Visual perception and cognition in healthy aging

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James Henry Chard

Birkbeck, University of London

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ABSTRACT

Healthy aging is accompanied by a complex set of physiological, neurophysiological and psychological changes. There has been particular interest in social cognition deficits in older adults, which are often attributed to changes in a postulated 'social brain' network. Lower level perceptual difficulties tend to be discounted due to an expectation that they could not account for a nuanced pattern of preservations as well as deficits. This thesis focuses on visual perception, presenting signal detection experiments assessing whether older adults exhibit difficulties integrating local features into a coherent whole (i.e. processing global configurations), alongside relative preservation in processing local features themselves.

Chapter 3 presents evidence of age-related decline in sensitivity to postural cues in point light walkers, with preserved kinematic sensitivity. Chapter 4 demonstrates reduced sensitivity to the presence of an emotion thought to be conveyed primarily by postural body language cues (happiness) but preserved sensitivity to emotions conveyed primarily by kinematics (sadness and anger). Cross-experiment comparisons support the conclusion that impaired postural processing contributes to that pattern. Chapters 5 and 6 assess whether findings on posture and kinematics reflect broader deficits in sensitivity to global configurations relative to local features. Chapter 5 does not find evidence of age-related configural processing difficulties employing a composite face paradigm, but more direct manipulation of configurations and features in Chapter 6 provides evidence of such a deficit.

A range of changes in healthy aging could account for patterns of change in visual perception. However, the underlying hypothesis arose from evidence of impaired neural connectivity related to reduced white matter tract integrity in older adults. Chapter 7 reports an

experiment involving older adults' sense of agency, implicating a wider neural network. Significantly reduced sensitivity was found in a task involving identifying whether self-generated hand movements corresponded with visual feedback, compared with a control task involving passive observation of an avatar.

In conclusion, this thesis provides evidence of difficulties in older adults processing spatial configurations, alongside preliminary evidence of broader integration problems. Findings provide an alternative explanation for social cognition changes in later life and may prove key in scaffolding strategies to reduce real-world effects.

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CHAPTER 1: INTRODUCTION

1.1 Patterns of change in healthy aging

Healthy aging in later life is accompanied by a complex pattern of changes including those of a physiological, neurophysiological, and psychological nature. Many such developments are in the same direction and manifest themselves as increasingly degraded perceptual inputs, deterioration in performance in a wide range of cognitive tasks and, to some degree, in worsening measures of mental as well as physical wellbeing.

However, this pattern is neither universal within nor between aging adults. Declines differ widely in their onset and trajectory and there are patterns of relative, and in some cases absolute, preservation which are common across older age-groups. Some individuals can also maintain high levels of cognitive performance far into older age. This chapter will begin by reviewing some key findings in relation to changes in healthy aging, before considering potential linkages and explanations of the observed patterns of preservation as well as deficit. It will conclude by introducing the question examined in the empirical work reported in the thesis – namely, whether particular patterns of perceptual decline can explain some of the patterns of age-related deterioration, as well as areas of preservation, in social perception, cognition, and agency.

Neurophysiology

In relation to neurophysiology, neuroimaging studies have consistently shown volumetric loss of brain tissue in healthy aging in both cross-sectional and longitudinal studies (Good et al., 2001; Resnick et al., 2003). This is notwithstanding that there may be some risk of overestimating the extent of such atrophy due to the inclusion of some older participants with preclinical dementia or other cognitive disorders, because exclusions are normally made for diagnosed disorders only so samples may include some undiagnosed individuals (Burgmans et al., 2009).

Studies have consistently indicated gradual grey matter loss in healthy aging with an onset in relatively early adulthood, starting in the fourth decade of life and proceeding in a broadly linear manner (Hafkemeijer et al., 2014; Neufeld et al., 2022). However, within this global pattern there are significant localised variations in particular areas of the brain, with volumetric loss appearing to be particularly pronounced in certain regions including temporal lobe structures, particularly the hippocampus (Jernigan et al., 2001; Long et al., 2012), as well as the anterior cingulate cortex and medial prefrontal regions (Pardo et al., 2007). There is also evidence of cortical thinning within the occipital cortex including the primary visual cortex (Salat, 2004). Meanwhile, some structures appear to be relatively preserved with minimal grey matter loss well into later life, including the cerebellum (Bergfield et al., 2010).

Whilst there is evidence that grey matter volumetric loss has its onset in relatively early adulthood and that loss is broadly linear in nature, a different pattern emerges for white matter. White matter volumetric loss appears to start later, with stable white matter volume up until the sixth decade of life followed by a non-linear decline, which is slow at first but gradually accelerates into later old age, and particularly impacts temporal and frontal brain regions (Allen et al., 2005).

As suggested by differing apparent ages of onset, the underlying nature of reduced integrity of white matter differs from that applying to grey matter in some respects. In particular, axons constituting white matter are, unlike grey matter axons, characterised by a coating of compacted cell matter called myelin. Myelination has been described as akin to electrical insulation, underpinning the role of white matter in providing rapid connectivity between brain regions (Jahn et al., 2009) but has also been implicated in more actively regulating the timing of impulses across neural connections of differing length (Fields, 2014; Kimura & Itami, 2009). There is evidence of structural changes in myelin sheaths in frontal regions having an impact on conductive properties (Bartzokis et al., 2010; Peters, 2002a). Diffusion tensor imaging has indicated deterioration in the structure of myelin in healthy aging (Bennett et al., 2010; Branzoli et al., 2016). White matter decline has been implicated in reduced and more variable processing speed in older adults (Nilsson et al., 2014) and more complex cognitive processes that are considered to be particularly reliant on connections across a wide neural network (Bennett & Madden, 2014). Such white matter changes may be expected to impact especially on tasks involve integrating information across representations within modalities (e.g. local and global information within a visual stimulus, or prosody and linguistic content within speech) and even more so between modalities (e.g. reconciling information from different sensory stimuli) (McDonough & Siegel, 2018; Ribeiro et al., 2024).

Consistent with the process of demyelination noted above, electrophysiological studies have indicated increased neural noise, and specifically low frequency 1/f noise, associated with disruption of long-range communication and synchronisation between neural regions (Dave et al., 2018; Voytek et al., 2015). Under the neural noise hypothesis, age related changes in cognition may relate to increased electrophysiological noise reducing the effective signal to noise ratio (Cremer & Zeef, 1987). Increased neural noise has been associated in older adults with reduced consistency in visual processing performance (Tran et al., 2020) and in mediating declines in working memory (Voytek et al., 2015).

General cognition

As would be expected given the wide range of neurological changes, there is also a substantial volume of evidence of age-related decline in cognitive function across a wide range of domains (Deary et al., 2009). These include reduced working memory capacity (Borella et al., 2008; Dobbs & Rule, 1989), increased occurrence of inaccuracy in long term episodic memory (Korkki et al., 2021), diminished general processing speed (Eckert et al., 2010; Kerchner et al., 2012), and declines in performance in a range of inductive reasoning tasks (Zhu & Neupert, 2021). Deficits appear to become particularly pronounced in more complex tasks requiring inhibition of distractors and dominant responses (Andrés et al., 2008; Hasher & Zacks, 1988), albeit it should be noted that the extent to which this susceptibility to distraction generalises across tasks has been challenged (Rey-Mermet & Gade, 2018).

However, alongside this discouraging general picture of cognitive decline in healthy aging, there are patterns of relative preservations as well as deficits. That is, older adults appear particularly vulnerable to deterioration in certain domains and tasks, but substantially more resilient in others. For example, in relation to language, there is evidence that although deficits in language production increase, comprehension remains particularly intact in healthy aging (Burke & Shafto, 2011; Diaz et al., 2016). It has been suggested that the pattern of deficit and preservation is in some respects consistent with the concept of two broad forms of intelligence, crystalised and fluid (Cattell, 1963; Horn & Cattell, 1967). The former relies on accumulated experience, which older adults have in abundance. The latter relies on more flexible problem solving, based on the ability to solve novel problems in the absence of specific pre-existing knowledge.

Perception

In relation to visual processing, which is a central focus of this thesis, healthy aging is associated with a range of physiological changes that would clearly be expected adversely to influence visual perceptual processing. These include decline in the senescent optics of the eye (Elliott et al., 2009), and thinning of retinal nerve fibre (Parikh et al., 2007). The impact of some such physiological deterioration, such as reduced visual acuity (i.e. clarity of contrast in objects at distance), are relatively easy to compensate for with corrective lenses. However, some other impacts such as visual contrast sensitivity (i.e. distinguishing detail at low contrast levels), appear to involve more complex macular degeneration which is less easy to correct. As such, it cannot be assumed that “corrected to normal” vision implies an equivalence in visual percept between individuals, even before consideration moves from the physiology of the eye to the neurophysiology of the visual cortex.

Once additionally considering the range of neural processes required for perception, the assumption that peripheral correction (e.g., glasses) can be expected to bring perception in older adults to equivalent levels to those of younger people clearly becomes increasingly untenable. For example, fMRI studies indicate cortical thinning specific to peripheral visual field representations in the anterior primary visual cortex (V1) which is not matched by thinning in other portions of V1 (Griffis et al., 2016). Elsewhere in the early visual cortex, neuroimaging has also shown a range of visual cortical changes in healthy aging including reduced surface area and compensatory increases in population receptive field (pRF) sizes in foveal representations (Brewer & Barton, 2014). EEG studies have also indicated reduced activity in the areas associated with selective attention in visual search tasks including the anterior cingulate cortex (Lorenzo-López et al., 2008) and anterior visual N1 (Wiegand et al., 2014).

In terms of behavioural impacts of these physiological and cortical changes in the initial stages of visual processing, healthy aging is associated with specific difficulties in relation to global form alongside relative preservation in relation to local detail. In the Navon task (Navon, 1977), participants are presented with stimuli consisting of a global form made up of congruent or incongruent local forms (e.g., a large number 2 made either of congruent small number 2s or incongruent small number 3s) and are asked to quickly and accurately report either the global or local form. This allows measurement of reaction times when asked to report global and local form and, crucially, the extent to which congruency or incongruency of the non-target form facilitates or impedes recognition. In general, older adults exhibit reduced 'global precedence' effects, such that the global forms are identified less quickly and are more subject to interference from incongruent local forms (Insch et al., 2012; Lux et al., 2008; Oken et al., 1994; Slavin et al., 2002). It has also been suggested that the larger foveal pRF size noted above manifests itself in reduced fine resolution (relevant in tasks such as reading) and in foveal crowding, which diminishes abilities to perceive larger visual arrays (de Best et al., 2019).(de Best et al., 2019).

As with other cognitive changes noted in this chapter, a further feature in healthy aging appears to be a disproportionately adverse influence of task-irrelevant distractors. In relation to auditory perception, for example, older adults are adversely affected by background noise, even where hearing is preserved in other contexts (Anderson et al., 2011). Similarly, in visual tasks there is evidence that older adults' performance is significantly more adversely influenced by the presence of distractors, although there remains debate as to whether this relates to reduced inhibition of the distractor or generalised reduction in speed of processing (Ben-David et al., 2014).

