words had facilitating effects on executive functions.

These results add to growing evidence that the effects of faces and words on processing and cognition are diverse. Previous studies that focused on the processing of emotional stimuli (Kensinger & Schacter, 2006; Rellecke et al., 2011) and attention for emotional stimuli (Vuilleumier, 2005; Vuilleumier & Huang, 2009) reported that orienting to emotional material was more pronounced for faces than for words (Kensinger & Schacter, 2006; Rellecke et al., 2011; Vuilleumier, 2005). These differences were usually explained with reference to the biological preparedness of emotional faces in contrast to verbal stimuli: It was suggested that the emotional significance of faces could be extracted based on perceptual features (Vuilleumier, 2005; Vuilleumier & Huang, 2009), whereas emotional significance needs to be extracted based on semantic knowledge from words (Kensinger & Corkin, 2003; Rellecke et al., 2011; Schacht & Sommer, 2009).

Assuming that the orienting to emotional faces is enhanced relative to emotional words due to the biological preparedness of the former, it could be expected that the effects of faces and words would differ in magnitude, with a stronger effect predicted for faces (cf. Kensinger & Corkin, 2003). However, the present research showed that faces and words were not associated with effects that differed in size but in their overall qualitative pattern. It is possible that extracting emotional significance by using semantic knowledge modified the effects of emotion on cognition not in a quantitative but a qualitative way. To gain a better understanding why differences in the effects were observed for faces and words, emotional pictures could be included in future research. These allow the extraction of emotional significance through perceptual features but can convey the same meaning as words (e.g., picture of bomb rather than word “bomb”). Similar findings between pictures and words would indicate that faces are special in their effect on executive functions, which could be due to their evolutionary importance. In contrast, similar effects between pictures and faces would suggest that the extraction of emotional significance through perceptual features or semantic knowledge is relevant for the effect of emotion on executive control.

Other or additional factors might also have played a role in the differential effects observed for faces and words. For instance, differences in the perception of threat and reward in faces and words could have contributed to the contrasting pattern of findings for these stimulus sets, which can be explained by grouping the stimuli according to valence. As suggested in Chapter 3.6, differences in the effects for angry faces and negative words might be due to the higher levels of threat associated with angry faces relative to negative words. The level of threat conveyed by faces might be higher and thus more detrimental to cognitive performance. In contrast, negative words might benefit from lower and thus beneficial levels of threat. This is in line with the dual competition theory, according to which executive functions can be improved by low levels of threat but impaired by high levels of threat (Pessoa, 2009, 2015, 2017). Following the same line of argument, differential effects for happy faces and positive words might be due to the perceived level of reward. It is possible that happy faces were associated with reward, which contributed to the facilitating effect of smiling faces. In contrast, it is possible that positive words were, despite some rewarding value (Hamann & Mao, 2002), not rewarding enough as to have a facilitating effect on performance.

Other relevant factors could be the conceptual size of the stimulus categories, with faces coming from a small pool of similar stimuli and words from a large pool of dissimilar stimuli. It is also possible that differences in spatial frequencies between the visual input of faces and words contributed to differential effects of emotion on executive functions. Previous research has shown that distinct neural channels are involved in the processing of high and low spatial frequency information from visual input (Vuilleumier, Armony, Driver, & Dolan, 2003), which might modulate the effect of emotional stimuli.

It is, however, difficult to evaluate whether or how these factors contributed to the observed pattern of results. Stimulus sets for emotional items such as the International Affective Picture System (IAPS; Lang, Bradley, & Cuthbert, 2008) or ANEW (Bradley & Lang, 1999) provide evaluation ratings that are restricted to factors such as valence and arousal (and other domain-specific factors such as word frequency). Other ratings on dimensions such as biological preparedness, reward, threat or spatial frequency are not available to this date. This makes the comparison across different stimulus sets difficult. The present research suggests that while no comprehensive comparisons across different stimulus sets are possible, conclusions from studies on emotion-cognition interactions are limited to the stimulus set that was used in the particular experiment.

6.3. Implications of the present research for existing theories

As discussed in Chapter 2.3, there are a number of theoretical frameworks that were proposed to explain how ageing affects executive functions, how executive functions interact with emotion and how emotional functioning changes with age (see Table 2.1). Although the latter theories hint at the role of cognitive functioning, the theoretical frameworks focus mostly on two factors rather than considering the interplay between executive functions, emotion, and ageing. With all three factors included in the present research, the results can help to evaluate the scope and validity of existing theories. In the following, these will be discussed and possible extensions will be suggested where appropriate.

Executive functions in ageing

One common element of theories that are concerned with age-related changes in executive functioning is that they focus on global, general trends in cognitive development. Whereas the frontal lobe theory (Dempster, 1992; Moscovitch & Winocur, 1992, 1995; Robbins et al., 1998; Troyer et al., 1994; West, 1996) proposes that age-related changes in the frontal lobes of the brain are associated with a decline in executive functioning, the goal maintenance theory (Braver & West, 2008) suggests that this decline is associated with older adults' overall difficulty to maintain goals. Similarly, the inhibition account of cognitive ageing (Hasher & Zacks, 1988; Hasher et al., 1999; Zacks et al., 1996) not only suggests that there is a global decrease in the efficiency of inhibitory processes, but also proposes that it could underlie other age-related changes in a wide range of cognitive tasks.

However, given this research's results highlighting the variable nature of age-related changes in different executive functions, a global approach seems unsuitable to explain the pattern of results across different executive functions. In the present research, three widely acknowledged executive functions tasks were used to examine executive functions in ageing and only the n-back task, targeting updating in WM, revealed pronounced age-related changes. In contrast, differences in Stroop performance and in task switching were largely due to age-related slowing or to a speed-accuracy trade-off in older adults. It should be noted that there were age-related differences in how emotion affected executive functions, which became apparent when investigating updating and interference. However, the three aforementioned theories do not allow drawing any conclusions about the role that additional factors such as emotion can play in executive functions in ageing.

Overall, it appears that more specific theories targeting specific functions of interest instead of an approach focusing on commonalities across these are better suited to shed light on age-related differences in executive functioning. The results also indicate that not only specific tasks tapping into different executive functions were needed but also detailed task analysis to understand the nature of age-related differences in performance. Moreover, the results also highlighted that the inclusion of emotion can actually help to assess age-related differences. For instance, in Experiment 3.1, older adults showed overall poorer performance on both match and non-match trials relative to younger adults. However, a differential effect of emotion in younger and older adults only occurred for non-match but not for match trials. This observation led to further analyses and to an additional follow-up experiment (Experiment 3.2), which revealed difficulties in older but not younger adults to perform a 2-back task when angry lures had to be manipulated in WM and when lures had the same emotional valence as current probes. These results highlighted age-related difficulties to flexibly bind and unbind information in WM particularly in the presence of resource-demanding stimuli. They also showed that the inclusion of emotional material in cognitive tasks can help to identify age-related differences that might otherwise be more difficult to detect.

