Emotion and aging: The impact of emotion on attention, memory, and face recognition in late adulthood

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It has been estimated that by 2050, 1.5 billion people will be aged 65 or older, representing 16 per cent of the world''s population. Hence, understanding the full picture of aging could provide a new lens for thinking about long-term planning for health, work policies, and opportunities for engaging and collaborating with older adults. Although aging is associated with cognitive deficit and the associated costs of losing cognitive functions, these do not provide a complete picture of aging. Increasing evidence in emotional aging literature offers a different perspective on how we age. Recent discoveries in functional neuroimaging also provide important insights into how the brain functions during various cognitive and emotional tasks as we age, granting a more comprehensive view of the aging brain. Therefore, the primary focus of this chapter is to provide multidisciplinary evidence from both behavioural and neuroimaging studies in the emotional aging literature. The chapter is organized based on the impact of emotion on three main categories of cognitive function as a function of age: *attention, memory,* and *face recognition.* Before discussing the main findings from each of these categories, some of the major discoveries and dominant models in the cognitive aging domain will be discussed briefly. Throughout this chapter, several questions are revisited: what are the underlying cognitive and neural mechanisms of the attentional biases toward positive items in aging? Do older adults have difficulties in processing negative emotions or do they process positive emotions differently than younger adults? How are the attention and memory process of emotional items linked? What factors influence the processing of emotional facial expressions in late adulthood? Do the temporal features of stimuli help older adults overcome difficulties in recognizing emotions? Are there any age differences in processing the six main emotions expressed by the face?

1   Cognitive Aging

Emotional and cognitive functions are interrelated and overlooking either of these two critical aspects of aging leaves us with an incomplete picture of aging. Although the fine details of the cognitive aging literature are beyond the scope of this chapter, we briefly acknowledge and discuss the central existing theories of cognitive aspects of aging, before discussing the emotion and aging studies. Understanding the existing theories in cognitive domains provides a deeper understanding of the underlying mechanisms for emotional processes, and subsequently will help reconcile emotional and cognitive aging theories/domains.

A substantial body of evidence now shows cognitive deficits among older adults in relation to speed of processing, memory, and attention (for review, see [1,2]). Multiple cognitive aging theories have been proposed and provided a foundation for understanding the underlying mechanisms associated with cognitive deficit as we age. Below we briefly present four particularly influential discoveries, and then describe some of the dominant theories in this domain.

1.1 Major Discoveries about the Aging Brain

Overactivation: Older adults activate some areas of the brain to a greater extent than younger adults during performing cognitive tasks. These patterns of activity have been thought of as the neural correlates of cognitive decline[1]. However, overactivation has been observed in high performing older individuals[3,4]. Therefore, overactivation could also reflect the compensatory mechanisms utilized by "successful" older adults who have greater cognitive

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ability and might recruit different neural networks relative to younger adults. However, it is still unclear whether older adults are using these additional brain regions to implement different strategies, or whether they are using the same cognitive strategies as young adults but relying on different brain areas. In other words, overactivation might have a function, or it might be a byproduct of aging influencing the brain. The former view has been supported by the compensatory viewpoint, which suggests that the increased bilateral recruitment of both hemispheres among older adults is associated with enhanced cognitive performance and has a compensatory role[5].

The hemispheric asymmetry reduction in older adults (HAROLD)[6] model is consistent with the second interpretation of overactivation as a by-product of aging. Evidence from episodic memory, semantic retrieval, working memory, perception, and inhibitory control provide converging evidence that older adults show increased activity in both hemispheres relative to younger adults, indicating that the overactivation can be considered a by-product of aging.

Dedifferentiation: Dedifferentiation refers to reduced regional specialization or specificity in a particular area[7]. Overactivity of the prefrontal regions and dedifferentiation of the ventral visual system are typically construed as being consistent with a compensatory mechanism.

Frontal compensation: Over-recruitment of prefrontal regions in a wide range of tasks is often seen in studies of older adults. Importantly, this over-recruitment of alternative brain networks could be related to improvement in cognitive performances[5]. Recruiting more anterior prefrontal cortex (PFC) regions is accompanied by deactivation of posterior regions such as the

medial temporal lobe and ventral visual cortex. This pattern also relates to the posterior-anterior shift in aging (PASA), which has been thought to reflect compensatory mechanisms with advancing age[8].

Default mode network (DMN): This network includes the medial PFC, posterior cingulate, and medial and lateral parietal regions, and seems to be involved "during mental explorations referenced to oneself including remembering, considering hypothetical social interactions, and thinking about one"s own future"[9]. In healthy young adults, the DMN is deactivated with increasing task demands. Several studies, however, reported that older adults failed to "deactivate" DMN during many cognitive tasks[10,11]. One reason for such a pattern might be that older adults have a reduced ability to suspend DMN activity when other cognitive tasks require their attention[11]. Results from longitudinal studies also indicate the task-induced deactivation in DMN remains stable over time among older adults[12].

1.2 Theories in Cognitive Aging

Three influential models, including the *inhibitory deficit hypothesis*, the *CompensationRelated Utilization of Neural Circuits Hypothesis* (CRUNCH), and the *Scaffolding Theory of Aging and Cognition* (STAC model) have been proposed to explain the underlying mechanisms of the cognitive deficit that accompanies aging.

One of the dominant hypotheses is the *inhibitory deficit hypothesis,* which could explain a wide range of age-related cognitive difficulties in working memory[13,14], decision making, and

social functioning[15,16]. Consistent with the notion that reduced inhibitory control underlies many age-related losses Hasher and Zacks [17], this hypothesis focuses on the effect of inhibitory control on working memory by suppressing irrelevant information. A number of studies have also shown that specific deficits in inhibitory control can lead to working memory impairment in aging. It has also been shown that age-related deficits in inhibitory control over distractors disrupt working memory performance[13,18]. Recently, a top-down modulation model in aging has been proposed[19]. According to this model, the "[t]op-down modulation defined as the modulation of neural activity in neurons of sensory or motor areas based on an individual"s goals, involves the enhancement of task-relevant representations and/or suppression for task-irrelevant representations"[20]. Two forms of top-down modulations have been examined: external (e.g., environmental stimuli) and internal (e.g., goals). Several studies have suggested that changes in any form of top-down modulations can lead to the working memory deficit observed with aging[21,22].

The *Compensation-Related Utilization of Neural Circuits Hypothesis (CRUNCH)* accounts for age-related changes as a function of task difficulty. According to this hypothesis, older adults are likely to engage more neural circuits than younger adults to meet task demands. When task demands are low, older adults show more overactivation (frontal and bilateral) whereas younger adults show more focal activation. As task load increases, younger adults may show more bilateral recruitment or overactivation of the anterior regions. However, because of the restricted dynamic range of neural responses among older adults, they may reach their resources" limit and may show underactivation and cognitive decline. Thus, neural compensation is more effective

when task demand is low. However, by increasing task difficulties, cognitive resources" limits are reached and decline in performance becomes more apparent[1,23].

Despite the changes in brain structure that come with age such as dopamine receptor depletion, white matter/gray matter deteriorations, and decline in capacity for neurogenesis, synaptogenesis, and angiogenesis, all systems remain functional and provide a mean for building alternative neural circuitry. These structural challenges are accompanied by functional changes (i.e., overactivation, dedifferentiation, compensation, and DMN changes), and recruiting alternative neural circuitry (scaffolds) helps maintain a high level of cognitive functioning – though it might work less efficiently. The *Scaffolding Theory of Aging and Cognition (STAC model)* describes how the scaffolding process starts during childhood when individuals face different challenges and their brains must adapt. Scaffolding is thus influenced by experiences such as learning new skills, engaging in new challenging activities, and cognitive training, all of which have the potential to enhance the brain"s ability to maintain high level function by creating new scaffolding.

2   Emotion and Aging

Despite cognitive decline, there are small to moderate gains in some emotional domains, including emotion regulation and biases toward positive emotions in memory and attention. A considerable number of empirical studies support the relative preference of positive (over negative) materials in cognitive processing – known as the "positivity effect" (PE)[24]. Despite the converging evidence supporting the positivity effect, the underlying mechanisms for such an effect remain unclear. Several theories such as the Socioemotional Selectivity Theory (SST)[25],

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the Aging Brain Model (ABM)[26], and the selective optimization with compensation model[27] have received considerable attention over the past decades in order to explain the PE.