Wellbeing

The focus of this introduction has been on physiological and cognitive changes in healthy aging, which may differ in onset, rate, and trajectory but, to a large extent, have a single direction of travel - deterioration. By contrast, many studies of subjective wellbeing in healthy aging suggest a different and more encouraging picture for older adults - indicating a U-shaped relationship whereby life satisfaction typically reaches a nadir in middle age (from mid-30s to early-50s) before recovering and remaining stable for some time in later life (Blanchflower & Oswald, 2008; Van Landeghem, 2012). Reasons suggested have included that older individuals may tailor their expectations thereby reducing the “goal-achievement gap” (Argyle, 2013), that they adopt a strategy of selectively attending to positive aspects of life (Mather & Carstensen, 2005), and that many older people enjoy an improved quality, albeit often alongside a reduced quantity, of social connections (Berg et al., 2006).

Set against this broadly positive picture of wellbeing in healthy aging, however, studies have indicated a link between low levels of affective wellbeing, ill-health, and mortality rates (Steptoe et al., 2015). It is therefore possible that temperamentally more positive individuals simply tend to survive longer, thereby contributing to the older group becoming more positive on average through a process of attrition that disproportionately affects those with a more negative outlook. In other words, evidence of improved wellbeing on the individual level may be at least partly illusory, and the measured average may instead change as a by-product of members of the older cohort with lower levels of wellbeing become less numerous sooner.

There is also some countervailing evidence of an *inverted* U-shape whereby life satisfaction peaks in late middle age before declining (Easterlin, 2006). Further, and potentially contributing to differing findings on whether or not the U-shape is inverted, there is evidence of substantial decline in wellbeing amongst the oldest individuals (Gwozdz & Sousa-Poza,

2010) and, precipitously, within one year of death (Mroczek & Spiro, 2005). Such end-of-life evidence is perhaps unsurprising in the context of declining physical health.

Additionally, notwithstanding that several studies indicate a general upward trajectory in wellbeing towards older age, there is an indication that there may be significant declines in specific facets of wellbeing, even if this is balanced by improvements in others. These include a perceived loss of control over situations or 'environmental mastery' (Wettstein et al., 2015) and declines in self-reported judgment of agency (Lachman, 2006; Mirowsky, 1995). In some cases, and potentially connected with declines in reported control over situations, older adults also experience high levels of anxiety in relation to perceived vulnerability (Myall et al., 2009).

1.2 Challenges in explaining patterns of deficit and preservation

As noted above, the pattern of deficit and preservation in healthy aging is complex in terms of onset, rate, and trajectory. A challenge in explaining the relationship between neurophysiology, cognition, perception, and wellbeing in healthy aging is that many studies are primarily correlational, making it difficult to distinguish between alternative interpretations (Monge & Madden, 2016). For example, a finding that a deficit in performance in a perceptual task predicts a deficit in a cognitive task could indicate that a common cause, specifically neurophysiological decline, separately gives rise to cognitive and perceptual deficits (Baltes & Lindenberger, 1997), or that cognitive load affects perceptual performance (Li et al., 2001), or alternatively that performance in higher-order cognitive tasks is being affected by a perceptual input that is degraded (Schneider et al., 2010). It should be noted that these possibilities are not mutually exclusive. A deficit in a cognitive task could plausibly be the result of some combination of degraded perceptual input, difficulties in higher level cognition, and the load of simultaneously dealing with perceiving and interpreting an input.

Additionally, it is risky to assume that inferences can necessarily be drawn from similarities between the onsets and trajectories of neurophysiological and behavioural changes. Equivalence of performance in a task, or at least relative preservation, may plausibly result from adoption of an alternative strategy, and this may be more achievable in some experimental designs than others. In particular, considerable variability has been noted in rates and trajectories of changes in performance in cognitive tasks by healthy older adults without any disorder (Ghisletta et al., 2012; Raz et al., 2005). It has been proposed that these individual differences in healthy aging do not reflect substantial differences in the fundamental course of neurophysiological change over time, but instead the activation of complementary neural circuits in response to decline in other areas - referred to as a 'scaffolding' response (Park & Reuter-Lorenz, 2009). According to this account, a slowed rate of decline in cognitive ability in some individuals may reflect reserves of cognitive resource accumulated at a younger age and/or a process of maintenance in aging (Cabeza et al., 2018). Such theories are encouraging in that they suggest neurophysiological decline can, up to a point, be met with a response involving changes of cognitive strategy. That is, adverse practical impacts may be delayed even if the neurophysiological change cannot, and this provides a potential basis for productive interventions. For example, there has been interest in interventions based on linguistic and communicative competence (Bambini et al., 2020), decision-making skills (Rosi et al., 2019), and working memory (Zinke et al., 2014). However, scaffolding also provides a reason for caution in drawing inferences about the underlying neurophysiological basis of a behavioural finding.

1.3 The case of social cognition

Within the wider discussion of changes in healthy aging, an area of particular focus has been the performance of older adults in social cognitive tasks. Social cognition is a multidimensional concept encompassing a broad range of mental operations involved in processing information in a way that enables individuals to participate in social groups, in particular, by recognising and responding appropriately to the intentions and emotions of others (Roheger et al., 2022). The broad umbrella of social cognition covers a wide range of operations. These include identity recognition, attribution of emotional states to others, discerning their intentions, and making more complex social judgments such as to own and others' degree of agency in relation to observed outcomes.

One reason for multidisciplinary interest in social cognition in healthy aging, including from economists and sociologists as well as psychologists, is its apparent relevance as a predictor of wellbeing in later life. Specifically, studies indicate social competency predicts quality of life outcomes across the lifespan (Amdurer et al., 2014), including into older age (Charles & Carstensen, 2010). As noted above, the overall picture on wellbeing in later life is far from discouraging, but this comes with the proviso that it varies substantially between individuals as well as between facets of wellbeing and is susceptible to late and rapid decline. Of particular concern, there is evidence in older adults of an interrelationship between social isolation, social cognition deficits, declining physical health and mortality - which is indicative of a cascade of difficulties associated with declining social cognition in older age groups (Luo et al., 2012; Shankar et al., 2011).

As well as variability in wellbeing outcomes suggesting the possibility of successful interventions in healthy aging, a further reason for taking an interest in social cognition in older adults is that substantial declines in social cognition have been observed in disorders which typically have their onset in later life. Perhaps inevitably, much past work in relation to changes in social cognition in older adults has focused on diagnosed, age-related disorders associated with catastrophic decline in social cognition, including Alzheimer's disease (Cosentino et al., 2014; Kumfor et al., 2014) and Parkinson's disease (Alonso-Recio et al., 2021; Narme et al., 2013) and, given evidence that cognitive impairments precede diagnosis (Swaddiwudhipong et al., 2023), improved understanding of the pattern of decline could support early intervention.

Behavioural evidence

This section reviews some of the key behavioural findings relating to social cognition that are explored further in this thesis, namely recognising identity, attributing mental state in the form of emotion, and making judgments as to agency.

Recognising identity, particularly from faces, is a fundamental aspect of reading a social situation in that accurate and rapid recognition unlocks a wealth of contextual information relevant to the social interaction (Wilhelm et al., 2010). There is substantial evidence of age-related decline in the ability to identify faces across a range of paradigms. This includes deficits in discrimination in same/different tasks with immediate sequential presentation (Chaby et al., 2011), in "odd one out" tasks involving simultaneous presentation of stimuli (Logan et al., 2022) in tasks using unfamiliar faces at different periods of delay (Boutet & Faubert, 2006), and in line-up tasks involving provision of contextual information and a one month delay between test and re-test (Searcy et al., 2001). Some signal detection studies have indicated age-related differences are driven by an increased false alarm rate (rather than reduced hit rate) by older adults, and it has been argued that this could reflect a differing strategy regarding face recognition based on familiarity rather than matching with contextual information (Bartlett & Fulton, 1991; Edmonds et al., 2012).

In relation to recognition of basic emotions (widely defined as anger, sadness, happiness, fear, surprise, and disgust), there has been substantial focus on recognition of affect from facial stimuli. An influential meta-analysis assessed studies carried out since 1995 that had compared performance of younger and older adults in relation to static images of faces (Ruffman et al., 2008). This found a reasonably consistent pattern of age-related deficits in recognising angry, sad, and fearful faces alongside relative, but not absolute, preservation in relation to happy and surprised faces. It also found no significant age-related effects – indeed a trend towards improved performance in older adults - in relation to disgusted faces. Many studies used the Ekman and Friesen Pictures of Facial Affect (1976) set of still images, but similar results in relation to angry, sad, and fearful faces were found with an alternative stimulus set which used Japanese as well as Caucasian faces (Matsumoto, 1998) - albeit with no significant effects for other emotions (in the case of happiness, this appeared to be related to ceiling effects). An updated meta-analysis (Hayes et al., 2020) broadly supported the earlier findings based on studies carried out since 2008, but with three important caveats. Firstly, studies using reduced intensity images indicated greater deficits, as opposed to relative preservation, in recognition of surprise. Secondly, findings in relation to disgust varied widely by stimulus set used. Thirdly, studies based upon videos rather than static stimuli showed a general age-related deficit but no significant differences between different types of emotion.

The meta-analysis referred to above (Ruffman et al., 2008) also assessed the smaller number of studies which had assessed age-related changes in recognition of emotion from bodies and human voices. The pattern from these was of deficits in relation to angry, sad, and happy auditory stimuli, and angry, sad, and fearful bodily expressions. It is noted that, comparing modalities, the degree of consistency between findings relating to the six "basic" emotions is somewhat limited. The existence of an age-related deficit in recognition of anger and sadness is a common feature across studies, but the position on whether this is part of a general impairment of emotion recognition across modalities in older adults, or whether recognition of other affective states is relatively or absolutely preserved, is unclear.

An additional factor potentially impacting on the interpretation of studies using emotional face stimuli is that stimulus sets end to depict younger to middle aged faces, but there is some evidence for own-age effects. In particular, visual scan patterns differ such that both older and younger adults spend more time attending to similarly aged facial stimuli (Ebner et al., 2011) and there is evidence that whereas younger adults' performance in emotion recognition tasks is improved by use of direct gaze rather than averted gaze stimuli regardless of age of the face in question, this is only true for older adults observing older faces (Campbell et al., 2015). It has also been suggested that age-related stereotypes could bias attribution of emotion in faces, for example leading participants to attribute negative emotions such as sadness to older faces (Fölster et al., 2014) particularly if the individual rating the expression is of a different age to the face depicted (Riediger et al., 2011).