Similarly, the inclusion of emotion revealed age-related differences in the ability to exhibit proactive control in the presence of angry target emotion (Experiment 4.2). It was observed that older adults were more affected by distraction under conditions that required high levels of proactive control when angry faces were presented, whereas younger adults did not show this effect. Despite no overall difference in proactive control, the inclusion of emotional material helped to reveal that older adults deployed proactive control less efficiently than their younger counterparts under particular conditions.

Executive functions and emotion

The results presented in this dissertation can also help to evaluate theories that were suggested to explain how emotion and executive functions interact. One theory that has been proposed to explain interactions between emotion and executive functions is the dual competition model (Pessoa, 2009, 2015, 2017). According to this theory, stimulus-driven emotion affects executive functions by recruiting common-pool resources, which are shared between executive functions and processing. An important role in the effects of emotion on executive control is assigned to arousal and the relevance of emotion for the task. Pessoa suggests that on a neural level, task networks (e.g., attentional network) and valuation networks (e.g., in the orbitofrontal cortex) communicate and interact (Pessoa, 2015, 2017). The theory does not consider age-related changes in the emotion-cognition interaction, but acknowledges that individual differences in state and/or trait anxiety and sensitivity to reward can modulate this interaction.

The dual competition framework can be helpful to explain results from individual experiments but the overall pattern of results is less reconcilable with this model. Important issues include the model's claims that the effects of emotion are driven by arousal and that task-irrelevant emotion can impair executive functions. Moreover, the model focuses on unitary aspects of executive functions without specifying how the effects of emotion might differ between them. In the following, the shortcomings will be discussed in more detail.

It should be noted that the results obtained in the present research cannot be explained by attributing the effects of emotion to arousal. Instead, it appears that valence needs to be considered as an additional factor: When facial stimuli were used, it was found that happy faces facilitated performance, whereas angry faces had a mixed and predominantly impairing effect, particularly in older adults. In contrast, when verbal stimuli were used, improvements in performance were observed for negative relative to neutral words, but not for positive words relative to neutral words. It is possible that arousal effects were underlying the results observed but that additional mechanisms also played a role, at least for one of the valence categories.

In terms of the role of task relevance of emotional information, the present findings support the model's suggestion that it is indeed important whether emotion is task-relevant, as it was found that only task-relevant emotional material affected performance. However, the model suggests that task-irrelevant emotional information can impair cognition and that the impairing effect will increase with higher arousal. These impairing effects of task-irrelevant emotional material were not observed in the present research. The results only remain reconcilable with the model's prediction if it is assumed that the emotional material used in the present research was relatively low in arousal. As examples of highly arousing material included shocks (Pessoa et al., 2012), it is possible that the material in the present research was not arousing enough to qualify as highly arousing within the dual competition framework.

Lastly, it is important to note that, despite the fact that emotion affected all three executive functions in the present research, the effects were not uniform. The dual competition model acknowledges a fractionation of the central executive and explicitly considers updating, inhibition, and shifting in reference to the model by Miyake et al. (Miyake & Friedman, 2012; Miyake et al., 2000). However, it focuses on the unitary aspects of executive functions and suggests that emotion affects them by recruiting common-pool resources that they share. As the theory does not make any assumptions about differential effects of emotion on individual executive functions, this general approach is difficult to reconcile with the effects observed in the present research.

Another attempt to account for interactions between emotion and executive functions was the extension of Baddeley and Hitch's (1974) WM model by the hedonic detector (Baddeley, 2007; Baddeley et al., 2012). The hedonic detector is understood as a system that helps to assess information and to choose appropriate actions according to their hedonic value. According to this approach, the hedonic detector has some storage capacity and depends on the central executive, as it needs to discriminate and judge between different possible actions in complex situations (Baddeley et al., 2012).

As both the concept of the hedonic detector and its interaction with the rest of the WM model's components were circumscribed in relatively broad terms, the emotion-cognition interactions observed in this dissertation can be reconciled well with the extended WM model. Given that the central executive was declared compatible with the existence of sub-functions (Baddeley, 1998, 2002) and that it was suggested to be important for the functioning of the hedonic detector, the findings of differential effects of emotion on executive functions are compatible with this model. It was also suggested that the hedonic detector has a neutral setting, which is needed to provide positive and negative evaluations (Baddeley et al., 2012). Thus, it is well compatible with the findings of the present research showing that valence affected executive performance. Furthermore, Baddeley et al. (2012) suggested that the hedonic detector is capable of assessing stimuli in order to choose most appropriate actions, which does not claim that task-irrelevant emotion could affect cognition but neither excludes this option. This is in line with the findings of this research showing that task-irrelevant material only played a role when it was part of the overall task goal and not when it was completely irrelevant. Although it appears that the concept of the hedonic detector within the WM model captures the pattern of results observed in this dissertation relatively well, modifications can be suggested to account for observed age-related differences. These will be discussed in the following section.

Interactions between executive functions and emotion in ageing

In both the dual competition model (Pessoa, 2009, 2015, 2017) and the WM model with a hedonic detector (Baddeley, 2007; Baddeley et al., 2012), it is acknowledged that individual differences may play an important role in the interaction between emotion and cognition. Based on the results observed in this dissertation, it is apparent that age-related differences also need to be considered.

The dual competition model (Pessoa, 2009, 2015, 2017) does not specify how the interaction between executive functions and emotion might change in ageing despite evidence that ageing affects brain regions that are involved in the attentional and valuation networks identified in this model. For instance, the model suggests that part of the direct pathways connecting the task and valuation networks are those between the lateral surface of the prefrontal cortex and cingulate regions (e.g., Pessoa, 2015). These pathways explicitly include the dorsolateral prefrontal cortex, which has been consistently identified in research on cognitive ageing as a region in which age-related changes in activity during WM performance can be found (MacPherson et al., 2002; Reuter-Lorenz & Cappell, 2008b; Rypma, Prabhakaran, Desmond, & Gabrieli, 2001; Turner & Spreng, 2012). These age-related changes in the dorsolateral prefrontal cortex might affect the pathways between task and valuation networks. Moreover, theories such as the Hemispheric Asymmetry Reduction in Old Adults (HAROLD; Cabeza et al., 2002), the posterior-anterior shift in ageing (PASA; Davis et al., 2008) or the Compensation-Related Utilization of Neural Circuits Hypothesis (CRUNCH; Cappell et al., 2010; Reuter-Lorenz & Cappell, 2008b) suggest that ageing is associated with a reorganisation of neurocognitive networks, possibly as a compensation mechanism for age-related brain changes including grey and white matter atrophy, blood flow reductions etc. These age-related changes in neural functioning and the reorganisation of neural networks could have important implications for the interplay between attentional and valuation networks proposed by the dual competition model and thus are likely to affect interactions between executive functions and emotion.

Age-related changes should also be taken into account in an extension to the hedonic detector in WM (Baddeley, 2007; Baddeley et al., 2012). Baddeley et al. (2012) proposed that the hedonic detector has a storage system and that it relies on the central executive. Thus, any age-related changes in the detector's storage capacity or the central executive are inevitably going to affect emotion-cognition interactions. It is also possible that the calibration of the hedonic detector differs between younger and older adults. This is possible as there were age-related differences in performance in the presence of angry faces: Although angry faces facilitated some aspects of performance (older adults made faster non-match responses to angry than to neutral faces in the n-back tasks in Experiments 3.1 and 3.2), impairing effects of negative material were greater in older than in younger adults. For instance, older adults were slower to respond when angry lures were part of a sequence in a 2-back task, whereas no such effect was found in younger adults (Experiment 3.2). Also, older adults were found to use proactive control less successfully in the presence of angry faces compared to younger adults in a Stroop task (Experiment 4.2).