2.1 Theories in Emotional Aging

2.1.1 Socioemotional Selectivity Theory

The Socioemotional Selectivity Theory (SST) is the dominant theory in the field of emotional and social aging[25]. This theory posits that as people grow older and their time starts to be perceived as limited, their motivational orientation begins to change. A limited time perception results in chronic activation of the goals related to emotional meaning and influences motivational preferences, which changes goal hierarchies – that is, goals will be more personfocused (such as seeking emotion and meaning) rather than future oriented (such as gaining new knowledge or establishing new social contacts)[28]. Goals, preferences, and cognitive processes change systematically as a subjective sense of remaining time becomes limited[29]. In one study testing this model, older and younger adults were asked to imagine that they were moving to the other side of the country. Findings showed that the effect of age disappeared and both groups preferred to spend more time with their familiar social partners. This study and similar studies showed how perceptions of time could influence the way people prioritize their social contacts (see [30] for more details).

Well-being is also affected by such a goal shift. People are attuned to the relevance of incoming information to their goals. They experience negative or positive emotions if something obstructs their goals, or if their goals have been attained. Given the limitation of working memory and attention, for instance, it seems to be an adaptive strategy to prioritize features of

events that facilitate or obstruct goals[31]. As a result of this motivational shift, positive emotions will be prioritized and older adults reallocate their resources to attain positive emotions and reduce negative emotions. In line with this, longitudinal studies have provided evidence of improvement in overall well-being with advancing age[32]. The positivity preference in attention and memory will be discussed in more details in Section 3 (Emotion and Attention in Aging) and Section 4 (Emotional Memory and Aging)

2.1.2   Aging Brain Model

An assumption underlying social neuroscience is that all humans" social behaviours are implemented biologically. The social neuroscience perspective focuses on fundamental changes in brain functions and how these changes in cognition and decision-making are associated with subjective well-being. The Aging Brain Model (ABM), as a derivative from social neuroscience, attempts to explain a link between affective processing and age-related changes in brain functions[26]. For a long time, cognitive and emotional aging were considered two separate constructs; ABM provides an important connection between these two fields of study.

In order to better understand the Aging Brain Model, we provide one study as an example and interpret the results from both the SST and ABM perspectives. In a 2004 functional Magnetic Resonance Imaging (fMRI) study, Mather et al.[33] presented negative, positive, and neutral pictures to older and younger participants, who were then asked to rate how excited or calm they felt when viewing each picture. Enhanced amygdala activation in response to positive (relative to negative) stimuli was found among older adults, whereas for younger participants, amygdala activation to positive and negative stimuli did not significantly differ. According to SST, this

result would be interpreted as the preference of focusing on positive emotional goals and recruiting regulatory strategies among older adults, which lead to the reduced cognitive focus on negative stimuli. On the other hand, ABM would interpret the enhanced activity for positive over negative stimuli among older adults as a reduced arousal response to negative items due to attenuated amygdala function.

To further test the Aging Brain Model, patients with a lesion in the amygdala/medial temporal regions were asked to rate their response toward emotional pictures[34]. It was found that patients with amygdala lesions rated negative pictures as lower in arousal, whereas the emotion categorization for these pictures remained intact. Thus, according to this model, age-related changes in memory for negative items among older adults could reflect changes in the function of the amygdala. Changes in amygdala function have an impact on how the arousal level of emotions is perceived (especially for negative emotions), and therefore reduce the impact of arousal on the memorability of emotional items. The reduction in arousal level to negative emotions can also be associated with enhanced well-being among older adults. Therefore, both the SST and ABM models predict that amygdala activation will be smaller for negative stimuli than positive stimuli among older adults; however, SST predicts that an increased focus on goals and emotional regulatory strategies may be the underlying mechanism leading to the reduced attention toward negative items among older adults [35]. Alternatively, ABM suggests that "these amygdala changes are the cause of the reduced impact of negative stimuli and, consequently, diminished depressive symptomatology and improved subjective well-being"[26]. Such changes in amygdala responses could partially explain the age-related positivity effect (see Section 3.2).

2.1.3   Selective Optimization with Compensation Model

Another proposal to reconcile the emotional and social aspects of aging is the selective optimization with compensation model. According to this model, people become aware of their losses and gains across adulthood, and due to the naturally diminished resources that come with aging, they select goals that are important or can be realistically obtained in their lifetimes. Therefore, less important goals will be sacrificed at the cost of obtaining other more important goals. If some of the goals cannot be achieved, people will engage in compensatory activities. According to this model, older adults engage in any task that is important for them despite their physical or biological constraints. In each case, there is individualization of selection, optimization, and compensation. To make it more tangible, consider a person who desires to run a marathon. If the runner wants to reach this level of running performance, he should give up other activities (selection) and should increase or optimize his conditions, such as daily diet (optimization), in order to become an expert in the activity of marathon running. This will then reduce the impact of losing in other activities (compensation). Therefore, the combination of these three elements can contribute to successful completion of the aging process, which requires adaptation and concentration on domains that are high priority for older adults[27,28].

Summary: Taken together, various models and hypotheses have been developed in order to explain the underlying mechanisms of age-related changes in emotional processing, including the Socioemotional Selectivity Theory, The Aging Brain Model and selective optimization with compensation model. Emotions can influence various cognitive functions, such as attention, memory, and face recognition. Hence, in the following sections we will discuss the existing

literature on the impact of emotion on three critical domains – attention, memory, and face recognition – in regard to the changes that occur in each of these domains with advancing age. In each section, relevant behavioural and neurological findings will be discussed.

3   Emotion and Attention in Aging

In order to better understand how emotions have an impact on attentional processes in advancing age, it is crucial to first understand how emotion and attention interact. Interest in this area of research is rapidly growing empirically, but it is still in its infancy theoretically. Theories of selective attention have been borrowed and adapted to explain the processing of emotional materials by considering these stimuli as highly salient information. Therefore, these theories indicate that highly salient information, such as emotions, is often prioritized for attentional processing.

The feature integration theory of visual attention[36], for instance, describes how certain perceptual characteristics such as orientation or colour can be processed automatically prior to any attentional selection. "Attention is conceived as the process by which representations of more complex stimuli are formed through the combination of individual features („conjunctions of features")"[36]. In visual search paradigms, participants are presented with an array of stimuli and asked to identify or locate the different item as quickly as possible. Using this paradigm, the question of whether emotional information has a feature that acts as a "pop out" effect, or whether emotional information instead requires complex processing in order to evaluate its emotional significance and capture attention, has been investigated extensively. Empirical studies support the former account that emotional information is a highly salient conjunction of features

and pops out from the rest of the visual environment. For similar models pertinent to this theory, please see [37].

Another influential theory in selective attention literature is the "biased competition model"[38]. The central tenet of this model is that limited capacity in our information processing systems leads to competition for attention between represented information. Emotions can enhance perceptual processing due to their enhanced perceptual distinctiveness, leading to bottom-up prioritization of emotional stimuli. Moreover, top-down factors (such as past experience or environmental context) can similarly influence the competitive bias to enhance the prioritization of one stimulus over the rest. The main implication is that selective attention occurs when stimuli presentation allows for direct competition between stimuli (Fig. 1).

Insert Figure 1 about here

In order to understand the interaction of emotion and attention at the neural level, researchers have looked at how particular brain regions such as the amygdala process emotional information when attentional resources are available and when they are limited. Previous brain imaging studies have reported mixed findings regarding the engagement of the amygdala under attention control conditions. While some studies found amygdala activation in response to threating stimuli without engaging attentional resources, others have provided evidence that amygdala responses may be modulated by selective attention[39,40]. In a study by Vuilleumier et al.[41], emotion and attention were independently manipulated in a paradigm where participants were instructed to do a matching task. Participants were presented with two faces and two houses arranged in horizontal or vertical pairs and asked to match two faces in either the horizontal pairs

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(upper picture) or on the vertical pairs (lower picture). The faces were sometimes emotional (fearful) and sometimes neutral in expressions (Fig. 2). Findings showed that while activation of the fusiform face area (a primary region involved in face processing) was modulated by spatial attention manipulation, the amygdala showed consistent responses to the emotional expression of the faces, irrespective of the attentional manipulation.