Recognition of basic emotions from a perceptual cue has widely been seen as a relatively automatic process perhaps even based on evolutionary imperative, and there is experimental evidence of rapid discrimination even under high cognitive load (Tracy & Robins, 2008). Theory of mind tasks, whilst in many cases drawing initially on correct classification of a perceptual cue, extend to more complex inferences as to the beliefs and intentions of another person, planning appropriate responses, and predicting outcomes (Frith & Frith, 2012). As such, there is considerable variation in the methodology of studies examining age-related changes in theory of mind and consequent challenges in categorising tasks and discerning robust patterns (Henry et al., 2013). Nevertheless, to sum, some studies indicate either improved or preserved performance in theory of mind tasks (Happé et al., 1998; Moran, 2013), but a preponderance of evidence indicates a pattern of decline (Phillips et al., 2011).

The discussion above relates principally to attributions based on an externally generated perceptual cue. Attributions in relation to agency are more complex as by their nature they involve determining whether a perceptual cue is self-generated or has an external cause. Sense of agency refers to the experience of being in control of one's own motor action (Haggard et al., 2017) and is commonly sub-divided into explicitly reported control of actions, or 'judgment of agency' and the sensation of control emerging from some combination of afferent and efferent signals, or 'feeling of agency' (Syonofzik et al., 2018). It has further been suggested that sense of agency is modulated by affective components including the individual's emotional priors (e.g. expectations as to efficacy of own action), motivational state, and retrospective attributional biases (Gentsch & Synofzik, 2014).

Reflecting this complexity, behavioural evidence in relation to age-related differences in sense of agency is more limited. However, there is some converging evidence that older adults have a reduced tendency to attribute perceived outcomes to their own agency rather than external sources. Studies using explicit reporting of control have indicated older adults have reduced susceptibility to illusory agency (Cioffi et al., 2017) and to temporal and spatial manipulations (Metcalfe et al., 2010). There is also some evidence from implicit measures indicating that the 'intentional binding effect' (Haggard et al., 2002), which suggests compression of perceived interval between voluntary action and perceived outcome is a marker of sense of agency in which sense of agency, is reduced in older groups (Mariano et al., 2024).

The "social brain hypothesis"

Explanations of age-related changes in social cognition have tended to emphasise differences between structures and mechanisms implicated in general cognition, and those involved in social cognition (Ruffman et al., 2008). Neurophysiological changes in this 'social brain' - i.e. purported domain-specific processes to sociocognitive tasks - are frequently taken to explain difficulties with face perception and other social tasks in healthy aging (Fischer et al., 2010; Ziaei et al., 2019). These 'social brain' ideas are based on a postulated specialised network involving regions such as the orbitofrontal cortex, cingulate cortex and amygdala, and is implicated in the 'accurate perception of the dispositions and intentions of other individuals' (Brothers, 2002).

The social brain theory recognises that deterioration in performance in tasks involving general cognition (particularly working memory, processing speed and fluid intelligence) predicts performance in a range of social cognition tasks. However, this shared variance is attributed to post-perceptual processes that are common to social and non-social cognition, and not pertaining to the core reason underlying poor performance in sociocognitive tasks (Kong et al., 2022).

As noted above in discussion of neurophysiological changes in healthy aging, there is evidence of volumetric grey matter loss being particularly pronounced in some structures but preserved in others. It has been suggested that, in certain respects, this pattern of deficit and preservation supports the social brain hypothesis. In particular, it has been noted that there is some evidence that age-related decline in emotion recognition is selective between different emotions, and that this may map onto patterns of decline and preservation in areas which are particularly activated in emotion recognition tasks. For example, the basal ganglia have been implicated in facial disgust recognition (Calder et al., 2001) and there is evidence that the region is relatively preserved in the aging process (Williams et al., 2006). Meanwhile, the orbitofrontal cortex has been implicated in recognising expressions of anger in faces (Fine & Blair, 2000) and there is evidence of relatively substantial age-related declines here (Allen et al., 2005).

As noted above, however, a more recent meta-analysis (Hayes et al., 2020), whilst confirming the pattern observed in Ruffman et al. (2008) in most respects in relation to full intensity photographs, indicated findings in relation to disgust were highly dependent on the specific stimuli set used, and that patterns including magnitude of differences varied between higher and lower intensity images, and between photographs and videos. The extent to which patterns of relative preservation and decline in healthy aging are dependent on stimulus set, modality, and intensity may suggest a greater role for more fundamental perceptual processes in explaining sociocognitive decline.

More generally, there remains academic debate as to the extent to which *social* cognitive operations involve separable functional and neurological pathways. For example, in relation to face processing, a distinction has been proposed between representation of invariant aspects of faces which are relevant to identity recognition, and processing of social information arising from changeable elements such as expression and gaze direction (Bruce & Young, 1986; Haxby et al., 2000). However, others have proposed a less bifurcated model where judgments about invariant and changeable aspects draw on different mechanisms but the separation of visual pathways is less clear-cut (Calder & Young, 2005; Connolly et al., 2019).

Visual perception and social cognition

Within the traditional psychological framework, low level inputs are detected by sensory organs, these are translated into perceptions, decisions are made based on perceptions, and actions are planned and executed based on those decisions. For example, an object may be observed and a decision made to reach for it based on perceived usefulness, or a noise of unknown source may be perceived as coming from a particular direction and a decision made to turn towards it to supplement the auditory information with visual information about the source of the sound. More recently, psychologists would be agreed that information flow is not unidirectional, as assumed under this classic model, but nevertheless, parcelling these stages of process is important for understanding underlying mechanisms. Social cognition can be seen as a subset of this general process (Frith, 2008) in circumstances where another individual is involved. In such cases, the external percept contains information of a social nature and/or the decision is a social response (e.g. perception of a facial expression, judgment of emotion of the person observed, and appropriate reaction).

A key question, however, is whether distinctive patterns of deficit and preservation can be explained by reference to the impact of changes to perceptual processing, and neurophysiological change at the global level before any reference is made to "social brain" networks. One view of visual perception would suggest that older adults should have a uniformly less reliable percept relating to all stimuli in an experiment such that, if difficulty is appropriately matched between experimental and control conditions, lower level age related perceptual deficits would be expected to result in equivalent declines across conditions. This view therefore implies that the distinctive pattern of deficits alongside relative preservation cannot be explained by differences in visual perception alone, but must instead relate to higher level inferences supported by the 'social brain'. However, as noted above, there is some preliminary (reaction time based) evidence of specific difficulties in configural processing, alongside relative preservation in processing of local features. Therefore, if recognition of certain types of social information in an experimental task are more reliant on configural processing and others on local features, a pattern of deficits and relative preservation could be observed which are explicable without recourse to the 'social brain'.

1.4 Approach in this thesis

Perhaps because of a widespread assumption that perceptual decline should imply performance deficits in any tasks involving a perceptual input and social response, and therefore has limitations in its ability to explain the distinctive pattern of deficit relative preservation in tasks, there has been limited focus on the extent to which findings in relation to social cognition derive from relatively low level differences in perceptual processing. Linked to this, theories have tended to seek to explain findings in social cognition by reference to specifically social rather than general cognitive impairments. This thesis focuses on circumstances in which age-related differences in social cognition may be derived from lower level perceptual differences.

Chapter 2 sets out the important methodologies employed in this thesis. In particular, it highlights the challenges associated with interpretative explanations of deficit when it is unknown whether the percept corresponds to objective physical reality. It also considers the potential impact of response bias on performance in tasks measuring accuracy, and why this may be a particular issue in studies of aging. It then briefly introduces psychophysical measures used in this thesis, including signal detection and drift diffusion models, and how these offer scope to assess more closely potential perceptual contributions to differences in social cognition and to distinguish different aspects that accuracy measures may not, including response bias, sensitivity, rate of evidence accumulation, and response thresholds.

Subsequent chapters apply the methodological approach set out in Chapter 2 to three different areas where there have been findings indicating social cognition deficits, and areas of relative preservation, in healthy aging.

Chapters 3 and 4 report three experiments involving perception of point light walker stimuli. The chosen stimuli remove contextual information such that the visual information conveyed relates to posture and kinematics only. Rather than immediately requiring participants to make a social inference regarding emotional state of the walker, Experiments 1 and 2, reported in Chapter 3, subtly alter posture in the form of angle of inflection at the elbow and acceleration or deceleration of the walker over the course of short videos, with participants asked to judge whether or not angles of inflection differed or the pace of the walker changed. The postural task required, by its nature, integration across space (i.e., judging angle of inflection requires information about the location across time of several points constituting the point light walker), whereas information in the kinematic task was in theory capable of being ascertained from a single point. Consistent with predictions, sensitivity was reduced in older adults in relation to judgment of postural cues, which rely upon configural processing across the points in space. In contrast, older adults exhibited similar sensitivity to kinematic cues relative to younger adults.

Given this pattern of relative deficit and preservation in fundamental perception of body stimuli, it enabled a prediction to be made in relation to judgment of emotional content. Specifically, that recognition of some emotional states, when conveyed by body language, rests more heavily on postural information and some more heavily on kinematic information, and that older adults should exhibit deficit to the extent that recognition relies primarily upon postural information. The results of Experiment 3, reported in Chapter 4, were consistent with those predictions – specifically, older adults exhibited deficits relative to younger adults in recognising happiness but not anger or sadness from point light walkers.

Chapters 5 and 6 assess whether the preserved sensitivity to posture, and relative preservation in relation to kinematics, is indicative of a broader pattern of deficit in processing configurations relative to local features. Experiments reported in Chapter 5 employ the composite face illusion, whereby the top and bottom halves of a face are presented either in alignment or slightly misaligned, with alignment considered to create a novel configural percept. Participants were asked to make a 'same or different?' judgment about a target half of two sequentially presented faces, ignoring the other half. The composite face effect is the finding that performance is impaired by alignment where information in the non-target half is incongruent with that in the target half, and facilitated when it is congruent. It was hypothesised that older adults would exhibit a reduced composite face effect to the extent they were less reliant on configural processing. Experiment 4 found trend in the hypothesised direction, which appeared to be driven principally by those participants aged over 70. However, an online replication (Experiment 5) did not show an appreciable trend.

Recognising a number of issues in the experimental design employed in Chapter 5, Chapter 6 reports two experiments which more directly manipulate features and configural arrangement of faces. Specifically, sequential presentations of images in a 'same or different?' task may either replace the eyes and mouth of the model pictured with different eyes and mouth, or alter the distances between the eyes or between the mouth and nose. The task was also undertaken with images of a house, to assess whether affects were face-specific or extended to non-face objects. As hypothesised, in both the original in-person task (Experiment 6) and online replication (Experiment 7), older adults exhibited reduced sensitivity to configural differences alongside preserved sensitivity to featural differences, in both faces and non-face objects.