However, a recalibration of the system through a simple shift of the neutral point in ageing (for instance in a positive direction) does not seem to capture the data sufficiently well as no corresponding improvement in performance for positive material was observed. A one-dimensional approach with a positive and negative pole and a neutral point somewhere in-between might be less appropriate to capture the pattern of results. Instead, a two-dimensional space between a positive and a negative dimension might be more appropriate, with greater age-related changes on the negative dimension.

Alternatively, it is also possible that age-related differences for negative but not for positive material were observed, as these items affect the detector's storage system to different degrees. Potentially, negative items such as angry faces put a greater strain on the detector's storage capacity than positive material. This is in line with other research highlighting the more demanding nature of negative information in a wide range of stimuli (Fox et al., 2001; Garcia et al., 2012; Hansen & Hansen, 1988; Ito, Larsen, Smith, & Cacioppo, 1998; Peeters & Czapinski, 1990; Taylor, 1991). Assuming that the capacity is reduced in older relative to younger adults, this could explain a breakdown in older adults' cognitive performance in presence of angry faces.

This hypothesis also links well with the dynamic integration model (Labouvie-Vief, 2003, 2009b), which suggests that older adults tend to avoid negative affect as they have fewer cognitive resources to process and integrate it. Thus, it is possible that impairments in the presence of angry faces became apparent in executive functions tasks that put high demand on older adults' cognitive abilities and did not allow them to direct attention away from negative material. This explanation seems particularly compelling, as the most pronounced age-related differences in cognition-emotion interactions were observed in the n-back task, in which older adults showed overall poorer performance compared to younger adults (Experiments 3.1 and 3.2). In contrast, there were no age-related differences in emotion-cognition interactions in tasks in which older and younger adults performed equally well (e.g., task switching tasks, Experiments 5.1 and 5.2).

In contrast, the results observed in the present research are less compatible with the SST (Carstensen, 1993), the framework that has often been cited in the context of age-related changes in emotion-cognition interactions. It suggests that older adults selectively direct their attention to positive material, as it is consistent with their emotion regulation goals, resulting in a positivity effect in cognition (e.g., attention and episodic memory). To explain why a positivity effect in cognition was observed in some previous studies but not in others, it was suggested that sufficient cognitive resources needed to be available for older adults to exhibit the effect and that other task goals (e.g., adopted through specific task instructions) could supplant this chronically active goal.

These restrictions can be applied to the present research: The limited capacity of the WM system and the use of specific instructions in each of the experiments are factors that presumably reduced the opportunity to exhibit biased processing in older adults. Indeed, no positivity effect was observed in any of the experiments besides generally faster responses on emotional relative to neutral non-match trials in older but not in younger adults in a 1-back task (Experiment 3.1). In contrast, it was found that both age groups showed better performance when responding to happy faces in tasks targeting updating and inhibition (see summary above). Although this pattern of findings could be interpreted as being consistent with SST, this theory cannot account for the mixed and predominantly impairing effects that angry faces had on older adults' executive functions. With a focus on positive material, SST does not offer a compelling explanation for this pattern of findings relating to negative material.

Overall, it can be summarised that extensions to theories on cognition-emotion interactions are needed to explain the age-related differences observed in this dissertation. The theory of the hedonic detector can account for these differences by accommodating assumptions of age-related changes in the detector's storage capacity, the functioning of the central executive and the calibration of the hedonic detector. These suggested extensions of the framework link well with the dynamic integration model of emotional functioning in ageing. It can also be concluded that the inclusion of emotional material in executive functions tasks does not necessarily help to improve older adults' cognitive performance as the impact of emotion on cognitive performance in older adults was overall mixed. However, the inclusion of emotional material can help to highlight age-related differences in cognitive performance, to shed some light on the mechanisms underlying these differences, and to inform theories on the interactions between emotion, cognition and ageing.

6.4. Limitations and future research

Despite the insights that the studies in this dissertation provided, a number of limitations of the present research are acknowledged. Whereas limitations of specific experiments and possible future studies were mentioned in each chapter's discussion, this section will focus on the more general outlook.

As not many research studies have tested age-related differences in the effects of emotion on executive functions, the aim of the present research was to explore particular aspects of this vast research field. With the inclusion of multiple executive functions in this dissertation and a number of factors in each study, it was possible to observe a general pattern but it was more difficult to examine specific mechanisms. The present research can, however, build a basis for further investigations aimed at examining the findings in more detail. For instance, this research showed that the most pronounced age-related differences in emotion-cognition interactions were observed for updating, an executive function that has been rarely investigated in ageing research to this date. Further studies could help to clarify why some aspects of updating performance in older adults were facilitated by emotion (e.g., identification of an item as a non-match), whereas others were impaired (e.g., responding to a probe with an angry lure). They could also examine whether these results can be replicated in updating paradigms other than the n-back task. Moreover, future studies would benefit from a more detailed analysis of specific executive functions tasks. Although the n-back paradigm is generally understood as a task that taps into updating, it is less clear which individual sub-processes are involved and how the n-back task can help to distinguish between them. A more detailed task analysis can help to shed light on which sub-processes are particularly sensitive to the effects of emotion and ageing.

It should also be noted that in the present research, a focus was placed on designing tasks that were not too difficult for older adults to perform. For instance, relatively long stimulus presentation times and inter-stimulus intervals were chosen, task blocks were kept short and the WM load was relatively low. It is possible that these characteristics masked age-related differences, which would have emerged in more difficult tasks. Given that task difficulty and cognitive load play an important role in theories on age-related changes in emotion-cognition interactions (e.g., the SST), future studies could investigate how increased task difficulty and cognitive load can affect age-related differences in the interaction between emotion and executive functions. Also, finding a good balance between having a sufficiently manageable task for both age groups and long enough task blocks to collect as many data points as possible (for instance, by creating a well-balanced design through pilot studies) will help enhance statistical power and thus increase the chance of detecting even small effects.

As mentioned in this dissertation’s introduction, this research focused on Miyake et al.’s model of executive functions (Miyake & Friedman, 2012; Miyake et al., 2000).

However, other models and theoretical frameworks have been suggested to explain what executive functions are. For instance, two published reviews on executive functioning and ageing (Braver & West, 2008; L. H. Phillips & Henry, 2008) have additionally included functions such as context processing or planning. Future studies could test how cognition-emotion interactions in tasks targeting other executive functions may change with ageing. Despite the popularity of Miyake et al.'s model, it is possible that other frameworks are better suited to investigate age-related changes in executive functions and in emotion-cognition interactions.