Insert Figure 2 about here

Studies such as Vuilleumier et al.[41] suggest that processing of facial expressions can occur automatically and support the possibility that the amygdala detects emotionally relevant stimuli quickly even without conscious awareness. Because the amygdala was unresponsive to attentional manipulation in this study, it was suggested that emotional processing does not require attentional resources. In order to test this further, Pessoa et al.[42] examined how emotional responses are modulated by attentional resources. Their design used the same images of faces but with two conditions: an attended face condition and an unattended face condition. In the attended face condition, subjects were required to indicate whether the face was male or female, while in the unattended face condition, subjects indicated whether the bars were of similar orientation (Fig. 3). Contrary to previous findings such as Vuilleumier et al.[41], it was found that when attentional resources were available, all brain regions responded to the emotional faces differently than the neutral ones. However, when attentional resources were depleted by another task (judging the orientation of the bars), the differential activation in responses to emotional vs. neutral faces was diminished. Unlike the Vuilleumier study which showed no evidence for modulation of activity in the amygdala in response to attentional demand, Pessoa concluded that

attention is necessary for the processing of emotional items. It is worth mentioning that Pessoa used a task manipulation that was more effective in depleting attentional resources than the Vuilleumier"s study.

Insert Figure 3 about here

In addition to the studies mentioned above, there is now a considerable empirical literature focused on better understanding the relation between emotion and attention using various methods such as filtering (Stroop task, dichotic listening), searching (visual search), cueing (dotprobe, spatial cueing), and multiple task paradigms (attentional blink). Using these methods, behavioural studies shed light on some interesting issues, such as whether attention to emotions during emotional bias occurs with/without awareness or if it requires attentional control, or what is the sufficient intensity level for threatening stimuli in order to influence our attentional biases. The basic conclusion that can be drawn from these studies is that emotional information, particularly negative information, can elicit prioritization of attentional resource allocation relative to non-emotional information. However, the main challenge facing researchers is to define how the classification of valence occurs and to what extent different types of classification of emotional information may bias attentional systems – for instance, perceptual (perceptual features of the faces such as eye region) vs. semantic (subjective rating) classification. Details of these studies are beyond the scope of this chapter, but for further information we refer our readers to Yiend [43]. Now that we have provided a brief background on how emotional information can influence attentional processes in general, we discuss studies that examined the age-related changes in attentional biases toward emotional items.

3.1 Behavioural Findings

One of the early pieces of experimental evidence of attentional positivity preference in aging comes from works by Mather and Carstensen [44] using the dot probe task. In the dot probe paradigm, participants were shown a pair of faces: one emotional (either positive or negative) and one neutral. After the faces were removed, a dot appeared in the location of one of the faces. The participants were then required to respond by detecting the dot as quickly as possible. Older adults exhibited faster responses in detecting the dot when it was in the same location as neutral faces, compared to when the dot was presented in the location of negative faces. Based on these findings, it was argued that during the initial attentional bias, older adults were avoiding negative information, and therefore detecting the dots in the location of negative faces took longer than detecting the dots in the location of neutral faces.

Isaacowitz et al. [45] investigated attentional biases among older adults using the dot probe task in conjunction with an eye-tracking device. Using an eye-tracker in this context has several advantages; first, it enables the researcher to track the gaze of participants, and second, it can provide an indirect measure of participants" attentional biases. The results from Isaacowitz"s study showed that older adults spent more time looking at happy faces than sad and neutral faces, but younger adults spent equal amounts of time looking at both happy and sad faces. Moreover, among older adults, faster reaction times in detecting the dot were found when the dots were positioned with the happy faces. In addition to supporting the attentional bias toward positive items, these studies suggest that the bias toward positive items occurs at a relatively early stage of attentional processing.

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To clarify more precisely how early the positivity bias emerges during attentional processing, Isaacowitz et al. [46] examined the time course of the positivity effect and demonstrated that the positivity preference among older adults emerged 500ms following stimuli onset and increased over time. Thus, the question becomes whether we can conclude that positivity bias among older adults requires cognitive resources as it happens at a later stage of attention, or if it occurs without cognitive control resources. According to the cognitive control hypothesis, the positivity effect relies on the availability of cognitive resources[47], but some studies failed to support this account, suggesting that the positivity effect might not be fully dependent on cognitive control resources[48,49]. Thus, it remains unclear whether the positivity effect relies on cognitive control mechanisms or if it is automatic.

In order to investigate the underlying cognitive resource dependency of the positivity effect, some studies have used a dual task paradigm. In this paradigm, participants were asked to perform one task, while their attentional resources were divided and deployed in another secondary task. Knight et al. [50] asked young and older adults to passively view emotionalemotional and emotional-neutral pairs of faces with angry, happy, and neutral valences while a secondary task was presented (auditory music). Both fixation and proportion of the fixations toward emotional items relative to the neutral items were measured using an eye-tracking device. The results suggested that when attentional resources are limited (divided attention condition or doing the dual task), attention is more likely to be drawn toward negative stimuli. When full cognitive resources were available (full attention condition), older adults exhibited positivity preference, thus suggesting that the positivity effect requires cognitive resources. Following this study, Allard and Isaacowitz [51] conducted a similar study using the dual

task paradigm but with a within-subjects rather than between-subjects design. The results indicated that regardless of conditions (divided or full attention), older adults showed preference in their fixation for positive and neutral pictures relative to negative pictures. Hence, contrary to Knight''s findings[50,52], this study suggests that the positivity effect might not be fully dependent on cognitive resources.

It has been argued that positive gaze preference toward positive items in attention reflects the regulatory mechanism that older adults benefit from to down-regulate their negative emotions and moods. In the context of the SST, the positivity effect in information processing can help older adults regulate their mood and optimize their affect. In order to test this possibility, several studies have examined gaze preference as a tool when older adults are in a negative mood. In line with this hypothesis, older adults demonstrated enhanced gaze preference to positive items when they were in a negative mood[53]. This idea has prompted the question of whether the positive gaze preference functions to improve mood over time.

For instance, Isaacowitz et al. [54] investigated the link between fixation patterns and mood as a function of age. Older adults who started a task in a positive mood retained their positive mood throughout the experiment. Interestingly, those older adults who resisted decline in their mood over time were those with good executive control ability. They also displayed positive gaze preferences by looking at happy faces and away from angry faces. Therefore, it seems that older adults do not only use their positive gaze preferences as a strategy for emotion regulation; they are also capable of using positive gaze preferences to regulate their mood in real time. In support of this finding, Larcom and Isaacowitz [55] found that older adults were more likely to rapidly regulate their emotions than younger adults. Moreover, older individuals who rapidly

regulated their negative mood had lower trait anxiety, neuroticism, and depressive symptoms, and a higher level of optimism, relative to those who did not regulate their negative mood. Thus, it seems that positive gaze preference can function as a regulatory mechanism tool among older adults, which they utilize it over an extended period of time.

There is also the possibility that the positive gaze preference among older adults reflects their motivation or desire to change their bad mood, and consequently requires a substantial level of cognitive control. Therefore, a number of studies questioned whether full cognitive effort is required to display positive emotional preference among older adults. If positive gaze preference is a regulatory mechanism, then it requires cognitive resources to operate. Allard et al. [56] conducted an experiment to test whether the gaze is used among older adults as a regulatory strategy in the absence of explicit instruction. They investigated this effect by using mood induction (happy, negative, and neutral) in addition to recording pupillary responses while participants were viewing emotional pictures. The results suggested that lower cognitive effort (as reflected in pupillary response) was expended when older adults were engaged in positive gaze preferences while experiencing a negative mood. Their findings suggest that gaze acts as an effortless regulatory tool used by older adults in order to display positivity preference while experiencing a negative mood.

Summary: In this section, we first discussed two influential studies by Vuilleumier et al.[41] and Pessoa et al.[42] regarding how emotion and attention interact and whether attentional resources are needed to process emotional items. However, there are still debates about how emotion influences attentional control and whether processing emotional information requires full attentional resources. Then, we discussed the key studies investigating the impact of emotion

on attentional biases in late adulthood. It seems that older adults" attentional bias toward positive emotions is perhaps an adaptive strategy to regulate their negative moods or emotions, which is consistent with the motivational account of the positivity effect (e.g., SST). The cognitive mechanisms underlying such an effect are still an open question, though. It is unclear whether the attentional bias toward positive items is effortless or requires cognitive control resources. Neuroimaging studies have attempted to address similar questions and may provide further understanding of the underlying cognitive mechanisms of the positivity effect.