One possible explanation of the patterns of deficits and preservations in Experiments 1 to 7 relates to physiological and neurophysiological changes specifically in the visual system in healthy aging. However, it is also possible that the deficit in integrating across space is reflected in a broader deterioration in tasks involving integrating information, potentially related to deterioration in the integrity of white matter tracts as noted above. This may be expected to be particularly the case in tasks across different modalities that rely on precision in mapping between them, such as those involving sense of agency where participants judge whether there is a correspondence between internally generated, planned movements and observed outcomes. Experiment 8 in Chapter 7 involved task where participants reported whether or not they controlled a dot seen moving on screen through their own simultaneous, but unseen, hand movement over a motion tracker. A control task asks the same for passive observation of an avatar hand and dot. As hypothesised and consistent with other findings in relation to sense of agency in healthy aging, older adults were differentially impaired in relation to the motor-visual task, providing preliminary evidence for a broader integration difficulty in healthy aging.

Finally, Chapter 8 provides a general discussion, including implications for interpretation of previous studies, wider relevance, limitations of the experiments reported, and possible future areas for investigation.

CHAPTER 2: METHODOLOGY

2.1 Limitations of accuracy measures

Social cognition involves inferring mental states to predict probable actions of a conspecific and to plan whether and how to respond (Roheger et al., 2022). This process can be characterised as involving several elements. Firstly, there needs to be a signal in the form of a cue in a particular modality, possessing objectively measurable physical characteristics, which is detectable, and from which the individual might meaningfully be able to draw useful information. Secondly, the receiver will need to attend to relevant features of the cue. Thirdly, the individual will need to form a subjective perception of the cue's physical characteristics which may or may not accord with its objective characteristics. Fourthly, the individual will need to make inferences based on their subjective perception of the cue including by drawing on experience of similar cues in the past. Finally, the individual will need to choose a response. Because the process involves several stages, patterns of findings are unlikely to derive from a sole cause, and a convergence of research methodologies is needed fully to assess observed differences.

Within an experimental setting, behavioural experiments assessing social cognition in older adults have often used accuracy measures, sometimes complemented with reaction time data. That is, stimuli are presented and an explicitly social, categorical response (e.g. a judge emotional valence) is elicited and recorded, typically from a selection of options available to the participant, which often include a "neutral" response. While these studies can provide highly useful first steps in understanding the nature of relative decline in healthy aging, there are also some interpretational challenges which must be considered.

Firstly, the approach assumes that either the subjective percept is unlikely to differ from the objectively measurable physical qualities of the stimulus presented or, to the extent it does, this is not likely to constitute a confound. For example, whilst vision tends to decline in later life, a participant using prescription lenses would generally be referred to as having "corrected to normal" vision and, to the extent any visual deficits cannot be fully corrected, these are often assumed to be likely to affect different conditions in the same way. However, as noted in Chapter 1, changes in visual perception in healthy aging is likely to exhibit a more complex pattern of deficit and preservation arising from changes in the senescent optics of the eye, the visual cortex, and potentially wider neurophysiology. It is not clear that conditions in experiments involving social cognition in healthy aging place equivalent demands on these processes. As such, the term "corrected to normal" is potentially misleading in that it typically refers to the best level of correction in visual acuity that can be achieved through optical means (i.e. glasses or contact lenses) rather than representation of the visual field at the neural level (Brewer & Barton, 2012). Additionally, there are reasons to hypothesise that changes may take place in attentional strategy in healthy aging. For example, eye-tracking studies have indicated that older adults preferentially attend to the lower half of faces (i.e. to the mouth more than the eyes) whether due to declining hearing and consequent increased value of lip-reading or for other reasons (Wong et al., 2005). These differences have not been ignored entirely, as it has been suggested that this attentional shift may partly account for patterns of deficit and preservation in relation to emotional faces - based on greater reliance on the lower part of the face in identifying happiness and disgust (Slessor et al., 2022; Wegrzyn et al., 2017).

Secondly, accuracy measures based on categorical responses carry a risk of response bias. Individuals may differ in their willingness to apply a label to a stimulus, or the degree of confidence they need to feel that they are correct in order to do so. This may particularly be the case where the label has a negative connotation (e.g. describing a face as "angry") and where the option of a "neutral" response is available. The possibility of response bias means that accuracy cannot be assumed to be equivalent to ability to discern and correctly interpret a sensory signal. Indeed, in an extreme case, a participant ignoring presented stimuli entirely and giving the same categorical response for every trial in an experiment would achieve 100% accuracy in one experimental condition. More realistically, noting it is relatively easy to exclude participants pursuing such a strategy, in a typical experiment two participants who both judge there is a 55% chance that a briefly displayed image was that of an angry face may label it differently, with one deeming this sufficient to categorise it accordingly and the other not. With an accuracy measure, over multiple trials, a participant with a liberal response bias (i.e., willingness to categorise on weak evidence) would score more highly than one with a conservative response bias. However, this would not meaningfully equate to the latter having a deficit in ability to discern the target emotion as, in the example, both share the same view on the likelihood that the target emotion is present.

Related to the above, an individual with a liberal response bias will, as well as being more likely to label a stimulus which does in fact feature the target characteristic correctly (the classic measure of accuracy), be more likely to label a stimulus that lacks it incorrectly. That is, their recorded "accuracy" comes at the expense of a high incidence of "false alarms". Even to the extent that behaviour in experimental conditions translates into similar behaviour outside, it is far from clear in the context of social interaction that making a categorical judgement based on limited confidence is optimal, and whether or not it may vary based on a range of circumstances. Continuing with the example of recognising facial expressions of emotion, it is possible to imagine circumstances where the cost of missing a signal is high but that of a false alarm is low. For example, a fearful expression conveys the presence of danger, and the cost of failing to register that a conspecific is afraid may be high compared with the embarrassment of taking evasive action when none is required (i.e., a liberal response bias may be the optimum strategy in relation to identification of fearfulness). Conversely, it may well be optimal in a conversational setting not to respond as if another person is angry unless you have a high degree of confidence that they genuinely are (i.e., to have a conservative response bias in identification of anger).

Importantly, there are reasons to anticipate biases may change at a group level in healthy aging. There is some evidence that older adults exhibit a general conservative response bias (e.g. reporting a target feature is not present unless they have a high degree of confidence that it is present (Ferris et al., 1980; Vakil et al., 2003). Conversely, the 'positivity effect', whereby older people attend preferentially to positive over negative information, has been widely reported (Carstensen et al., 2012; Reed et al., 2014) and may imply a more liberal response bias in specific tasks. This could contribute to previous findings in relation to relatively preserved detection of happiness relative to anger and sadness in emotional faces (Ruffman et al., 2008) in that older adults could have a more liberal response bias, achieving a comparable accuracy rate to younger adults, but at the expense of more false alarms.

A further methodological issue in relation to previous studies relates to calibrating conditions such that the level of difficulty is comparable for younger adults across conditions. Ceiling effects are potentially particularly relevant in aging studies due to general cognitive decline in healthy aging and evidence that age-related differences are magnified by increasing task difficulty (Earles et al., 2004; Verhaeghen & Cerella, 2002). For example, a feature of many studies of facial expressions of emotion is that younger adults tend to perform close to ceiling levels in terms of accuracy when presented with images of happy faces, and this may be a factor in relative preservation in older adults' ability to discern happiness in facial expressions (Calder, 2003).

2.2 Methodology in this thesis

This thesis makes use of a range of psychophysical methods to assess perceptual differences in healthy aging. Psychophysics studies the relationship between objectively measurable qualities of physical stimuli and subjective perception of those stimuli. Nineteenth century psychophysics evolved from studies by Ernst Heinrich Weber of the relationship between the proportionate change in the intensity of stimuli, and the detectability of such changes - e.g., that participants more readily perceive the difference between 10g and 15g weights than between 100g and 105g weights. The work of Weber and others was developed and systematised in a set of classical methods by Gustav Fechner in Elemente der Psychophysik (Fechner, 1860; translation, 1948).

A typical psychophysical study selects a stimulus of interest within a sensory domain which can vary in intensity on an objective scale (e.g. brightness of an image or pitch of a sound) and attempts to measure the limits of detectability or discriminability, often to test a hypothesis that particular independent variables account for differences in such limits. In practice, there may not be an abrupt tipping point between non-detection and reliable detection, since both subjective experience of, and response to, the same stimulus varies between presentations. This reflects the position in neurophysiology whereby measurements differ for the same stimulus and averages are taken over multiple trials to produce an overall measure of activation. Indeed, a fundamental presumption of psychophysics is the existence of an underlying correspondence between neural activity and perception. Psychometric functions (see figure 2.1, left panel) offer a fuller description of the transition between chance and perfect performance.

Classical and adaptive psychophysical methods

Classical psychophysical methods encompass the method of adjustment, method of limits, and method of constant stimuli (Gescheider, 2013). The method of adjustment involves, over multiple trials, participants themselves altering the level of a stimulus until they report it is barely detected. However, participants tend to vary in level of precision, and threshold measures obtained by adjustment can be markedly different from those obtained by other means (Foley & Matlin, 2015). Therefore, this method is rarely used experimentally. In the method of limits, the level of a stimulus (or the difference between stimuli where differential threshold is being measured) is gradually increased by the experimenter until perception is reported, or reduced until a failure to perceive is reported. The average between reports on ascending and descending trials is taken to be the relevant threshold. A difficulty with this approach is that there may be a tendency either to continue reporting in a particular direction beyond the threshold until a participant has an internally determined level of confidence ("habituation error") or to report too early ("anticipation error"). Whilst averaging ascending and descending measures is intended to address this problem, there is no strong reason to assume the magnitude of any error would be the same in both directions or for different modalities. In the method of constant stimuli, originally described by Hegelmaier in 1856 (Laming & Laming, 1992), a range of stimuli are pre-selected by the experimenter (and in that sense are constant) and presented in a random order to participants, thus addressing anticipation and habituation errors. In theory this approach can, with sufficient repetitions, fully describe a psychometric function by giving average accuracy rates across a range of stimulus levels.

One challenge for psychophysicists has been to determine how to separate "sensitivity" (i.e., ability to determine whether or not a signal is present) from "bias" (i.e., willingness to report a signal is present) given that individuals may differ in the level of confidence they require in order to give a particular answer, and that this may vary depending on the specification of the task. A traditional approach has been to accept that a participant may report detection in the absence of a signal ("false alarms") but to assume a linear relationship between this and correct reports of detection ("hits"), and to set a suitably high performance level as corresponding to the threshold to correct for a "guessing factor". However, both theory and data support a non-linear relationship (the "receiver operating characteristic" curve) such that this is a poor way to separate sensitivity from bias (Macmillan & Creelman, 2004). Signal detection theory, illustrated in figure 2.1 (right panel), assumes that variation in perception of equivalent stimuli is approximated by a Gaussian noise distribution, and that an objectively measurable physical change in the stimulus shifts this to create a similarly shaped signal distribution. Whilst an unbiased decision criterion would be at the point of overlap of distributions (where the sensory experience is equally likely to reflect the presence of the signal as it is random noise), performance will tend to reflect both sensitivity (*d'* – the extent to which the stimulus affects the signal distribution for that individual) and bias (*c*).