Lastly, this research can be taken further by examining how age-related changes in the effects of emotion on executive functions are linked to changes in cognitive as well as emotional functioning in older age. For instance, older adults' greater difficulty to update information in WM, particularly in the presence of angry lures, which was observed in Experiment 3.2, could be related to age-related decline in source memory, given that updating was found to play an important role in memory consolidation (Hupbach, Gomez, & Nadel, 2009). Similarly, research has also shown that the ability to manipulate emotional information in WM, for instance through updating, is linked to the efficacy of emotion regulation (e.g., Levens & Gotlib, 2010). It was beyond the scope of this research to assess whether age-related changes in updating of emotional items (see Experiments 3.1 and 3.2) were associated with age-related changes in mood or emotion regulation. Further studies could investigate this link further, for instance by adding an emotion manipulation component in a WM experiment or by assessing the link between mood at pre- or post-test to performance in an updating task.

6.5. Final conclusion

This dissertation contributed to research differentiating between enhancing and impairing effects of emotion on executive functions in younger and older adults. This research showed that emotion affected performance across the three often-postulated executive functions of updating, inhibition, and task switching, whereas these functions were not found to undergo the same age-related changes. It was also found that despite similar effects of emotion on cognition in both age groups, there were age-related differences. More specifically, it was found that positive emotion improved cognitive performance in both age groups, whereas the impairing effects of negative emotion were particularly pronounced in older adults. The research also highlighted that theories regarding the effects of emotion on executive functions need to be extended to accommodate age-related differences in cognition-emotion interactions.

This research is important as executive functions play an important role for both cognitive and emotional functioning, thus affecting everyday life. Understanding the facilitating and impairing effects of emotion on cognition in ageing can help identifying areas in which emotion can help in buffering age-related WM decline. They can also help in creating interventions that are needed to dampen the impairing effects of emotion on cognitive functioning. These approaches are promising avenues to foster healthy development up to and including very old age.

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Appendices

Appendix A: Evaluation of faces

Ten younger (21 – 32 years old; M = 27.80, SD = 3.12) and ten older adults (66 – 76 years old; M = 71.27, SD = 3.13) rated 234 preselected faces from the FACES database (Ebner et al., 2010). Seventy-eight faces per emotional category (happiness, anger, and neutrality) were included and one-third of the faces were from young adults (19–31 years), one-third from middle-aged adults (39–55 years) and the remaining faces from older adults (69–80 years). Half of the faces were male and the other half were female. The faces were rated on a 9-point Likert scale regarding valence (1 = very unpleasant; 9 = very pleasant) and arousal (1 = not arousing; 9 = very arousing) and raters were also asked to estimate the age of the presented face. Valence and arousal ratings were ranked according to difference scores of younger and older adults' ratings. Data from this rating study indicated that all happy faces (with the exception of one face) were rated as being more pleasant by older relative to younger raters, which was also reflected in marginally significant higher valence ratings for those faces in older compared to younger adults ($p = .051$).

From these 234 faces, 72 faces with the highest agreement between younger and older raters were selected for the main experiment (see Table A.1 for a list of stimuli). Twenty-four showed a happy expression, 24 showed a neutral expression and the remaining 24 showed an angry expression. Faces were selected such that both age group and sex of the face models were balanced equally in each emotion category, resulting in eight pictures per age group and emotion category with four pictures showing male faces and four pictures showing female faces. Each picture showed a unique individual.

Table A.1. *List of facial stimuli*

Angry	Neutral	Happy
066_y_m_a_b.jpg	071_y_f_n_b.jpg	028_y_f_h_a.jpg
089_y_m_a_b.jpg	072_y_m_n_a.jpg	090_y_f_h_b.jpg
125_y_f_a_a.jpg	171_y_f_n_b.jpg	147_y_m_h_a.jpg
150_y_f_a_a.jpg	175_y_m_n_b.jpg	153_y_m_h_a.jpg
014_m_m_a_b.jpg	038_m_m_n_b.jpg	032_m_m_h_a.jpg
035_m_f_a_a.jpg	061_m_f_n_a.jpg	043_m_f_h_a.jpg
052_m_f_a_b.jpg	113_m_f_n_b.jpg	070_m_m_h_a.jpg
058_m_m_a_a.jpg	126_m_m_n_a.jpg	157_m_f_h_b.jpg
036_o_f_a_a.jpg	012_o_f_n_b.jpg	005_o_f_h_b.jpg
118_o_m_a_a.jpg	065_o_m_n_a.jpg	033_o_m_h_b.jpg
146_o_m_a_a.jpg	074_o_m_n_b.jpg	102_o_m_h_a.jpg
154_o_f_a_b.jpg	079_o_f_n_b.jpg	164_o_f_h_a.jpg
048_y_f_a_a.jpg	037_y_m_n_b.jpg	008_y_m_h_b.jpg
119_y_m_a_b.jpg	040_y_f_n_b.jpg	010_y_f_h_b.jpg
123_y_m_a_a.jpg	162_y_f_n_a.jpg	057_y_m_h_b.jpg
177_y_f_a_a.jpg	170_y_m_n_a.jpg	069_y_f_h_a.jpg
045_m_m_a_b.jpg	103_m_f_n_b.jpg	029_m_f_h_b.jpg
093_m_f_a_b.jpg	139_m_f_n_b.jpg	087_m_m_h_b.jpg
117_m_f_a_b.jpg	178_m_m_n_b.jpg	138_m_f_h_b.jpg
149_m_m_a_a.jpg	179_m_m_n_a.jpg	165_m_m_h_a.jpg
039_o_m_a_b.jpg	004_o_m_n_b.jpg	076_o_m_h_b.jpg
060_o_f_a_a.jpg	015_o_m_n_b.jpg	110_o_f_h_b.jpg
107_o_m_a_b.jpg	021_o_f_n_b.jpg	143_o_f_h_b.jpg
130_o_f_a_a.jpg	112_o_f_n_b.jpg	161_o_m_h_b.jpg

Age ratings for the final 72 faces were submitted to a 3 × 2 mixed factors ANOVA including the within-subjects factor of age of the face (young vs. middle-aged vs. old) and the between-subjects factor of age of rater (younger vs. older). Emotional arousal ratings and emotional valence ratings for the 72 faces were analysed by a 3 × 2 mixed factors ANOVA including the within-subjects factor of emotion of the face (angry vs. neutral vs. happy) and the between-subjects factor of age of the rater (younger vs. older), respectively. Post-hoc t-tests with a Bonferroni adjustment to the alpha level were performed to follow up significant effects and interactions.

The analysis of age ratings yielded a significant main effect of age of the face, *F*(2, 36) = 834.67, *MSE* = 16.90, *p* < .001, partial η^2 = .98, with young faces receiving lower age ratings (*M* = 25.77, *SD* = 2.81) than middle-aged faces (*M* = 45.33, *SD* = 3.30), *t*(19) = 22.30, *p* < 001, and middle-aged faces receiving lower age ratings than older faces (*M* = 69.92, *SD* = 5.07), *t*(19) = 27.72, *p* < 001. No further main effects or interactions were observed for age ratings.