3.2 Neurological Findings

Although a number of studies have investigated the role of various brain regions such as the hypothalamus, amygdala, and prefrontal regions during emotional processes, it has been shown that these regions do not work in isolation, but instead form a highly connected network[40,57]. The role of regions such as the hypothalamus, thalamus, basal ganglia, cingulate cortex, anterior insula, orbitofrontal cortex, and cerebellum in processing emotional items has been documented in a number of studies[58,59]. However, it has recently been shown that each emotional category is uniquely associated with a pattern of activity across multiple brain regions and is not constrained with any one region or system[59].

The amygdala has been considered a particularly important region in emotional processes, and is a highly connected node integrating sensory and higher cognitive information (Fig. 4). Also in the aging literature, amygdala atrophy has been considered a major contributor to the positivity effect in attention and memory, the Aging Brain Model. However, there are still unresolved arguments regarding the underlying mechanism of the positivity effect. In the

following paragraphs, we briefly explain neuroimaging studies in this field and provide a summary of the current knowledge on the role of the amygdala in processing emotional items in the aging brain.

Insert Figure 4 about here

Using event-related potential (ERP) and fMRI modalities, Williams et al. [60] tested teenagers, young adults, and older adults in order to understand the brain mechanisms that underlie emotional processing with advancing age. Their findings suggest a significant decline of negative emotion recognition and increase of positive emotion recognition by age. Additionally, during the processing of fearful faces, older adults showed increased activation in the medial prefrontal cortex (mPFC) and decreased amygdala activation. However, unlike with happy faces (within 150ms), fearful faces elicited increased neural activity during the later phase (180450ms) of processing stimuli (measured by ERP). Williams et al. [60] have argued that this shift of resource allocation from early to later phases might support the selective control over negative stimuli by advancing age. Their results suggest that a shift toward increased control over negative emotions in the later stage and less control over positive emotions in an early stage might be predictive of better emotional stability with advancing age.

It seems that older adults might engage cognitive control or the emotional network differently than do younger adults. Older adults might recruit more prefrontal regions for emotional processing relative to younger adults (for review see [61]), which might reflect older adults" motivational tendency to regulate their negative affect. These neural patterns are generally consistent with the Posterior-Anterior Shift in Aging (PASA) hypothesis[8] (see Section 1.1). Recall from our earlier discussion of cognitive aging (Section 1) that healthy aging is

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associated with increased engagement of the anterior brain regions and decreased activity in the posterior regions during the cognitive task. Enhanced activity of the frontal cortices and reduced activity of the amygdala and parieto-occipital regions has been reported during processing emotional items among older adults[62] as well, which resembles the PASA pattern. St Jacques et al. [63] found support for the PASA pattern of activity during the process of emotional stimuli in a study in which participants were asked to view three sets of emotional pictures and rate each picture. Their findings suggest that the right amygdala was functionally connected to the ventral anterior cingulate cortex among older adults, and was connected to the posterior regions – including the parahippocampus and visual cortices – among younger adults. Interestingly, this study also found functional activity preservation in the amygdala among older adults, which is consistent with previous findings of Wright et al. [64] but not in line with some other studies such as Iidaka et al. [62] and Gunning-Dixon et al. [65]. These inconsistent patterns in amygdala activity might be related to the different paradigms used. For instance, in the study by Wright et al. [64], novel fearful faces were compared to familiarized neutral faces, which revealed greater amygdala activity. In the studies by Gunning-Dixon et al. [65], an emotion discrimination task was used, and participants were asked to rate the intensity of each emotional expression. Therefore, preserved amygdala activity among older adults in these studies suggests that the aging positivity bias might not be due to impaired processing of negative emotions as has been suggested with the Aging Brain Model (for details, please refer to Section 2.1.2).

Therefore, the pattern of Fronto-Amygdala Differences in Emotion (FADE) has been suggested by St Jacques et al. [66]. According to the FADE hypothesis, amygdala function remains intact throughout aging. This FADE pattern might reflect three potential mechanisms in

agerelated emotional processing. First, the increased activity in frontal regions could be related to the posterior-anterior shift in aging, which has been observed in cognitive domains as well. This shift could reflect the compensatory mechanism, as increased frontal activity was found to be predictive of subsequent memory performance for negative stimuli. Second, the age-related increased activity in the medial PFC might reflect the recruitment of self-referential processes, which have been shown to be associated with this region. In line with this interpretation, Leclerc and Kensinger [67] argued that older adults recruit this region more for positive items and less for negative, suggesting that older adults might interpret positive stimuli in a self-relevant manner. Third, FADE could reflect enhanced emotion regulation strategies by older adults for processing negative stimuli. This is consistent with the results from emotion regulation literature indicating that emotion regulation imposes substantial demands on cognitive control operations[68,69], although some studies failed to provide support for this model (See [62,70,71]).

Summary: It seems that neurological evidence supports the enhanced activity of prefrontal regions in response to emotionally valenced items. There are a number of possible explanations for this change as proposed by St Jacques et al. [66]: such enhanced PFC activity might be related to the emotion regulation strategies older adults are utilizing for down-regulating negative emotions, or it may be due to the general pattern observed in aging (PASA pattern). However, it is still unclear whether older (relative to younger) adults recruit different networks for processing emotionally valenced items or whether the strength of connectivity between brain regions involved in processing emotional items might change as we age. Furthermore, there is a need to explore how the attentional processes during encoding have an impact on subsequent outcome measures, such as memory for emotional items.

4   Emotional Memory and Aging

The effect of emotion is not only limited to attentional functions. There is now a considerable literature on how emotion can influence memories, including working, autobiographical, and long-term memories. Some studies emphasize how emotion can enhance or disrupt memory in different circumstances[72], others have examined the distinctive role of valence and arousal features of emotional stimuli on memory functions[73], and still others have investigated how some emotional information is likely to be forgotten. A number of studies have also investigated the role of different brain regions during different stages of memory such as encoding, storage, and retrieval.

Emotional information can constrain memory, a concept usually referred to as "memory narrowing". This effect reflects the phenomenon whereby memory is better for central items, which in turn disrupts memory for unrelated or peripheral items. However, not all studies reported memory narrowing for emotional items. Important emotional items are sometimes forgotten and peripheral information is preserved. According to Levine and Edelstein [72], it seems that "memory narrowing as a result of emotion, and a number of violations of the memory narrowing pattern, can be explained by the view that emotion enhances memory for information relevant to currently active goals".

Recall that according to the biased competition model[38], information is prioritized for further processing based on the competition between stimuli to reach our attentional focus. Furthermore, the "Arousal-Based Competition" (ABC) model[74] suggests that arousal modulates the strength of mental representation and determines which item will be dominated for selective

attention. This competitive process begins during perception and continues into long-term memory. Evidence supports that arousal can lead to memory narrowing, enhance the memory for gist (rather than details), and enhance consolidation, although there are still somewhat mixed findings regarding these effects (for review see [74]). Previous studies have also reported a distinction in recruitment of brain networks as a function of arousal and valence[73]. Therefore, both the valence and arousal dimension of the emotional items could modulate the strength of the memory for that item.

4.1 Behavioural Findings

In a recent meta-analysis[82] it has been shown that the aging positivity effect in memory occurs in a wide range of paradigms including long term memory, working memory, autobiographical memory, as well as decision making. A variety of stimuli such as faces, words, and pictures have also been used. Detailed descriptions of these studies are beyond the scope of this chapter, but in the following paragraphs we briefly review some of the key behavioural findings in this field before discussing the underpinning neurological mechanisms. For further details we refer our readers to a paper by Reed and Carstensen [24] and a recent meta-analysis by Reed et al. [75].

One of the earliest studies to provide important insights into age-related changes in emotional memory was conducted by Charles et al. [76], in which they assessed both recognition and recall for emotional items. Overall, they found greater age differences for negative items compared to positive items as a function of age. In both recognition and recall memory tests the memory advantage for negative items decreased with increasing age. These findings have been

replicated over the last decade and number of studies examined this effect by using different materials, such as words and pictures (for review see[75]), and different memory indices, such as response bias.