Measures of sensitivity and bias may be derived mathematically from tasks comparing performance in trials where a signal is present or absent and the participant is required to give a yes/no response or required to choose between a fixed number of alternatives (Stanislaw & Todorov, 1999). Specifically, as sensitivity (*d'*) represents the extent to which participants are more likely to report the presence of a probed stimulus when it is present than when it is absent, it can be calculated as the difference between the z-scores of the hit rate (HR; proportion of trials where the feature of interest is present and correctly identified) and false alarm rate (FAR; proportion where the feature of interest is absent and wrongly reported as present. This is represented in the formula: $\boldsymbol{d' = \theta^{-1}(HR) - \theta^{-1}(FAR)}$. As bias (*c*) represents the extent to which participants tend to report the presence of the probed stimulus regardless of its objective presence, it may be calculated as the inverse of the mean of the z-scores of HR and FAR represented by the formula: **$c = -0.5\ (\theta^{-1}(HR) + \theta^{-1}(FAR))$**.

Whilst signal detection theory is a better fit with real data and generally accepted more clearly to distinguish sensitivity from bias thus enabling more robust interpretation of results, it should be noted that it makes assumptions about underlying distributions which may not hold in all cases (Bröder & Schütz, 2009). It is also relevant to point out that, whilst conceptually and statistically separate, measures of sensitivity and bias cannot be assumed to be fully functionally separate (Pastore et al., 2003). In particular, low sensitivity can result in more extreme bias, and this may be an optimal response – for example, where a person is navigating a dimly lit room (i.e., lower sensitivity to the presence or absence of objects) a cautious approach to minimise risk of injury would be to become more biased in a liberal direction (i.e., more prepared to make 'false alarm' errors) (Lynn & Barrett, 2014).

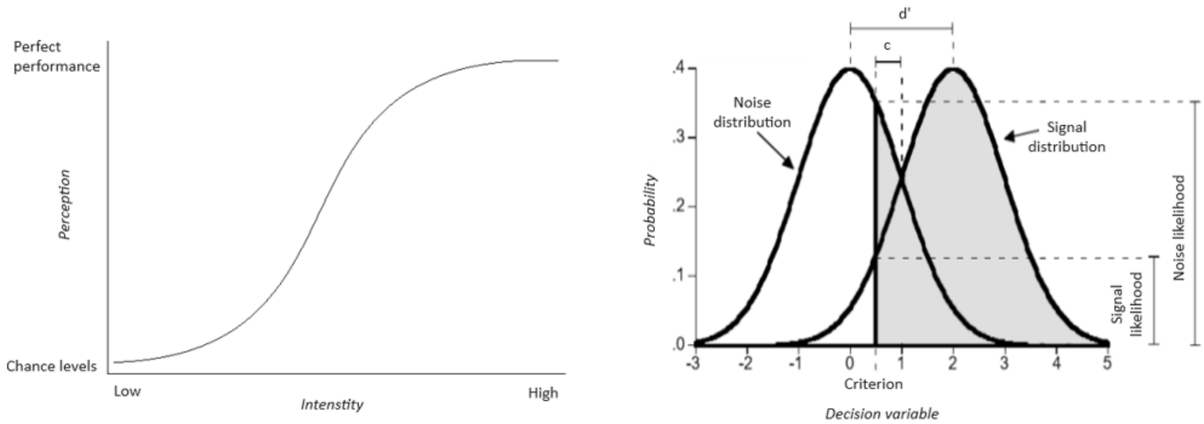

Figure 2.1: Left panel shows an example of a psychometric function, and right panel illustrates distributions underlying signal detection theory (Stanislaw & Todorov, 1999).

Drift diffusion models

Whilst signal detection measures are helpful in distinguishing sensitivity (*d'*) from response bias (*c*), differences in sensitivity within a signal detection paradigm are susceptible to different explanations, and further psychophysical methods are available to assess the nature of sensitivity differences. To this end, a type of models referred to as 'drift diffusion models' have become popular in recent years. Drift diffusion models treat decision making as involving sequential sampling of sensory evidence to compute a decision variable (Ratcliff et al., 2016). When this accumulated decision variable meets a response boundary, the appropriate response is triggered. Within this model, in a two alternative forced choice task, greater sensitivity could be explained either by more efficient accumulation of evidence or by a reduced willingness to make a judgment based on limited accumulated evidence. Where reaction time data is available over multiple signal detection trials, a hierarchical drift diffusion model can be fitted, with parameters for each participant drawn from group level distributions, using Bayesian Markov Chain Monte Carlo sampling to estimate group and participant level parameters simultaneously. It parameterizes drift rate (v), representing efficiency of evidence accumulation; threshold (a), representing the extent of separation of decision-making boundaries; and non-decision time (t), representing processes not directly involved in stimulus discrimination, such as motor preparation to press the relevant response key.

It is noted that a threshold difference in the context of hierarchical drift diffusion model differs from the form of bias identified by traditional signal detection measures. Such measures relate to whether a participant is more or less likely to report a signal as present rather than absent in circumstances of uncertainty, whereas threshold differences instead relate to the amount of evidence needed for the participant to respond in either direction. Figure 2.2 below illustrates the model, across multiple trials with positive drift in green towards the upper decision boundary (i.e., correct responses, whether they be signal present or signal absent trials) and negative drift in purple towards the lower decision boundary.

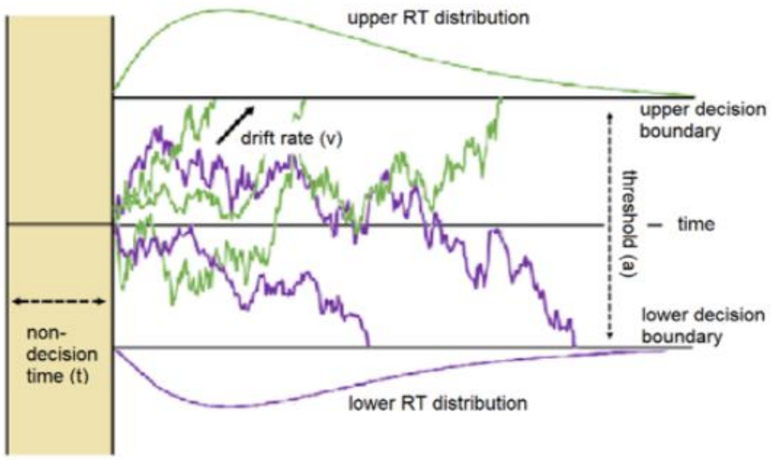

Figure 2.2: Illustration of drift diffusion model, where Bayesian Markov Chain Monte Carlo sampling produces estimates of non-decision time (t), drift rate (v) and threshold (a) based on reaction time data over multiple trials (Ratcliff et al., 2016).

Applying psychophysical methods to aging and social cognition

The methods used in the experiments reported in this thesis seek to address problems identified above in relation to accuracy measures, and to use signal detection methods to clarify some respects in which findings regarding age-related changes in social cognition may be rooted in lower level perceptual deficits.

This thesis mainly employs social (i.e., human) stimuli but most studies do not ask social questions about them, like the emotion or identity conveyed, instead asking about lower level properties of the stimuli. For example, some studies use same/different judgements about the images, and others require detection of postural or kinematic features. The aim here is to assess age related changes in sensitivity towards different physical attributes of stimuli, before assessing whether patterns of deficit and relative preservation may contribute to higher level differences in relation to making social inferences. In other words, noting that inferences cannot be drawn from a cue that is not perceived, it assesses whether there may be systematic differences in low level perception that could explain aspects of observed differences in explicit measures of social cognition between older and younger adults that have been viewed as relating principally to higher level changes in the “social brain”.

The signal detection measures and drift diffusion modelling reported provide ways of ascertaining the nature of differences that have tended to be measured in terms of accuracy. In particular, a signal detection paradigm enables a clearer distinction to be made between cases where reduced accuracy can be explained by sensitivity deficits, and those where they result from conservative response bias (which, as noted, could be an advantageous strategy in making social judgments in certain circumstances). Additionally, using signal detection measures enables adjustment of levels of difficulty to limit ceiling and floor effects. Signal strength can be calibrated via pilot studies so that tasks are sufficiently challenging for errors to be made, but not so challenging that typical participants perform at or near chance levels, and so that younger adults perform similarly across conditions, revealing areas of relative preservation as well as deficit amongst older adults. Drift diffusion modelling provides a further way to assess whether sensitivity differences are themselves driven by differences in rate of evidence accumulation or of the level of evidence deemed sufficient to reach a decision.

Whilst a contribution of this thesis is to approach questions regarding social cognition in healthy aging using psychophysical methodologies, it is important to note at the outset that the value from this perspective comes when converging with other research methodologies. In particular, it has potential to identify the nature of any perceptual degeneration that may contribute to difficulties with sociocognitive tasks in healthy aging. It does not, however, allow one to ascertain whether these constitute the sole causal contributions, or whether there are additional higher-level inferential difficulties – either fundamental or cascading from any perceptual difficulties.

CHAPTER 3: VISUAL PERCEPTION OF POSTURE AND KINEMATICS

3.1 Introduction

Note: The work in this chapter and Chapter 4 draws upon and extends work that has previously been published (Chard et al., 2019).

Chapter 1 noted that it is conceivable that distinctive patterns of deficit and preservation in social cognitive tasks could be explained or contributed to by low-level perceptual processes, without recourse to 'social brain' explanations. In particular, it set out some preliminary evidence for configural processing deficits in healthy aging, and the physiological and neurophysiological changes that may underpin such deficits, including differential decline in peripheral visual fields, and difficulties integrating information related to white matter decline (McDonough & Siegel, 2018; Ribeiro et al., 2024). Chapter 2 then set out methodological issues, and psychophysical methods used in this thesis to address some of the limitations in conventional accuracy measures and more specifically identify the nature of deficits.

Chapters 3 and 4 apply this approach, using the methods outlined in Chapter 2, to perception and interpretation of body language in a series of experiments involving point light displays. Point light displays represent each major joint of the human body as a point of light against a uniform background (Johansson, 1973). These displays are widely used in the study of body perception because they allow presentation of kinematic and postural information while removing other cues, such as facial expressions. There is evidence that typical individuals can and do derive useful information from body language, and point light display studies have indicated that participants are reasonably proficient in making judgments of a social nature based on the relatively sparse information available from point light displays, including identifying known individuals from their gait (Troje et al., 2005), recognition of gender (Pollick et al., 2005), and categorisation of emotional state (Ross et al., 2012; Ruffman et al., 2009).

There is a notable difference between the two categories of cue conveyed by point light displays, namely posture and kinematics. Recognising posture from point light displays requires integration across space because it involves making a judgment of relative position of limbs based on angles of inflection at the joints as represented by points of light. In making kinematic judgments, an observer could also pursue a strategy of integrating across space but could alternatively make a judgment based on observing a single point of light, whereas this strategy is, by definition, unavailable for postural judgments.