The analysis of emotional arousal ratings yielded a significant main effect of emotion of the face, *F*(2, 36) = 21.61, *MSE* = 1.32, *p* < .001, partial η^2 = .55, with angry faces receiving higher arousal ratings (*M* = 6.77, *SD* = 1.24) than neutral faces (*M* = 4.60, *SD* = 1.20), *t*(19) = 7.05, p < .001, and happy faces receiving higher arousal ratings (*M* = 6.54, *SD* = 1.40) than neutral faces, *t*(19) = 5.40, *p* < .001. There was no significant difference between emotional arousal ratings for angry and happy faces (*p* = .570), and no further main effects or interactions were observed for emotional arousal ratings.

The analysis of emotional valence ratings yielded a significant main effect of emotion of the face, *F*(2, 36) = 222.61, *MSE* = 0.77, *p* < .001, partial η^2 = .93, with neutral faces receiving higher valence ratings (*M* = 4.78, *SD* = 0.46) than angry faces (*M* = 2.62, *SD* = 0.66), *t*(19) = 12.09, *p* < .001, and happy faces receiving higher valence ratings (*M* = 7.47, *SD* =1.07) than neutral faces, *t*(19) = 12.18, *p* < .001. There was also a significant effect of age of the rater, *F*(1, 18) = 5.37, *MSE* = 0.15, *p* = .032, partial η^2 = .23, as valence ratings were overall higher by older (*M* = 5.16, *SD* =.29) than by younger adults (*M* = 4.76, *SD* =.45). The main effects of emotion and age were qualified by a significant age × emotion interaction, *F*(2, 36) = 4.37, *MSE* = 0.77, p = .036, partial η^2 = .20, revealing that only valence ratings for happy faces were higher in older adults (*M* = 8.05, *SD* = 0.63) than in younger adults (*M* = 6.90, *SD* = 1.13), *t*(19) = 2.81, p = .012. No differences in valence ratings for angry (p = .584) or neutral faces (p = .340) were observed between younger and older raters.

To create two face sets for counterbalancing purposes, 12 neutral, 12 happy, and 12 angry faces were allocated to Set A and the remaining 12 neutral, 12 happy, and 12 angry faces were allocated to Set B. The faces in Set A and Set B did not differ significantly in terms of arousal, *t*(19) = .07, p = .948, ns, or valence, *t*(19) = 1.30, p = .208, ns.

Effect of emotional expression on age estimates (relevant for Experiment 3.1)

To evaluate whether the emotional valence of the faces affected the age ratings of the faces that were used in the main experiment, age ratings were analysed additionally by a 3 × 3 × 2 mixed factors ANOVA including the within-subjects factors of emotion (angry vs. neutral vs. happy) and age of the face (young vs. middle-aged vs. old) and the between-subjects factor of age of the rater (younger vs. older). Additionally to a main effect of age of the face (see above), there was a significant emotion × age of the face interaction, *F*(2, 36) = 10.00, *MSE* = 3.17, $p < .001$, partial η^2 = .37. We analysed responses to young, middle-aged and old faces separately to follow up this interaction. The main effect of emotion was not significant for middle-aged faces (p = .402), but it was for young faces, *F*(2, 36) = 4.82, *MSE* = 1.39, p = .002, partial η^2 = .21, and for old faces, *F*(2, 36) = 14.57, *MSE* = 2.84, $p < .001$, partial η^2 = .45. For younger faces, age ratings were slightly higher for happy faces (*M* = 26.39, *SD* = 2.83) than for angry faces (*M* = 25.21, *SD* = 3.86), *t*(19) = 2.81, p = 012. The difference in age ratings between neutral and angry faces was non-significant (*p* = .332) as was the difference between neutral and happy faces (*p* = .055) after Bonferroni correction. For old faces, age ratings were higher for neutral faces (*M* = 71.56, *SD* = 5.32) than for happy faces (*M* = 68.85, *SD* = 5.27), *t*(19) = 6.48, *p* < .001, or angry faces (*M* = 69.36, *SD* = 5.24), *t*(19) = 3.25, *p* = .004. Age ratings were not significantly different for happy and angry faces of older models (p = .375).

The emotion × age of the face interaction was qualified by a significant emotion × age of the face × age of the rater interaction. For younger faces, it was driven by a stronger effect of emotion on age ratings by younger raters when the faces were happy and angry. Younger raters' age ratings for younger faces were significantly higher if they showed happy expressions (*M* = 25.58, *SD* = 2.26) than angry expressions (*M* = 23.31, *SD* = 2.37), *t*(9) = 4.33, *p* = .002, whereas age ratings for angry and happy young faces did not differ in older raters (*p* = .922). For older faces, there was a stronger effect of emotion on age ratings by older raters when the faces were angry and neutral. Older raters' age ratings for older faces were significantly higher if they showed neutral expressions (*M* = 73.29, *SD* = 4.59) than angry expressions (*M* = 69.79, *SD* = 4.84), *t*(9) = 3.40, *p* = .008, whereas age ratings for angry and happy neutral faces did not differ in younger raters (*p* = .236).

Appendix B: Accuracy scores, Experiment 3.1

Accuracy scores for younger and older adults in the 1-back and 2-back tasks of Experiment 3.1 are presented in Table B.1.

Table B.1. *Accuracy scores for two age groups in Experiment 3.1*

	1-back task				2-back task			
	Younger adults		Older adults		Younger adults		Older adults	
Trial type	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Emotional task instructions								
Match responses								
Angry	87.33	12.78	87.56	10.05	82.33	13.41	69.17	17.18
Neutral	96.00	4.68	98.67	3.32	87.83	13.44	82.50	14.03
Happy	97.11	5.10	95.78	5.84	92.50	11.85	84.33	11.74
Non-match responses								
Angry	94.89	5.98	92.89	7.09	88.50	12.28	80.50	16.13
Neutral	91.78	6.83	89.78	10.96	87.00	12.17	71.83	18.95
Happy	93.33	6.99	95.33	6.74	87.17	13.76	76.83	15.41
Non-emotional task instructions								
Match responses								
Angry	91.78	9.77	89.56	9.26	85.17	10.35	75.67	13.05
Neutral	87.78	9.76	86.22	11.01	84.83	8.50	76.83	13.45
Happy	89.56	6.28	82.89	11.99	86.50	12.57	73.33	10.96
Non-match responses								
Angry	93.11	7.04	84.89	9.82	85.67	9.17	75.83	13.23
Neutral	94.22	6.89	86.67	7.69	86.00	9.15	73.83	14.90
Happy	89.33	7.84	83.78	10.13	82.50	13.12	71.67	16.00

Appendix C: Evaluation of words

Forty younger (19 – 37 years old; M = 26.80, SD = 6.12) and 40 older adults (62 – 78 years old; M = 71.64, SD = 5.53) rated a total of 300 preselected words from the ANEW database (Bradley & Lang, 1999). The stimuli were divided in two sub-sets of 150 words, respectively, and each sub-set was rated by 20 younger and 20 older adults. In each sub-set, 50 words were negative, 50 were neutral and the remaining 50 were positive. Assignment to these emotional categories was based on the evaluation ratings by students that were provided in the ANEW database. Similar to the evaluation procedure for faces (as described in Appendix A), these words were rated on a 9-point Likert scale for valence (1 = very unpleasant; 9 = very pleasant) and arousal (1 = not arousing; 9 = very arousing).