For instance, in one study participants had to decide whether they truly remembered each of the items or if they knew them more vaguely. The response biases of both age groups were examined as well as memory accuracy. Findings showed that younger adults tended to say "old" or "remember" to negative items more frequently than positive and neutral items, whereas older adults responded "old" and "remember" to both positive and negative items equally frequently[77]. These findings suggest that the positivity effect in late adulthood needs to be construed more broadly to include not only memory enhancement but also more receptiveness to positive stimuli indicated by response biases.

Although several studies showed age-related positivity bias in memory, some studies failed to support such changes[78,79]. The impact of instruction on the positivity effect has been suggested to be the main factor explaining some of these discrepancies in the literature. In the Charles et al. [76] study, participants were instructed to passively view pictures as if they were watching TV. Across two experiments, participants were also instructed to emotionally evaluate the items (e.g., rating the picture based on how it makes them feel while viewing it) or perceptually evaluate them (e.g., rating the visual complexity of the picture). Perceptual evaluation decreased older adults" ability to recall emotional items whereas the emotional evaluation did not have any impact on older adults" memory. Hence, it seems that older adults" memory for emotional items is at optimum level when they are able to encode them using their own strategies like passive

viewing, or when they can focus on the emotional ratings of the pictures, such as when they emotionally evaluated the pictures (see [80]).

As mentioned, according to the Arousal Biased Competition (ABC) model[74], arousal dimension of emotions can influence their memory storage. In line with this model, two separate neural networks processing arousal and valence have also been proposed previously[81]. In the aging literature, the question has become whether the positivity effect occurs equally for arousing and non-arousing words[82]. To date, the positivity effect has been found for nonarousing words but not for arousing words. Given that non-arousing words are thought to be remembered as a result of engaging controlled processes, Kensinger [82] concluded that the positivity effect relies on "controlled processing of emotional information".

Summary: In this section, we first provided a brief overview of how emotional items can constrain memory processing, referring to memory narrowing. Arousal features of emotional information have been shown to influence memory narrowing as well as enhance memory for gist. Next, we discussed evidence suggesting that the positivity effect in aging might occur in different stages of the memory process. However, it should be noted that several studies failed to find the positivity effect (for examples see [78,83,84]). One of the potential reasons for the lack of positivity effect in some of the previous studies might be due to the instruction. Using instruction is thought to constrain the positivity effect and consequently does not allow for the positive chronic goals to emerge naturally. Moreover, the impact of arousal and valence on memory of emotional items needs to be considered in interpreting emotional memory results in aging (see next section).

4.2 Neurological Findings

The amygdala is a major node in processing emotional items, but the role of this region is not limited to the attentional stage. The amygdala can modulate both the encoding and storage of information by interacting with the hippocampal region[85]. Buchanan and Adolphs[86] described the role of the amygdala in emotional memory by providing converging evidence from lesion, pharmacological, and neuroimaging studies. One pathway by which the amygdala is argued to influence memory is via neurotransmitter and hormonal output. Specifically, the connection between the amygdala and hypothalamus mediates the release of both epinephrine and cortisol when encountering emotionally arousing information, which consequently can influence the central nervous system and amygdala. The other pathway by which the amygdala may influence memory is via noradrenergic neurotransmission in the lateral/basolateral nuclei of amygdala. Animal studies have provided important insights into how the manipulation of activity within these sub nuclei of the amygdala could influence hippocampal and cortical function. Additionally, in a review paper, LaBar and Cabeza formulated how the amygdala mediates the role of arousal of emotional stimuli on memory, depicted in Fig. 5 (for more details, see [87]).

Insert Figure 5 about here

In addition to examining the role of the amygdala, neuroimaging studies have shown that so-called "emotional regions" (e.g., the amygdala) and medial temporal regions (e.g., the hippocampus) can influence the higher cognitive areas (e.g., the prefrontal regions) in order to encode and store emotional information. The influence of emotional regions during each memory stage serves to modulate mnemonic function and increase the likelihood of retaining the details

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of attended information (see [88] for more details). This conclusion has been supported by a review paper using the Activation Likelihood Estimate (ALE) method[89] to examine a wide range of brain regions involved during the encoding of emotional items, including the bilateral amygdalae, anterior hippocampus, anterior and posterior parahippocampal gyri, and the ventral visual stream (including the middle temporal, middle occipital, fusiform gyri, left lateral PFC, and the right ventral parietal cortex). It has been concluded that the amygdala interacts with the prefrontal and parietal cortices in order to enhance perceptual processing, semantic elaboration, and attention – which in turn influence subsequent emotional memory performance.

Interactions between emotional and cognitive processes occur at multiple levels of processing and across many different types of memory and cognitive tasks. However, relatively little is known about the relation between emotion and working memory (WM), specifically. Recent investigations have found that emotional distraction during a WM task reduces performance[90]. This behavioural effect has been shown to be related to enhanced activation in brain regions involved in emotional processing, along with decreased activity in brain regions associated with active maintenance of relevant information in WM. Furthermore, it has been shown that top-down attentional regions were involved while attending to the relevant and ignoring the irrelevant items during the encoding stage of the working memory task. The important consequence of goal-directed attention during encoding is to enhance the impact of behaviourally relevant stimuli at the expense of ignoring irrelevant stimuli. Thus, emotional stimuli may affect goal-directed behaviour by either enhancing or disrupting task-relevant processes during both the encoding and retrieval stages of WM.

Underlying neural mechanisms that might explain behavioural asymmetry in memory with aging have been examined in a number of studies. In one study, Kensinger and Schacter [91] examined the emotional memory network by using a subsequent memory paradigm. In this paradigm, participants viewed a series of pictures during encoding and were then asked to judge whether each picture would fit inside a cabinet drawer. Outside the scanner, participants had to indicate whether each picture was the same, similar, or new. This paradigm previously showed enhanced memory for negative items in younger adults, and overall emotional memory bias relative to neutral items in older adults[79,92]. Kensinger and Schacter [91] found an age-related effect emerged during the encoding of positive items, where older adults showed stronger activity than younger adults in the medial PFC. As this region has been shown to be activated during selfreferential tasks[71], it was argued that older adults might process positive information in a more self-referential manner, which in turn will result in better memory for positive items[81]. The activity of frontal region replicated in another study during processing of positive (relative to negative) words but not pictures[93].

Effective connectivity has been used to examine age-related changes in connectivity between regions involved in emotional memories[94]. Age-related changes were observed only for successful encoding of positive items, and not negative. The results showed that older adults'' hippocampal activity was modulated by the amygdala and ventromedial regions, and no age differences were observed during encoding of negative items. These results indicate that there might be age-related changes in how positive items are being processed, rather than changes in the processing of negative items[94].

The functional relationship between subcortical regions (such as the amygdala and hippocampus) and cortical regions during both memory encoding and retrieval has been examined by Murty et al. [95]. They investigated age-related changes in declarative memory using neutral and aversive stimuli in both younger and older adults. During encoding, older adults showed significantly greater dorsolateral prefrontal cortex (dlPFC) activity for aversive stimuli relative to younger adults. During retrieval, older adults showed greater coupling between the dlPFC and amygdala, whereas younger adults showed increased valence related activity (aversive > neutral) in the amygdala and hippocampus. These findings are in line with the compensatory hypothesis (see Section 1.1), as older adults recruited more prefrontal regions during both recognition and encoding. Moreover, these results also might suggest that older adults recruited PFC regions to a greater extent than younger adults in order to down-regulate their negative emotional reactions.

There is mounting evidence regarding age-related changes in the way that older adults process and remember emotional expressions on faces (see Section 5 for more details). To extend previous studies on emotion recognition, Fischer et al. [96] investigated the memory of facial expressions of fearful and neutral faces among younger and older adults. No memory recognition advantage for emotional items (relative to neutral items) was found in either age group, but older adults recruited more PFC and insular regions while processing negative faces. This finding is consistent with the general pattern of age-related shift in cortical-subcortical recruitment, as discussed in Section 1 (Cognitive Aging) and Section 3 (Emotion and Attention in Aging). It is also important to consider the link between different stages of cognitive processes, such as

attention, recognition, and memory, in order to form a more comprehensive picture of emotional processes in aging.