Chapter 1 reviewed some of the physiological and cortical changes in visual regions associated with healthy aging. Several of these suggest that older adults may be differentially impaired in tasks involving integration of visual information across space, but relatively preserved in tasks involving local detail. In particular, evidence of white matter decline including deterioration in the structure of myelin (Bennett et al., 2010; Branzoli et al., 2016) has been associated with difficulties in integrating information across a distributed neural network, while cortical thinning differentially affecting peripheral visual field representations (Griffis et al., 2016) may also present difficulties in older adults. There is also behavioural evidence including from the Navon task (Insch et al., 2012; Lux et al., 2008; Oken et al., 1994; Slavin et al., 2002) albeit that the pattern of findings of a reduced global precedence effect in older adults as measured by the Navon task is not wholly consistent and findings are primarily based on reaction time data (noting issues of interpretation as set out in Chapter 2).

This chapter tests the hypothesis, derived from the evidence referred to above, that older adults are differentially impaired relative to younger adults in sensitivity to postural relative to kinematic information in tasks involving point light displays. Chapter 4 then applies the findings to a task involving emotion recognition and makes cross-experiment comparisons with the experiments reported in this chapter. As discussed further in Chapter 2, experiments use a signal detection paradigm, allowing dissociation of signal sensitivity from response biases (Kingdom & Prins, 2016), in contrast with previous studies which have typically used accuracy measures.

3.2 Experiment 1 – Postural differences

3.2.1 Background

Experiment 1 required participants to judge a postural feature of walkers depicted in short videos via point light displays. Specifically, they were asked to report whether a specific arm (e.g., right arm) of a walker depicted in a point light display was flexed at a more acute angle at the elbow than the other (e.g., left arm). To do so, participants needed to assess the position of the dot representing the wrist on one side of the body relative to those representing other body parts – particularly the elbow and shoulder on the same side – in order to estimate an angle of inflexion, and to compare with the same angle derived from the position of equivalent body parts on the other side of the body. The experiment included 'Postural Difference' trials, where the described difference was present and 'No Postural Difference' trials where it was not (i.e., both arms were equally flexed). Although the point light displays were in apparent motion in Experiment 1, the manipulation did not affect other aspects of implied movement so, for example, walking speed was the same for Postural Difference and No Postural Difference trials.

As in other experiments in this thesis and as further explained in Chapter 2, sensitivity to probed stimuli was calculated as *d’,* which indicates the extent to which participants are more likely to report the presence of a probed stimulus when it is present than when it is absent. In Experiment 1, hit rate (HR) was the proportion of Postural Difference trials correctly identified, while false alarm rate (FAR) was the proportion of No Postural Difference trials wrongly identified as Postural Difference trials; $d' = \theta^{-1}(\text{HR}) - \theta^{-1}(\text{FAR})$.

The hypothesis tested in Experiments 1 and 2 pertained to sensitivity, so results focus on *d’* below. However, we also note findings in relation to response bias (*c*) as a feature of the methodology adopted is that, as part of dissociating the possible influence of response bias, experiments also measured the extent to which participants report the presence of the probed stimulus regardless of its objective presence; as set out in Chapter 2, $c = -0.5(\theta^{-1}(\text{HR}) + \theta^{-1}(\text{FAR}))$.

It should be noted that the experimental procedure described below results in an unequal numbers of trials where the target difference was present and where it was absent (a 4:3 ratio between signal present and signal absent trials). For this reason, caution is needed in interpreting absolute values for *c* (Terman & Terman, 1972; Wyart et al., 2012). In contrast, unequal ratios are not generally deemed a problem when interpreting d’ measures (Sherman et al., 2015; Swets et al., 1961). That is, *c* would be negative rather than zero for an entirely unbiased observer because there were more trials where it was correct to answer in the affirmative in the present experiment.

3.2.2 Method

Participants

Two groups participated in Experiment 1, 30 younger adults aged 35 or under (M = 27.5, SD = 4.7, 21 females and 9 males) and 27 older adults aged 60 or older (M = 73.5, SD = 7.5, 17 females and 10 males). One further older adult was excluded from analysis due to a large negative *d'*, making the participant a statistical outlier and indicating confusion over task demands (n.b., a small negative *d'* in a signal detection task is consistent with a participant having low sensitivity). The sample size was determined in all experiments reported in Chapters 3 and 4 such that we would have at least 80% power to detect a medium-sized group x condition interaction effect (η_p^2 = 0.06, alpha = 0.05). This sample size was also in line with previous studies of emotion recognition (Ruffman et al., 2008). This requirement led to the calculation that we would require at least 24 in each group to detect effects. Note that, in all experiments reported in Chapters 3 and 4, there are more than 24 are reported in each group because we tested all who responded to our recruitment drive within a specified timeframe.

In Experiment 1, as in all experiments in Chapters 3 and 4, participants had normal or corrected-to-normal vision according to self-report. The experiments were carried out in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki and approved by the Birkbeck, University of London Ethics Committee.

Weschler Abbreviated Scale of Intelligence (WASI) scores were obtained for two subtests (matrix reasoning and vocabulary) for 26 older adults and 28 younger adults in Experiment 1. The raw scores achieved by older adults (M = 70.5, SD = 7.1; FSIQ2 equivalent = 128.3) did not differ significantly from the raw scores obtained by younger adults (M = 71.9, SD = 5.4, FSIQ2 equivalent = 122.7): $t(52) = 0.84$, $p = 0.41$.

Stimuli

In Experiment 1, and in other experiments reported in Chapters 3 and 4, stimuli were point light display videos adapted from those developed by Alaerts et al., 2011 (see also Nackaerts et al., 2012 and Edey et al., 2017). Experiment 1 used point light display videos of two actors (one male, one female) in affectively neutral states shown from two different viewpoints (coronal - 0°; or intermediate to coronal and sagittal - 45°) and played at a rate of 40 frames per second (mean velocity = 3.91 pixels/frame [SD = 1.69]; mean acceleration = 1.30 pixels/frame^2 [SD = .21]). All videos in Experiment 1 had a duration of 2000ms.

In No Postural Difference trials, the angle of flexion at the elbow was equivalent for right and left arms. Postural Difference trials adapted the videos such that the average angle of flexion at the elbow of one arm was greater than the other arm. For each frame of each video, the angle was calculated between the elbow and wrist, and elbow and shoulder. Coordinates for a revised wrist position were then established based on rotating its position relative to the elbow by a proportion of the original angle. This manipulation maintained the appearance of a natural arm swing in that the precise angles of flexion for both arms varied systematically across the video but generated a more acute angle between the points representing the wrist, elbow, and shoulder in one arm than the other. Figure 3.1 illustrates the difference between Postural Difference and No Postural Difference trials by giving three equivalent example frames from Experiment 1 (see also Supplementary Videos). Two versions of each Postural Difference video were produced, differing in the extent of arm flexion and therefore signal strength. Small signal videos reduced the apparent angle between the shoulder, elbow and wrist by 10%, and large signal videos by 15%, over the course of the video.

The combination described above of two actors, two viewing angles, left and right arm flexion versions, and large and small postural signals, generated 16 Postural Difference videos.

There were four No Postural Difference videos, corresponding to the two actors and two viewing angles.

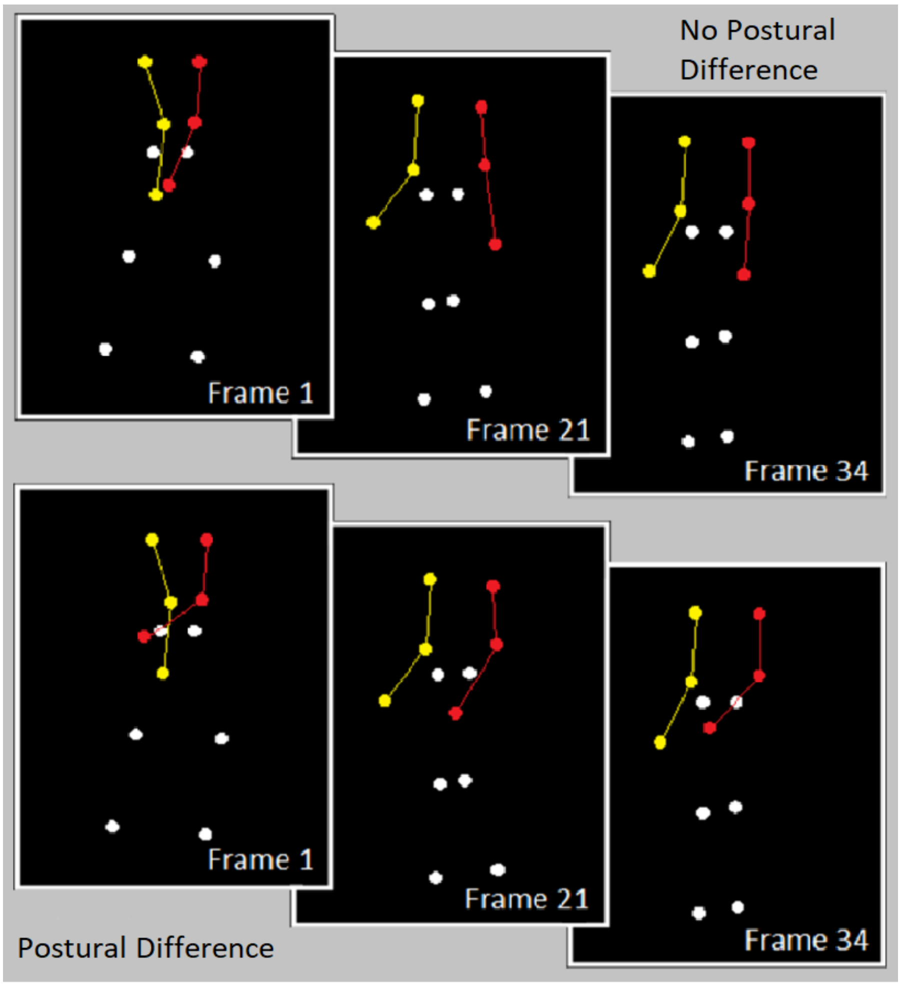

Figure 3.1: Example frames from videos used in Experiment 1 (frames 1, 21, and 34) in the No Postural Difference (top) and Postural Difference (bottom) conditions. Colour and lines are used to highlight the arm position at equivalent frames; in the Postural Difference stimulus the red arm on the right of the image is flexed at a more acute angle than the yellow arm on average across the video. In the actual videos, all point light displays were white on black, without connecting lines. The question presented in this example was, 'Was the arm on the right of the screen more bent?'

Procedure

In Experiment 1, and all other experiments reported in Chapters 3 and 4, participants were seated in a dimly lit room at an approximate distance of 50 cm from a 24 inch LCD computer monitor (resolution = 1920 x 1200 pixels; refresh rate = 60 Hz). The experiments were conducted in MATLAB® using the Cogent graphics toolbox.