Mean arousal and mean valence ratings for the 150 words of each set were submitted to a 3 × 2 mixed factors ANOVA including the within-subjects factor of stimulus emotion (positive vs. neutral vs. negative) and the between-subjects factor of age of rater (younger vs. older), respectively. Post-hoc t-tests with a Bonferroni adjustment to the alpha level were performed to follow up significant effects and interactions.

Set 1

The analysis of arousal ratings yielded a significant effect of stimulus emotion, *F*(2, 76) = 25.64, *MSE* = 3.46, $p < .001$, partial $\eta^2 = .40$, with negative words receiving higher arousal ratings (*M* = 6.73, *SD* = 2.18) than neutral words (*M* = 4.64, *SD* = 1.76), *t*(39) = 5.08, $p < .001$. Positive words were also given higher arousal ratings (*M* = 6.82, *SD* = 1.71) than neutral words, *t*(39) = 11.06, $p < .001$, whereas arousal ratings for negative and positive words were not significantly different (*p* = .816). No further main effects or interactions were observed for arousal ratings.

The analysis of valence ratings yielded a significant effect of stimulus emotion, *F*(2, 76) = 613.16, *MSE* = 0.71, *p* < .001, partial η^2 = .94, as negative words received valence ratings (*M* = 2.00, *SD* = 1.03) that were lower than for neutral words (*M* = 5.48, *SD* = 0.67), *t*(39) = 18.24, *p* < .001, or for positive words (*M* = 7.94, *SD* =0.54), *t*(39) = 31.99, *p* < .001. Positive words also received higher valence ratings than neutral words, *t*(39) = 20.03, *p* < .001. No further main effects or interactions were observed for valence ratings.

Set 2

The analysis of arousal ratings yielded a significant main effect of stimulus emotion, *F*(2, 76) = 119.71, *MSE* = 1.36, *p* < .001, partial η^2 = .76, as negative words received higher arousal ratings (*M* = 6.23, *SD* = 1.43) than neutral words (*M* = 3.07, *SD* = 1.51), *t*(39) = 11.73, p < .001. Positive words also received higher arousal ratings (*M* = 5.97, *SD* = 1.44) than neutral words, *t*(39) = 12.51, *p* < .001, whereas arousal ratings for negative and positive words were not significantly different (*p* = .092). No further main effects or interactions were observed for arousal ratings.

The analysis of valence ratings yielded a significant effect of stimulus emotion, *F*(2, 76) = 480.72, *MSE* = 0.82, *p* < .001, partial η^2 = .93, as negative words received lower valence ratings (*M* = 2.38, *SD* = 0.76) that neutral words (*M* = 5.18, *SD* = 0.25), *t*(39) = 23.58, *p* < .001, or positive words (*M* = 7.25, *SD* =0.73), *t*(39) = 23.31, *p* < .001. Positive words also received higher valence ratings than neutral words, *t*(39) = 16.92, *p* < .001. No further main effects or interactions were observed for valence ratings.

Final selection of words

As these analyses showed, no interactions between the factors stimulus emotion and age of rater were found, suggesting that ratings for negative, neutral and positive words did not significantly differ between younger and older adults. To select the final stimulus set for Experiment 3.3 and Experiment 4.4, valence and arousal ratings were ranked according to difference scores of younger and older adults' ratings. Seventy-two items with the lowest difference between ratings of younger and older adults were selected.

Table C.1. *List of verbal stimuli*

Negative	Neutral	Positive
suicide	vest	gift
hell	month	triumph
torture	ankle	beauty
killer	context	success
stress	statue	victory
abuse	unit	sun
danger	ketchup	glory
cruel	engine	puppy
angry	pencil	treat
lonely	phase	reward
terrible	clock	fun
hurt	column	inspire
death	foot	thrill
rape	chin	friend
assault	knot	delight
anger	trunk	talent
cancer	corridor	humour
insult	barrel	holiday
scared	ink	desire
misery	bench	joy
debt	news	hug
crime	kettle	pleasure
fever	hat	comfort
wounds	method	kiss

The final selection of 72 words comprised 24 words per emotional category (see Table B.1 for a list of stimuli). For this selection, valence ratings for negative words were lower (*M* = 1.96, *SD* = .96) than valence ratings for neutral words (*M* = 5.47, *SD* = .74), whereas valence ratings for emotionally neutral words were lower than valence rating for positive words (*M* = 7.90, *SD* = .82). Moreover, arousal ratings were higher for negative words (*M* = 6.66, *SD* = 1.85) than for neutral faces (*M* = 3.73, *SD* = 2.02), but were similarly high as those for positive words (*M* = 6.77, *SD* = 1.54). No inferential tests were conducted due to the fact that different groups of participants have evaluated different sub-sets of words. Neither an independent-samples nor a paired-samples t-test were appropriate to analyse mean differences for valence and arousal ratings and thus, only descriptive statistics are provided.

Appendix D: Accuracy scores, Experiment 3.3

Accuracy scores for younger adults in the 1-back and 2-back tasks of Experiment 3.3 are presented in Table D.1.

Table D.1. *Accuracy scores for younger adults in Experiment 3.3*

	1-back task		2-back task	
Trial type	*M*	*SD*	*M*	*SD*
Match responses				
Angry	92.08	7.97	88.54	8.93
Neutral	87.36	8.67	83.54	5.23
Happy	80.97	9.51	80.21	10.20
Non-match responses				
Angry	92.78	6.89	88.65	10.19
Neutral	88.06	7.60	87.92	7.72
Happy	86.11	6.37	86.67	10.08

Appendix E: Results for repeat trials, Experiment 5.1

Statistical analysis

Statistical analysis of the data from repeat trials was conducted with SPSS 22 (IBM Corp., Armonk, NY). Accuracy and RTs for repeat trials were analysed separately for the happy vs. neutral and the angry vs. neutral blocks. Data were analysed in the same way as for switch trials by a 2 × 2 × 2 × 2 mixed factors ANOVA including the within-subjects factors task (age vs. emotion), target emotion (happy/angry vs. neutral) and previous emotion (happy/angry vs. neutral) as well as the between-subjects factor of age (younger vs. older). Post-hoc t-tests with a Bonferroni adjustment to the alpha level were performed to follow up significant main effects and interactions. All tests were two-tailed with $\alpha = .05$.

Happy vs. neutral faces

Accuracy. The four-way omnibus ANOVA on repeat trials yielded a main effect of age, $F(1, 59) = 15.05$, $MSE = .003$, $p < .001$, partial $\eta^2 = .20$, which was qualified by a task × age interaction, $F(1, 59) = 4.71$, $MSE = .002$, $p = .034$, partial $\eta^2 = .07$. Follow-up t-tests revealed that in the age task, older adults were significantly more accurate ($M = 99.50$, $SD = 0.96$) than younger adults ($M = 96.60$, $SD = 3.92$), $t(59) = 3.88$, $p = .001$. In the emotion task, the difference in accuracy between older adults ($M = 98.91$, $SD = 2.29$) and younger adults ($M = 97.76$, $SD = 2.39$) was less pronounced and only marginally significant, $t(59) = 1.92$, $p = .061$.