Summary: In this section we first provided evidence of how the brain processes emotional items and how different brain structures interact to form memories of emotional items. Then, we presented results from behavioural and neuroimaging studies supporting the possibility that older adults might process positive and negative items differentially. However, there is need for further investigation in this area to provide direct evidence on the age-related changes in recruiting brain networks involved during encoding of different emotionally valenced items. It seems that there might be different networks engaged in processing emotionally-valenced items as a function of age, but the evidence is disparate. Although some studies failed to observe positivity bias in memory (for instance see [78,84]), this discrepancy might be influenced by the conditions, the task instructions, and the paradigms that have been used across different studies.

5   Emotion Recognition and Aging

Recognizing emotions on the face is one of the most fundamental aspects of our social communications. There is now a considerable literature focused on how different facial emotions are processed in late adulthood. In this section we introduce behavioural evidence in relation to the most studied emotions, happy and angry emotions, and then describe some of the neuroimaging findings on the topic. There is an increasing interest in understanding the link between the way older adults process emotional items and their ability to detect and respond to social cues in everyday life interaction. However, the social cognitive aspect of aging is beyond

the scope of this chapter. For more information on this topic, please refer to Phillips et al. [97] and Von Hippel and Henry [98].

Empirical evidence suggests that relative to younger adults, older adults have difficulty recognizing negative emotions such as fear, anger, and sadness – findings which have been reviewed in a meta-analysis by Ruffman et al.[99]. However, critical issues have been raised regarding the studies examining emotion recognition in aging. First, the people who model various emotional facial expressions in the photos used in these studies were either young or middle-aged. Secondly, presenting static images lowered the ecological validity of these studies. Such methodological issues make the conditions for facial emotion recognition dissimilar from everyday life experiences, and have been argued to affect our understanding of emotion recognition with advancing age. Therefore, it is important to address some of these methodological issues in more detail before discussing the relevant findings.

One of the methodological caveats that has been addressed in several studies is the age of the models used for facial expression photos. Some of the earliest evidence regarding the potential importance of model age was presented in a study using the Multi-Source Interference Task (MSIT) by Ebner and Johnson [100]. It was shown that both younger and older adults were more distracted by faces similar in age to themselves. They extended this initial study by investigating the visual scan patterns of different ages displayed with different facial expressions[101]. The results suggested that age of model influences visual inspection of the face (measured by total gaze times). That is, both age groups spent more time on faces similar to their own age relative to other-age faces. Moreover, they found that spending a longer time looking at

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the own-age faces predicted better own-age emotion identifications. According to a review paper by Folster et al. [102], "[l]ower expressivity, age-related changes in the face, less elaborated emotion schemas for older faces, negative attitudes toward older adults, and different visual scan patterns may lower decoding accuracy for older faces". Therefore, it seems that using older models might add valuable insight into our understanding of emotion recognition, a view that previously had not been considered widely.

In order to address the ecological validity of stimuli used in emotion recognition studies, more dynamic stimuli sets have recently been used to examine age differences in emotion expression identifications. Sze et al.[103], for instance, found that older adults had difficulty judging emotional expressions from static images (e.g., angry and disgusted), while they outperformed younger adults in continuous emotion recognition using a dyadic interaction. Therefore, it seems that using dynamic stimuli that resemble everyday situations will influence the accuracy of emotion recognition and will enhance judgment of the authenticity of the expressions. Using dynamic emotional expressions will not only increase ecological validity but also enhance activity in areas involved in emotion and processing socially relevant information[104]. For instance, Schultz and Pilz [105] reported more activation in response to dynamic faces in face-sensitive areas, including the bilateral fusiform gyrus, the left inferior occipital gyrus (IOG), and the right superior temporal sulcus (STS).

It is worth noting that there are mixed findings regarding dynamic stimuli such as video clips[106]. For instance, using video stimuli for recognition of basic emotions in the face and body, as well as incorporating body, facial, and situational cues, has shown that older adults still perform worse than younger adults in recognizing some emotions[107] (also see [108,109]). Ruffman [110]

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has argued that using static images for emotion recognition has reasonable ecological validity and more importantly explains the age differences in various tasks such as social understanding (using a faux pas task[111]), verbosity[112], and deception[113]. Therefore, it seems that although using dynamic stimuli is an important methodological consideration and a number of studies provide support for the use of dynamic stimuli, static emotional stimuli are also informative.

Given that most of the studies mainly focused on the two basic emotions of anger and happiness, in the following section, empirical evidence regarding these two emotions will be discussed.

5.1 Behavioural Findings

5.1.1 Anger

There are evolutionary reasons for quicker detection of threat-related stimuli from a survival point of view. There is also empirical support for this perspective, with younger adults detecting an angry face more quickly than a non-threatening face[114]. Mather and Knight[115] demonstrated a similar effect in aging by looking at the visual search task using nine schematic faces in a search array. Both age groups tended to identify angry faces quicker than sad and happy faces, known as the pop-out effect. In another study, real faces were used in addition to the schematic faces[116]. Participants were asked to identify whether all faces were identical or if one of the faces was different in the array of faces, and in a second experiment, participants were also asked to label the emotion of the face that was different from the rest of the faces in the search array. It was found that although older adults were less accurate in labelling the angry schematic and real faces compared to younger adults, they responded as quickly as younger adults to the

angry faces when they had to identify the different face from the array. It has been argued that at some level (probably more an implicit level) older adults are able to differentiate angry faces equally as fast as younger adults.

Older adults" responses to angry facial expressions have been studied using electromyography (EMG)[117]. EMG measures changes in activity of the facial muscles that index the implicit mimicry responses toward stimuli. No age differences in corrugator supercilii (which pulls the eyebrow muscles into frowning) responses to angry expressions were found in the early stage (200-500ms post-stimulus onset). However, older adults" corrugator supercilii responses to anger in the later stage (500-800ms post-stimulus onset) were associated with difficulties in labelling the emotions. Although older adults might not have difficulty with implicit angry mimicry responses, the mimicry in the later stage might have been confounded by their difficulties in labelling the expressions. Future studies examining dynamic stimuli and unfolding emotional responses over time by using mimicry responses are necessary in order to better understand when age-related differences in identifying angry emotions emerge, and whether such differences have consequences in everyday life interactions.

5.1.2 Happiness

While converging evidence supports the idea that younger outperform older adults in recognizing negative emotions, the evidence for age-related changes in identifying positive emotions is not clear. In a review paper by Isaacowitz et al.[118], 11 out of 13 studies reviewed showed no age effect for recognition of happiness, possibly due to the ceiling effect. However, Ruffman et al. [99] reported age differences for recognition of happiness. Medium effect size in

recognition of happiness from voices (mean effect size (M) = .37) and matching voices to faces (M = .42) have been reported in the Ruffman et al. [99] meta-analysis. Given that dynamic stimuli provide additional temporal cues and resemble more naturalistic occurrences of daily social interaction, they may allow for more accurate emotion discrimination. Using dynamic stimuli rather than static images may allow older adults to use their lifetime experience in distinguishing different emotional expressions, such as happiness[119].

Given the older adults" preference toward positive stimuli, the question has been raised whether such preference is extended toward different types of smiles, such as a posed versus spontaneous smile. In order to investigate older adults ability in discriminating smile types, Murphy et al.[119] conducted a study in which actors were videotaped while they gave expressions in response to three situations: receiving news that they won a prize, being invited on a cruise with friends, or being left out of a group or not invited. The actors" posed and spontaneous smiles were identified by coders using the Facial Action Coding System (FACS)[120]. Synthetic results from two experiments using these video clips suggest that older adults showed superiority in distinguishing posed vs. spontaneous smiles compared to younger adults. Given that dynamic stimuli contain temporal information about emotional expressions and are an approximation of real word experiences, older adults may use this information to judge and discriminate between smile types – particularly when the stimuli involve a different age group. However, the underlying mechanism of how older adults use these temporal cues to discriminate posed from spontaneous smiles is not fully understood.

The question of age-related changes in emotion recognition of faces has been brought forward to investigate whether sensitivity in discriminating different types of smiles can impact the social meaning underlying these smiles. The ability to distinguish smiles has been shown to play a crucial role in interpersonal functioning[121]. In addition, increased difficulty distinguishing between smiles is associated with greater social functioning impairments among autistic individuals[122]. The question is how these changes in emotion recognition are linked to older adults" social functioning. In one study[123], older adults were asked to choose from whom they would ask a favour between people with a spontaneous enjoyable smile, a posed enjoyable smile, and a deliberately-posed non-enjoyment smile. Although there were no age differences in discriminating between spontaneous and posed smiles, contrary to Murphy et al. [119] study, older adults were more likely to ask for a favour from a person displaying a non-enjoyment smile.