On each trial, participants were shown a point light display video and then asked either 'Was the arm on the right of the screen more bent?' or, 'Was the arm on the left of the screen more bent?'. Participants did not know which of the two questions they would be asked during the stimulus presentation. Participants responded 'yes' or 'no' using left and right keys, respectively. In order to guard against confusion between keys, participants were shown their answer, and prompted to change their response or press a key to continue. However, no feedback was given as to whether or not any answers were correct. Participants saw no videos containing a signal other than the probed target signal (e.g. there were no trials where the arm on the right was flexed to a greater extent but the question referred to the left arm). Figure 3.2 summarises the procedure followed in Experiments 1 (which, aside from detail of the particular question asked, was also followed in Experiments 2 and 3).

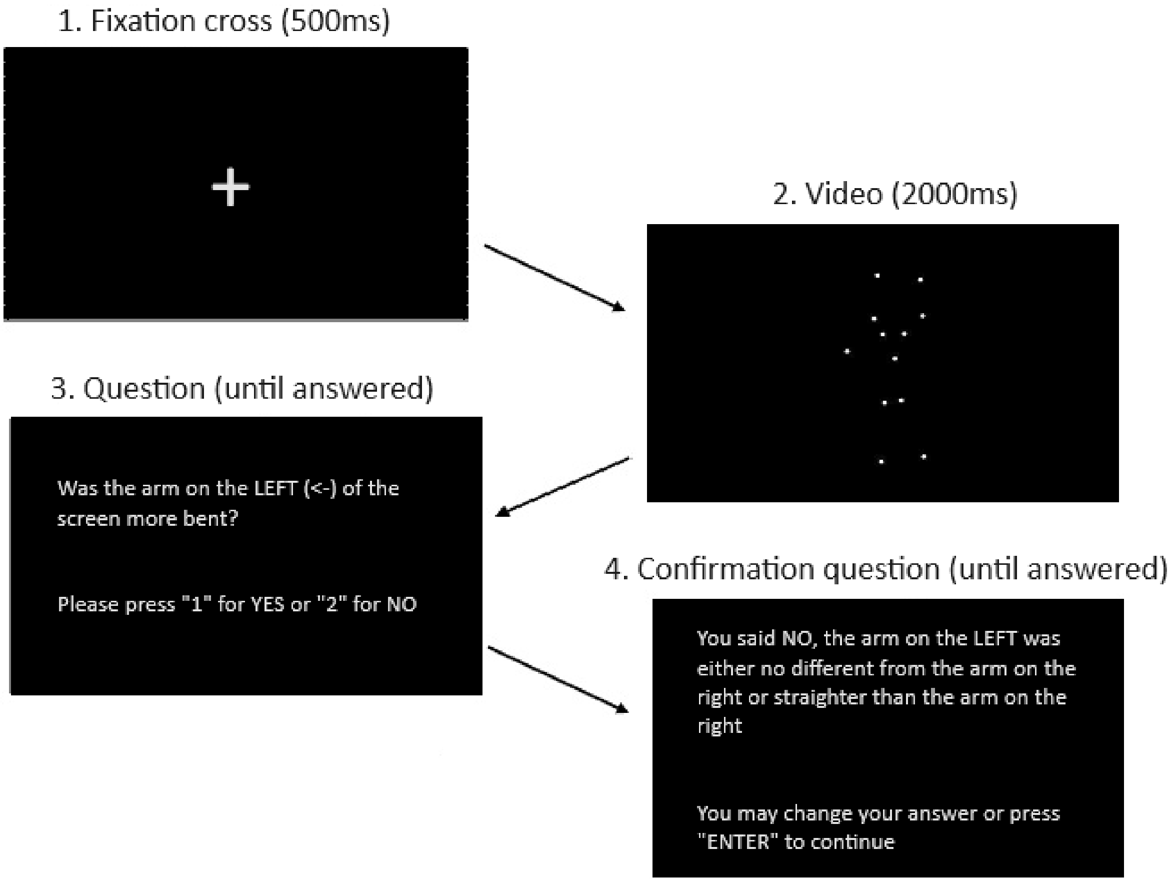

Figure 3.2: Summary of Experiment 1 procedure (n.b. Experiment 2, and Experiment 3 in Chapter 4 differed only in the detail of the questions asked).

Trials were presented to each participant in two blocks of 56. Within each block, each Postural Difference video was presented twice, and each No Postural Difference video was presented six times, resulting in 32 Postural Difference trials and 24 No Postural Difference trials. Presentation order was fully randomised within each block.

3.2.3 Results

One sample t-tests confirmed that *d'* was significantly positive for both younger adults (M = 0.87, SD = 0.45; $t(29) = 10.58$, $p < 0.001$) and older adults (M = 0.62, SD = 0.32; $t(26) = 10.07$, $p < 0.001$) indicating that both groups were able to distinguish Postural Difference from No

Postural Difference trials. All individuals had positive *d'*s across the Experiment. One younger and one older participant had a marginally negative *d'* in one condition but had both had positive *d'*s across the experiment and the pattern exhibited was therefore consistent with low sensitivity and unlikely to reflect confusion over the task or lack of engagement in the task (noting that review of response times and the absence of sequences of repeated answers did not indicate a failure to engage). A mixed ANOVA was carried out on the *d'* data with size of the postural signal (large or small based on the extent of implied arm flexion) as a within-participants factor, and age group as a between-participants factor. Unsurprisingly, there was a main effect of size of the postural signal, confirming that the signal was harder to detect when the extent of implied arm flexion was lower ($F(1,55) = 44.10$, $p < 0.001$, $\eta_p^2 = 0.45$). Importantly, there was also a main effect of age group, with younger adults more sensitive to differences in posture than older adults ($F(1,55) = 6.30$, $p = 0.01$, $\eta_p^2 = 0.10$). There was no interaction between the size of postural signal and age group ($F(1,55) = 1.86$, $p = 0.18$).

These findings therefore demonstrated that older adults were less sensitive than younger adults to postural body features. Figure 3.3 summarises the results of Experiment 1.

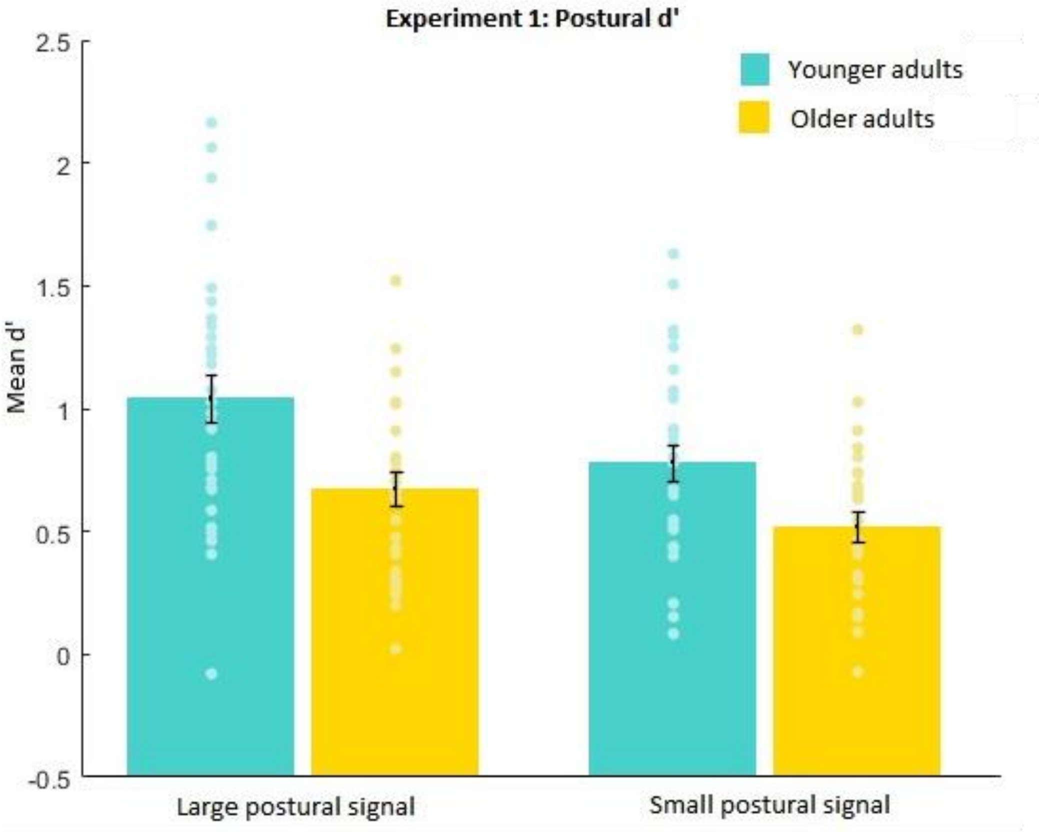

Figure 3.3: Mean sensitivity (d') to postural signal in younger and older adults with larger and smaller postural signals. Bars show group level differences with standard error bars, and light dots show individual participants.

In relation to response bias, *c* did not differ between age groups; older adults M = 0.02, SD = 0.52, younger adults M = 0.22, SD = 0.41, $t(52) = 1.60$, $p = 0.12$.

3.3 Experiment 2 – Kinematic differences

3.3.1 Background

The findings of Experiment 1 demonstrated that older adults exhibited lower sensitivity to postural body features. Reduced performance in Experiment 1 was unlikely to be due to a decline in intellectual capabilities (Salthouse, 2012; Salthouse, 2005)(Salthouse, 2012; Salthouse, 2005)(Salthouse, 2012; Salthouse, 2005) given that WASI scores were matched between age groups and the older adult impairment was numerically smaller in the more demanding version of the experimental task (see Figure 3.3) whereas an account based on general cognitive decline would suggest the opposite pattern. However, as already noted, older adults exhibit reduced functioning in several aspects of visual processing and it is important to ascertain the specificity of the effect, especially given that the visual acuity was assessed simply according to self-report. Experiment 2 was therefore designed such that task demands were broadly similar to Experiment 1, but participants were required to detect whether the velocity of the walker in the point light display increased or decreased across the time-course of the video. Participants thereby identified a kinematic feature of the stimuli, rather than a postural feature. To this end, the experiment included 'Kinematic Difference' trials, where the described difference was present and 'No Kinematic Difference' trials where it was not (further described below).

As in Experiment 1, sensitivity to probed stimuli was calculated as *d',* where in this case hit rate (HR) was the proportion of Kinematic Difference trials correctly identified, while false alarm rate (FAR) was the proportion of No Kinematic Difference trials wrongly identified as Kinematic Difference trials; $d' = \theta^{-1}(HR) - \theta^{-1}(FAR)$. As in Experiment 1, the hypothesis related to sensitivity, so results focus on *d'* below. However, we also note findings in relation to response bias (*c*) as a feature of the methodology adopted: $c = -0.5\,(\theta^{-1}(HR) + \theta^{-1}(FAR))$.

3.3.2 Method

Participants

Two groups participated in Experiment 2, 39 younger adults aged 35 or under (M = 27.5, SD = 4.7 years, 26 females and 13 males) and 39 older adults aged 60 or older (M = 70.7, SD = 6.9 years, 26 females and 13 males).