Reaction times. The four-way omnibus ANOVA on repeat trials yielded a main effect of task, $F(1, 59) = 7.56$, $MSE = 32260$, $p = .008$, partial $\eta^2 = .11$, with overall slower RTs in the emotion task ($M = 822$ ms, $SD = 223$ ms) compared to the age task ($M = 777$

ms, *SD* = 224 ms). This main effect was qualified by a task × target emotion interaction, *F*(1, 59) = 7.83, *MSE* = 12716, *p* = .007, partial η^2 = .11. Follow-up t-tests revealed that in the age task, RTs were slower for happy targets (*M* = 798 ms, *SD* = 243 ms) than for neutral targets (*M* = 757 ms, *SD* = 216 ms), *t*(60) = 3.04, *p* = .004. In the emotion task, there was no significant difference between RTs for neutral or happy targets (*p* = .289). There was also a target emotion × previous emotion interaction, *F*(1, 59) = 10.57, *MSE* = 18416, *p* = .002, partial η^2 = .15. Follow-up t-tests revealed that RTs for neutral targets were faster when the previous emotion was also neutral (*M* = 735 ms, *SD* = 216 ms) rather than happy (*M* = 778 ms, *SD* = 243 ms), *t*(60) = 2.14, *p* = .036. Similarly, RTs for happy targets were faster when the previous emotion was also happy (*M* = 767 ms, *SD* = 226 ms) rather than neutral (*M* = 827 ms, *SD* = 289 ms), *t*(60) = 2.45, *p* = .017. This is evidence for a response repetition effect for repeat trials. Finally, there was also a main effect of age, *F*(1, 59) = 17.12, *MSE* = 290092, *p* < .001, partial η^2 = .26, as older adults were overall slower (*M* = 896 ms, *SD* = 217 ms) than younger adults (*M* = 694 ms, *SD* = 167 ms). No further main effects or interactions were observed for reaction times to happy versus neutral faces.

Angry vs. neutral faces

Accuracy. The four-way omnibus ANOVA on repeat trials yielded a main effect of task, *F*(1, 59) = 7.07, *MSE* = .010, *p* = .010, partial η^2 = .11, as accuracy scores were higher in the age task (*M* = 97.52, *SD* = 3.58) than in the emotion task (*M* = 95.77, *SD* = 4.49). There was also a main effect of target emotion, *F*(1, 59) = 10.37, *MSE* = .004, *p* = .002, partial η^2 = .15, with lower accuracy scores for angry targets (*M* = 95.70, *SD* = 4.59) than for neutral targets (*M* = 97.58, *SD* = 3.05). This main effect was qualified by a task × target emotion interaction, *F*(1, 59) = 6.63, *MSE* = .005, *p* = .013, partial η^2 = .10. Follow-up t-tests revealed that in the emotion task, accuracy was lower for angry targets (*M* = 94.01, *SD* = 7.58) than for neutral targets (*M* = 97.53, *SD* = 3.96), *t*(60) = 3.42, *p* = .001, whereas accuracy for neutral and angry targets did not differ in the age task (*p* = .713). There was also a task × previous emotion interaction, *F*(1, 59) = 7.47, *MSE* = .004, *p* = .008, partial η^2 = .11, which was qualified by a task × previous emotion × age interaction, *F*(1, 59) = 12.30, *MSE* = .004, *p* = .001, partial η^2 = .17. Separate analyses for younger and older adults revealed that the task × previous emotion interaction was only significant in younger adults, *F*(1, 28) = 11.56, *MSE* = .006, *p* = .002, partial η^2 = .29, whereas this interaction was not significant in older adults (*p* = .411). Younger adults were more accurate in the emotion task if the previous emotion was angry (*M* = 96.88, *SD* = 4.34) rather than neutral (*M* = 92.21, *SD* = 6.81), *t*(28) = 3.19, *p* = .003. In contrast, accuracy scores in the age task did not differ depending on previous emotion (*p* = .087). There was also a main effect of age, *F*(1, 59) = 17.52, *MSE* = .006, *p* < .001, partial η^2 = .23, as older adults were more accurate (*M* = 98.08, *SD* = 2.24) than younger adults (*M* = 95.06, *SD* = 3.35). No further main effects or interaction were observed for accuracy scores for angry versus neutral faces.

Reaction times. The four-way omnibus ANOVA on repeat trials yielded a main effect of task, *F*(1, 59) = 24.23, *MSE* = 49550, *p* < .001, partial η^2 = .29, as participants were slower in the emotion task (*M* = 880 ms, *SD* = 225 ms) than in the age task (*M* = 781 ms, *SD* = 243 ms). There was also a main effect of target emotion, *F*(1, 59) = 11.03, *MSE* = 24199, *p* = .002, partial η^2 = .16, with slower RTs for angry targets (*M* = 854 ms, *SD* = 239 ms) relative to neutral targets (*M* = 806 ms, *SD* = 216 ms). This main effect was qualified by a target emotion × age interaction, *F*(1, 59) = 4.54, *MSE* = 24199, *p* = .037, partial η^2 = .16. Separate analyses for the two age groups revealed that older adults showed slower RTs for angry targets (*M* = 967 ms, *SD* = 262 ms) than for neutral targets (*M* = 891 ms, *SD* = 246 ms), *t*(31) = 3.49, *p* = .001, whereas this effect was not found in younger adults (*p* = .329).

Although the task × target emotion interaction was not significant (*p* = .217), separate analyses for the age task and for the emotion task were conducted to assess whether the effect of emotion differed in size in the two task. This was done as in the switch trials for happy/neutral and angry/neutral faces and in the repeat trials for happy/neutral faces, emotion affected performance on the non-emotional age task. The separate analyses revealed that in the age task, RTs were slower for angry targets (*M* = 814 ms, *SD* = 261 ms) than for neutral targets (*M* = 748 ms, *SD* = 238 ms), *t*(60) = 4.57, *p* < .001. In the emotion task, the difference in RTs for neutral targets (*M* = 864 ms, *SD* = 220 ms) and angry targets (*M* = 895 ms, *SD* = 268 ms) was not significant (p = .216).

There was also a target emotion × previous emotion interaction, *F*(1, 59) = 25.98, *MSE* = 16593, *p* < .001, partial η^2 = .31, which was qualified by a task × target emotion × previous emotion interaction, *F*(1, 59) = 5.56, *MSE* = 17278, *p* = .022, partial η^2 = .09. Separate analyses for the age and emotion tasks were conducted to follow up on this interaction. The target emotion × previous emotion interaction was significant in the age task, *F*(1, 59) = 5.00, *MSE* = 12013, *p* = .029, partial η^2 = .08. Follow-up t-tests showed that in the age task, RTs to angry faces were faster if the previous emotion was angry (*M* = 785 ms, *SD* = 262 ms) rather than neutral (*M* = 842 ms, *SD* = 286 ms), *t*(60) = 2.61, *p* = .011, whereas previous emotion did not play a role for responses to neutral targets (*p* = .011). The target emotion × previous emotion interaction was also significant in the age task and the interaction was more pronounced, *F*(1, 59) = 21.37, *MSE* = 21857, *p* < .001, partial η^2 = .27. Follow-up t-tests showed that in the emotion task, RTs to angry faces were faster if the previous emotion was angry (*M* = 852 ms, *SD* = 275 ms) rather than neutral (*M* = 939 ms, *SD* = 308 ms), *t*(60) = 2.94, *p* = .005.