Hence, it seems that older adults are less likely to base their judgment on these social cues (enjoyment smiles/genuine), which can offer cooperation, approachability, or reciprocation in social interaction. Whether this age difference in approaching the non-enjoyment smile could influence older adults" social functioning, and in turn, could make them more prone to fraud as a result of approaching deceptive smiles, is a topic for further investigation in the field of emotion recognition and aging.

Additionally, dynamic stimuli were used in another study to investigate the age-related changes in identifying emotional experiences accompanying three different smile expressions[124]. Smile expressions are shown in different emotional contexts, including when people feel happy or amused. Thus, rather than using two types of smiles (posed/non-enjoyment vs. spontaneous/enjoyment), actors were filmed in three different conditions in which they were

asked to display a smile: first, as if they were being accused of something unfairly; second, as if they were watching an amusing film or cartoon; and third, in an affectively neutral situation. Older and younger adult participants were asked to identify the emotional experience of each of these models. Overall, they found that younger adults were more accurate than older adults in identifying the emotional experiences accompanying each smile. Older adults were better at correctly ascribing positive affective experiences to the older models than the younger ones. Although these results are in contrast with some previous findings[119,123], it seems that the context of displayed emotions associated with different types of smiles is an important factor in understanding the age-related changes in recognition of happy facial expressions.

Slessor and her colleagues[125] have looked at the time course of mimicry responses to enjoyment and non-enjoyment smiles. The activity of the *Zygomaticus major* muscle region (which pulls the corner of the lips into a smile) and the *Orbicularis oculi* muscle region (which forms wrinkles around the outer corners of the eyes) were recorded. No age differences were found in the pattern and timing of *Zygomaticus major* activity in response to either type of smile. However, older adults showed extended *Orbicularis oculi* contraction in response to the nonenjoyment smiles. Moreover, older adults rated both types of smile as happy independent of the *Orbicularis oculi* responses. These results suggest that emotion recognition and mimicry responses might rely on different processes. Further investigation is warranted to replicate these findings and examine the timings of these two processes by using high temporal resolution techniques such as Electroencephalography (EEG).

5.2 Neurological Findings

In addition to the role of the amygdala in attention and memory functions, this region plays a crucial role in processing emotional expressions from faces and decoding other socially relevant cues such as eye gaze (for review see [126,127]). One of the earliest insights into the key role of the amygdala in processing facial expression was provided by a review on brain lesion and neuroimaging studies by Adolphs [128]. Most of the neuroimaging studies of emotion at the time were confounding the encoding, retrieval, experience, and reaction to emotions, which makes it difficult to specifically attribute activation of the amygdala to any one of these psychological functions. However, our understanding of the neural mechanisms involved in processing facial expression has advanced from brain lesions and neuroimaging studies.

Two visual streams have been identified in non-human studies: one for object recognition leading to the temporal lobe called the ventral stream, and one for localizing objects in space leading to the parietal lobe called the dorsal stream[129]. Although a number of studies have addressed the dissociation between the two streams in processing concrete information, this dissociation has not been addressed in relation to emotion. Adolphs et al.[130] investigated the naming and recognition of emotion in a patient known as patient B., who has an impairment in retrieving conceptual knowledge for many different entities. They hypothesized that this patient might be able to recognize emotion from dynamic stimuli, but not from static ones. The results suggested that patient B. was able to recognize emotions at the basic level of categorization if the stimuli contained temporal information. The fact that he was impaired in recognizing and verbally labelling emotions from static pictures suggests that recognizing emotions and labelling emotions rely on distinct neural systems. The other interesting finding from this study was that

the patient had difficulties recognizing fear and anger, but not happiness and sadness. This finding could suggest that "conceptual knowledge of emotions might be organized in subordinate and superordinate levels"[130]. Primary categorization of emotions falls into superordinate categories such as "happy" and "unhappy" distinctions based on the valence. Patient B. can recognize happiness and sadness in most cases, perhaps because these sadness and happiness categorizations are examples of superordinate categories, but anger and fear fall in between and require more basic level recognition (subordinate). Therefore, it seems that such dissociation might be related to the impairment in subordinate categorization level rather than superordinate. The other explanation might be that this dissociation reflects that he fails to retrieve knowledge about arousal but is able to recognize information regarding valence.

Another reported case is patient Roger by Feinstein [131], who has bilateral damage to the insula, ACC, medial PFC, OFC, basal forebrain, hippocampus, amygdala, parahippocampal gyrus, and temporal poles. One of the interesting findings from comparing patient Roger and B. is that emotion relies on a highly distributed network and not attributable to a specific brain region. Although these two case studies are informative and provide valuable knowledge about the causal role of these brain regions in emotion recognition, neuroimaging techniques can provide alternative perspectives in order to understand the underlying neural networks and the relation between brain regions during emotion recognition.

One of the early studies in emotion recognition in aging using an fMRI was carried out by Iidaka et al. [62], in which participants were shown pictures of six different facial emotions (happy, angry, disgusted, fearful, sad, and surprised). Participants were asked to label the gender of the actor modelling the emotional expressions, as well as the intensity of each emotion. The results

suggested that relative to younger participants, older adults showed reduced activity in the medial temporal lobe in response to both negative (e.g., left amygdala) and positive emotions (e.g., right parahippocampal gyrus). None of these regions showed increased activity among older adults. This dissociation in decreased activity of the medial temporal lobe may suggest that aging might affect the neural networks involved in processing emotionally valenced facial expressions differently.

In another study, Gunning-Dixon et al.[65] investigated facial emotion processing using a task in which they asked participants to discriminate the age of the models during an emotion discrimination task. Older adults recruited more frontal regions relative to the temporo-limbic regions, which were more activated among younger adults. The authors argued that the decreased activity of the amygdala in the emotion discrimination task relative to younger adults was consistent with post-mortem studies of age-related loss of neurons in the limbic regions.

However, these data need to be interpreted cautiously, as the sample size of this study was very small (8 participants), and consequently low statistical power could affect the generalizability of the findings.

It has been argued that the emotion recognition difficulties observed with aging might be associated with the cognitive declines associated with advanced age. In order to minimize the role of cognitive mechanisms involved in processing emotional items, a passive viewing paradigm was administered by Fischer et al.[70]. They examined age-related changes in emotional face processing by using a relatively larger sample size than previous studies (24 younger and 22 older adults). Pictures of angry and neutral faces were presented to participants. The results

showed reduced amygdala activity for negative faces among older adults relative to younger adults. Moreover, increased activity in the anterior-ventral insula cortex was found among older adults in response to negative faces. Again, the age-related increases in engagement of cortical regions for processing emotional faces could reflect "compensatory mechanisms" older adults use for processing emotional faces[70]. The inconsistencies of the results of amygdala activity in Fischer"s study and previous studies mentioned above[62,65] could simply be related to methodological differences. Specifically Fischer"s[70] study used a passive viewing paradigm, whereas the other two studies included labelling and emotion discrimination tasks, which could potentially involve more top-down modulation of sensory information contributing to the discrepancy between the results.

As discussed, the ecological validity of stimuli, such as using own-age faces, is a critical methodological factor in emotion recognition studies in aging. In a neuroimaging study, Ebner et al. [132] addressed the role of identified regions of interests (ROIs), such as the ventromedial prefrontal cortex (vmPFC), dorsomedial prefrontal cortex (dmPFC), and amygdala, in identifying emotional expressions as a function of the age of the faces presented to participants. First, the results showed that greater vmPFC activity emerged for identifying happy (relative to angry) faces. Second, both age groups showed enhanced activity of the amygdala in identifying happy relative to negative emotions, suggesting the saliency of positive affective processing. Greater activity of dmPFC was found in response to angry faces among older adults, indicating older adults" difficulty in recognizing angry faces. Thus, the results of the Ebner et al. study[132] highlight the underlying neural mechanisms involved in processing own-age faces during emotion recognition tasks.

Ebner et al.[133] further demonstrates the importance of the age of faces used as stimuli in aging studies. In this study, the ability to identify emotion was examined in younger and older adults as a function of own-age vs. other-age biases and emotional expressions of the faces. In both age groups, greater activity in the ventromedial PFC and insula for own-age faces was found, particularly for happy and neutral faces, but not for angry faces. These findings provide additional support for the differential neural mechanisms involved in processing own-age faces relative to other-age faces, which need to be considered in facial emotion recognition studies when comparing different age groups.

6   Closing Remarks

The main focus of this chapter was to introduce recent findings in the field of emotional aging. We focused three main domains and explored how the emotion influences attention, memory, and face recognition systems. To gain a better understanding of age-related changes, the underlying mechanisms of how emotions impact various cognitive functions needs to be fully understood. As has been discussed, the distinction between whether attention influences emotions or vice versa has not been fully clarified by recent studies. Instead, widespread networks linking emotional and cognitive domains suggest that these areas are working in concert, and this perspective needs to be considered in life-span developmental research as well. Hence, rather than looking at changes with age in isolated areas (such as the amygdala), change in the network and interregional connections needs to be a primary focus.

To reach a more comprehensive understanding of emotional changes in aging, there is a need for research that integrates emotion and cognitive domains. Existing hypotheses and

discoveries from the cognitive domains can be borrowed and adapted to obtain a better understanding of emotional aging. Some attempts to link the cognitive and the emotional aging literature have been launched over the past few years. For instance, the proposed FADE hypothesis in emotional aging has been influenced by the PASA hypothesis from cognitive aging studies. However, further research is required to reach a more comprehensive and integrative model in aging.

There are still several questions in the emotional aging literature that need further investigation, including, Can different biases toward emotional items be beneficial for older adults and if yes, through what mechanisms? Can emotional enhancement or emotion regulation be considered a compensatory mechanism for cognitive deficits that occur with advancing age? Can changes in emotional processing have consequences/implications for social aspects of aging? Future research is required to provide a more comprehensive and integrative model of existing findings in the cognitive, emotional, and social domains of aging.

In the face recognition literature, happy and angry expressions have been investigated extensively. Further studies are now required to examine age-related changes in other domains (such as trustworthiness, pride, and shame) by considering the ecological validity of the stimuli set. Given that some behavioural studies provided support for the importance of temporal cues and the age of face models used to measure emotion recognition ability with advancing age, using more ecologically valid stimuli in combination with fMRI, Magnetoencephalography (MEG), and Electroencephalography (EEG) methods would open new avenues for better understanding the underlying neural mechanism of age-related changes in emotional processes in general.

7. Acknowledgment

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Figure Captions

Fig. 1. Biased competition model of visual attention and process of emotional information presented by Pessoa and Ungerleider, 2004. Courtesy of Dr. Pessoa.

Fig. 2. Example of experimental design presented by Vuilleumier et al. 2001 to examine the emotion and attention relationship. Courtesy of Dr. Vuilleumier.

Fig. 3. Example of experimental design presented by Pessoa et al. 2002 to examine the emotion and attention relationship. Copyright (2002) National Academy of Sciences, U.S.A. Courtesy of Dr. Pessoa.

Fig. 4. Brain connectivity graph presented by Pessoa, 2008 (40). This graph shows that the amygdala is a strong region integrating emotional and cognitive information as it links multiple hubs from separate functional clusters. Courtesy of Dr. Pessoa.

Fig. 5. The mechanism by which the amygdala mediated the influence of emotion on memory proposed by LaBar and Cabeza, 2006. Courtesy of Dr. LaBar.
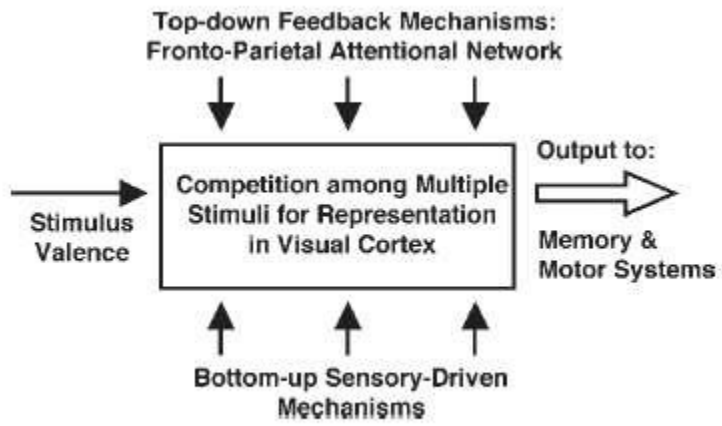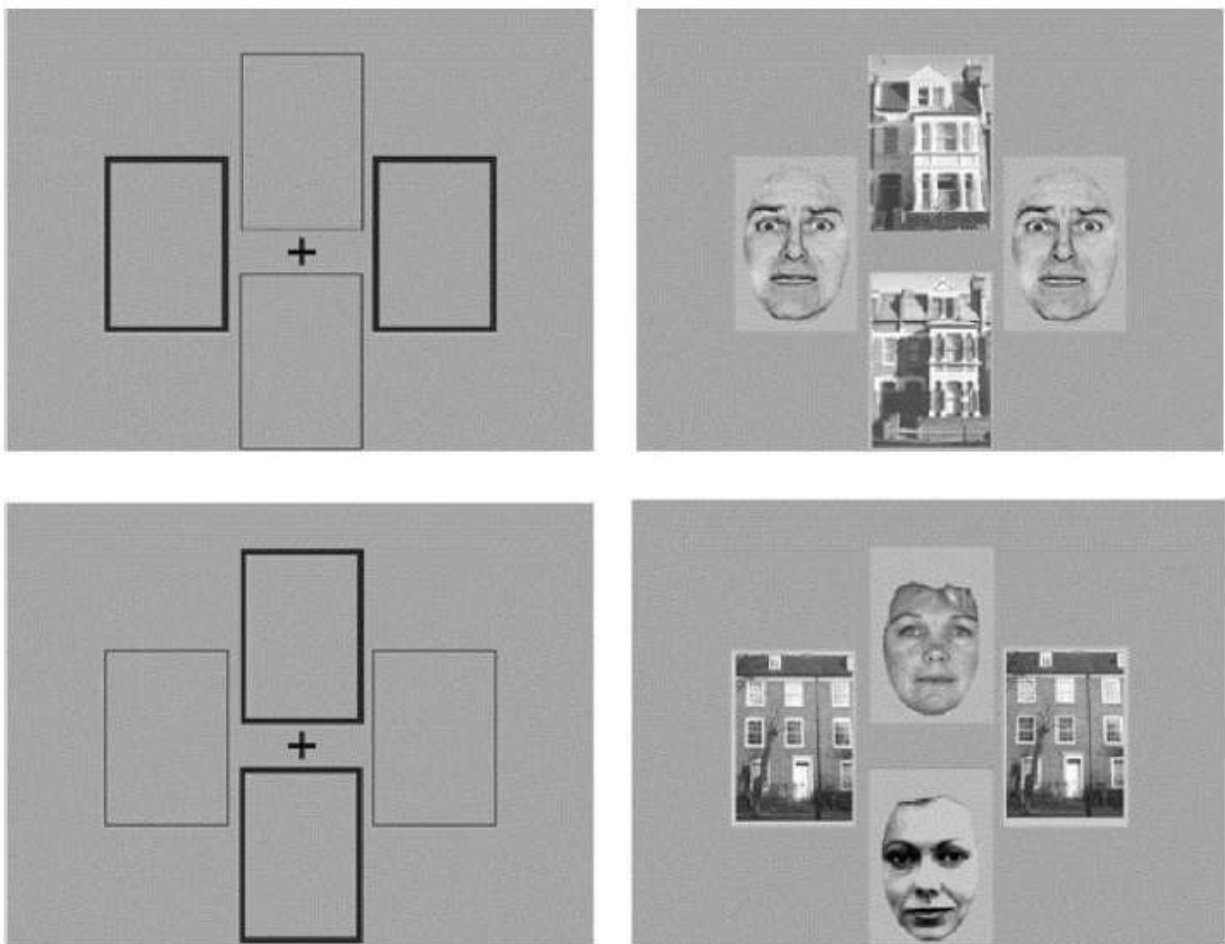
Fig.1

Top-down Feedback Mechanisms:
Fronto-Parietal Attentional Network

Stimulus Valence

Competition among Multiple Stimuli for Representation in Visual Cortex

Output to:
Memory & Motor Systems

Bottom-up Sensory-Driven Mechanisms

Fig.2

Fig.3

Fig.4

Fig.5