Similarly, RTs to neutral faces were faster if the previous emotion was neutral (*M* = 852 ms, *SD* = 275 ms) rather than angry (*M* = 939 ms, *SD* = 308 ms), *t*(60) = 4.13, *p* < .001. Again, this pattern of results is evidence for a response repetition effect for repeat trials.

Lastly, there was also a main effect of age, *F*(1, 59) = 17.03, *MSE* = 308142, *p* < .001, partial η^2 = .22, as older adults were overall slower (*M* = 929 ms, *SD* = 246 ms) than younger adults (*M* = 721 ms, *SD* = 119 ms). No further main effects or interactions were observed for reaction times for angry versus neutral faces.

Appendix F: Results for repeat trials, Experiment 5.2

Statistical analysis

Statistical analysis of the data from repeat trials was conducted with SPSS 22 (IBM Corp., Armonk, NY). Accuracy and RTs for repeat trials were analysed separately for the happy vs. neutral and the angry vs. neutral blocks. Data were analysed in the same way as for switch trials by a 2 × 2 × 2 × 2 mixed factors ANOVA including the within-subjects factors task (age vs. gender), target emotion (happy/angry vs. neutral) and previous emotion (happy/angry vs. neutral) as well as the between-subjects factor of age (younger vs. older). Post-hoc t-tests with a Bonferroni adjustment to the alpha level were performed to follow up significant main effects and interactions. All tests were two-tailed with $\alpha = .05$.

Happy vs. neutral faces

Accuracy. The analysis of accuracy for repeat trials yielded a significant task × target emotion × previous emotion interaction, $F(1, 59) = 8.61$, $MSE = .003$, $p = .005$, partial $\eta^2 = .13$. Separate analyses for the age and the gender task were conducted to follow up on this interaction. In the age task, the target emotion × previous emotion interaction was significant, $F(1, 59) = 6.36$, $MSE = .002$, $p = .014$, partial $\eta^2 = .10$, whereas it missed significance in the gender task ($p = .076$). Follow-up t-test revealed that in the age task, participants responded more accurately to neutral targets if the previous emotion was happy ($M = 98.46$, $SD = 3.81$) rather than neutral ($M = 96.18$, $SD = 7.33$), $t(28) = 2.31$, $p = .024$. In contrast, previous emotion did not play a similar role in accuracy for happy target faces ($p = .477$). There was also a main effect of age, $F(1, 59) = 8.96$, $MSE = .004$, $p = .004$, as older adults were more accurate ($M = 98.86$, $SD =$

1.27) than younger adults (*M* = 96.00, *SD* = 2.93). No further main effects or interactions were observed for accuracy scores for happy versus neutral faces.

Reaction times. The four-way omnibus ANOVA on repeat trials yielded a significant target emotion × age interaction, *F*(1, 59) = 4.22, *MSE* = 15196, $p = .044$, partial $\eta^2 = .07$. Follow-up t-test revealed that younger adults responded marginally slower when the target emotion was happy (*M* = 674 ms, *SD* = 149 ms) rather than neutral (*M* = 641 ms, *SD* = 131 ms), *t*(28) = 2.00, $p = .055$. In contrast, there was no significant difference in RTs for neutral or happy targets in older adults ($p = .472$). There was also a main effect of age, *F*(1, 59) = 14.48, *MSE* = 237439, $p < .001$, partial $\eta^2 = .20$, as older adults were overall slower (*M* = 825 ms, *SD* = 201 ms) than younger adults (*M* = 657 ms, *SD* = 133 ms). No further main effects or interactions were observed for reaction times to happy versus neutral faces.

Angry vs. neutral faces

Accuracy. The analysis of accuracy for repeat trials yielded a main effect of age, *F*(1, 59) = 8.96, *MSE* = .004, $p = .004$, as older adults were more accurate (*M* = 98.58, *SD* = 1.65) than younger adults (*M* = 95.35, *SD* = 4.19). This main effect was qualified by a significant task × age interaction, *F*(1, 59) = 6.12, *MSE* = .003, $p = .016$, partial $\eta^2 = .09$. Follow-up t-tests revealed that younger adults were more accurate in the gender task (*M* = 96.41, *SD* = 3.51) than in the age task, (*M* = 94.28, *SD* = 6.00), *t*(28) = 2.23, $p = .034$. In contrast, accuracy scores for the age and gender tasks did not differ in older adults ($p = .356$). Moreover, there was a task × target emotion interaction, *F*(1, 59) = 7.02, *MSE* = .003, $p = .010$, partial $\eta^2 = .11$. Follow-up t-test revealed that in the gender task, participants responded more accurately to angry targets (*M* = 98.26, *SD* = 3.55) than to neutral targets (*M* = 96.59, *SD* = 4.96), *t*(60) = 2.27, $p = .027$. In contrast, no difference in accuracy for angry and neutral targets was found in the age task (p = .234). No further main effects or interactions were observed for accuracy scores for angry versus neutral faces.

Reaction times. The four-way omnibus ANOVA on repeat trials yielded a significant task × target emotion interaction, $F(1, 59) = 7.81$, $MSE = 15037$, $p = .007$, partial η^2 = .12. Follow-up t-test revealed that in the age task, RTs were slower for angry targets (M = 783 ms, SD = 237 ms) than to neutral targets (M = 745 ms, SD = 217 ms), $t(60) = 2.72$, $p = .008$. In contrast, no difference in RTs for angry and neutral targets was found in the gender task (p = .162). There was also a target emotion × previous emotion interaction, $F(1, 59) = 5.77$, $MSE = 11867$, $p = .019$, partial η^2 = .09, which was qualified by a target emotion × previous emotion × age interaction, $F(1, 59) = 6.37$, $MSE = 11867$, $p = .014$, partial η^2 = .10. Separate analyses for younger and older adults revealed that younger adults showed a significant target emotion × previous emotion interaction, $F(1, 28) = 7.93$, $MSE = 17298$, $p = .009$, partial η^2 = .22, whereas this interaction was not significant in older adults (p = .908). Follow-up t-tests showed that younger adults responded faster to neutral targets if the previous emotion was also neutral (M = 654 ms, SD = 171 ms) rather than angry (M = 707 ms, SD = 198 ms), $t(28) = 2.31$, $p = .028$. Similarly, they also responded faster to angry targets if the previous emotion was also angry (M = 649 ms, SD = 120 ms) rather than neutral (M = 694 ms, SD = 196 ms), $t(28) = 2.08$, $p = .047$. Lastly, there was also a main effect of age, $F(1, 59) = 12.22$, $MSE = 274147$, $p = .001$, partial η^2 = .17, as older adults were overall slower (M = 842 ms, SD = 208 ms) than younger adults (M = 676 ms, SD = 156 ms). No further main effects or interactions were observed for reaction times to happy versus neutral faces.