WASI scores were obtained for 27 older adults and 28 younger adults in Experiment 2. Raw older adult scores (M = 70.4, SD = 6.9; FSIQ2 equivalent = 128.0) did not differ significantly from raw younger adult scores (M = 71.5, SD = 4.9, FSIQ2 equivalent = 122.3; $t(53) = 0.67$, $p = 0.50$).

Stimuli

No Kinematic Difference trials presented unadapted point light display videos identical to those presented as No Postural Difference trials in Experiment 1. In Kinematic Difference trials the same point light display videos were manipulated so that the velocity of the point light display steadily increased or decreased during the second half of the video, while leaving posture unchanged. To generate the appearance of a gradual change in velocity, the coordinates of each point in each frame in the second half were recalculated according to a power function such that they appeared increasingly ahead of (or behind) the original while remaining on the same trajectory. It is noted that it has been suggested that acceleration cannot be directly detected over short time periods (Brouwer et al., 2002)(Brouwer et al., 2002)(Brouwer et al., 2002) and therefore participants may in fact use velocity information as the basis for discriminations. However, the hypothesis does not rest on which of these features are used by participants. The velocity change function was in the form $\boldsymbol{w = x + y^a (z)}$, where ‘x’ is the original position of a point in frame number ‘y’, ‘z’ the change in position between frames ‘y’ and ‘y+1’, and ‘a’ is the power constant (alteration of which makes the change in velocity over the course of the video either more or less extreme).

Two versions of each Kinematic Difference video were produced, differing in the size of kinematic signal based on degree of change in velocity (i.e. varying the power constant, ‘a’). Small kinematic signal videos presented implied velocities at the end of the video that differed from the first half by 30%, and large signal videos by 50%, with the rate of change in velocity constant across the second half. The combination of two actors, two viewing angles, videos where velocity increased and decreased, and large and small kinematic signals, generated 16 Kinematic Difference videos.

Procedure

The procedure matched Experiment 1 (see figure 3.2), except that participants were asked either ‘Was the person speeding up?’ or, ‘Was the person slowing down?’. As in Experiment 1, trials were presented to each participant in two blocks of 56 and presentation order was randomised within each block.

3.3.3 Results

One sample t-tests confirmed that sensitivity (*d’*) was significantly positive for both younger adults (M = 1.20, SD = 0.46; $t(38) = 16.14$, $p < 0.001$) and older adults (M = 1.22, SD = 0.42; $t(38) = 18.21$, $p < 0.001$), indicating that both groups were able to distinguish Kinematic Difference from No Kinematic Difference trials. One younger participant had a marginally negative d’ in one condition, but exhibited a positive d’ across Experiment 2, indicating low sensitivity rather than confusion as to task demands. A mixed ANOVA was conducted on d’ with size of kinematic signal (large or small based on extent of implied change in velocity) as a within-participants factor, and age group as a between-participants factor.

Unsurprisingly, there was a main effect of size of kinematic signal, confirming that participants were more sensitive to the signal when there was greater velocity change ($F(1,76) = 274.27$, $p < 0.001$, $\eta_p^2 = 0.78$). Importantly in relation to the hypothesis, there was no significant main effect of age group, with older adults and younger adults both exhibiting equivalent sensitivity towards changes in velocity ($F(1,76) = 0.03$, $p = 0.87$). The interaction between age group and size of kinematic signal was also not significant ($F(1,76) = 2.39$, $p = 0.13$).

Experiment 2 therefore demonstrated equivalent performance between older adults and younger adults with similar stimuli and task requirements to Experiment 1, but in a task that required detection of a kinematic rather than postural cue. Figure 3.4 summarises the results of Experiment 2.

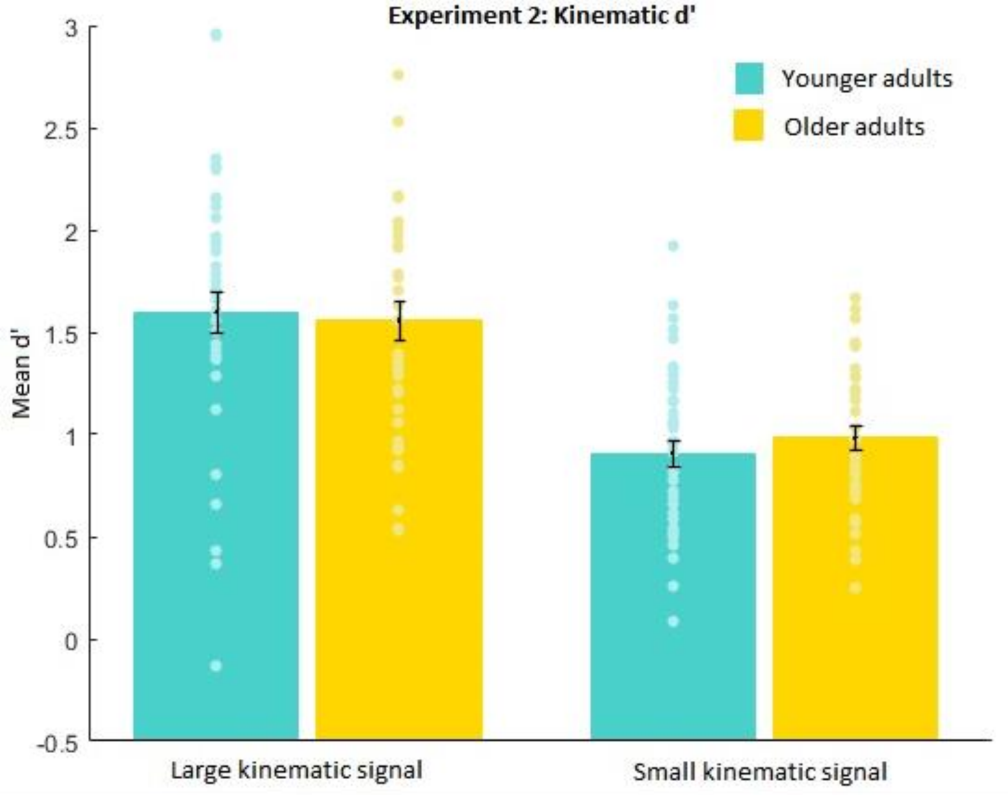

Figure 3.4: Mean sensitivity (d') to kinematic signal in younger and older adults with larger and smaller kinematic signals. Light dots against each bar show individual participants' sensitivity.

As was the case in Experiment 1 response bias, *c*, in Experiment 2 did not differ between age groups; older adults M = 0.46, SD = 0.55, younger adults M = 0.48, SD = 0.54, $t(76) = 0.18$, $p = 0.86$.

3.4 Discussion

The results of Experiments 1 and 2 demonstrated difficulty processing postural cues in older adults relative to younger adults (Experiment 1), alongside intact processing of kinematic cues (Experiment 2).

It is purported that the deficit older adults show in postural processing is related to difficulties with visual configural processing, and it was under this hypothesis that the experimental manipulations were designed. For instance, as noted in Chapter 1, older adults exhibit smaller 'global precedence' effects, such that the speed advantage typically observed in recognising the global form of objects in comparison with local features is reduced in older adults (Oken et al., 1999; Slavin et al., 2002; Lux et al., 2008; Insch et al., 2012; see also Murray et al., 2010; Slessor et al., 2013). Postural information requires computing the relative position of effectors – in the case of Experiment 1, the position of the dot representing the wrist on one side of the body relative to those representing other body parts – and therefore deficits processing configural information would yield posture perception difficulties. Although perception of kinematic features may often require configural processing, the task presented in Experiment 2 likely did not. Specifically, participants could perform the required judgment by focusing on any single point on an arm or leg.

Therefore, under this hypothesis, the findings of the two experiments reported in this chapter would indicate that deficits in perceiving posture will typically be found in older adults because the nature of this cue is typically configural, but problems in perceiving kinematics may depend upon whether the kinematic feature required configural processing (Di Domenico et al., 2015; Grainger et al., 2017).

However, it is important to note that an explanation based on a more general pattern of deficit in configural processing, and relative preservation in featural processing, is speculative as, although Experiment 1 allowed for kinematics to be ascertained through a strategy not involving integrating across space, it did not rule out that participants were doing so. Chapters 5 and 6 return to the question of the precise nature of the deficit, and the extent to which it may generalise beyond perception of posture and kinematics, through experiments involving static images of faces (and, in Chapter 6, non-face objects) and in a fashion where configural cues are more precisely isolated from elemental counterparts.

CHAPTER 4: EMOTION RECOGNITION IN POINT LIGHT DISPLAYS

4.1 Introduction

Note: The work in this chapter and Chapter 4 draws upon and extends work that has previously been published (Chard et al., 2019).

The two experiments reported in Chapter 3 deliberately did not ask a question of a socio-cognitive nature (e.g., asking participants to infer the mental or affective state of the walker), and instead simply focused on the sensitivity of older adults relative to younger adults to postural and kinematic signals - finding evidence for a deficit in relation to postural cues, but relative preservation for kinematic ones. In this chapter, Experiment 3 assesses whether impaired recognition of affective states could be explained, at least partly, by findings set out in Chapter 3 regarding deficits in processing these cues.

As introduced in Chapter 1, there is evidence that older adults exhibit impaired recognition of affective states of others, and that impairment is thought to result in a cascade of problems in social understanding and communication and hence exacerbate social difficulties associated with isolation (Happé et al., 1998; Luo, 2012; Shankar et al., 2011). A range of processes are required for recognising the affective states of others (Happé et al., 2017), many of which are directly involved in identifying that a certain hidden state (e.g., anger) was the driving force behind another individual's observed behaviour. However, it is also particularly important that we process the perceptual cues providing information about these states. A variety of cues provide this information, including the lexical content and intonation of our speech, our facial expressions and our body language – both our posture and the kinematics of our movements. For example, perception of relaxed limbs can signal happiness, while perception of fast, jerky movements can signal anger (Dael et al., 2012; Montepare et al., 1999; Wallbott, 1998). If we are insensitive to a certain perceptual cue, e.g., relaxed limbs in another, we will be unable to use this information to determine another's affective state, and to use this state attribution for effective social understanding and communication.

As noted in Chapter 1, age-related difficulties with emotion recognition are often hypothesised (e.g., Ruffman et al., 2008; Sullivan & Ruffman, 2004) to arise from neurophysiological changes in the 'social brain' and it appears to follow from this account that problems with social cognition are caused directly by problems in post-perceptual mechanisms for computing internal states.

Many of the studies using visual cues that underlie the 'social brain' account are based on deficits in recognition of affective states from facial expressions (Calder et al., 2003; Keightley et al., 2006; Kessels et al., 2014; MacPherson et al., 2006). However, in addition to methodological challenges set out in Chapter 2, there are differences in the pattern of deficit and preservation dependent on the nature of stimuli used. This is not only the case for different modalities (e.g. visual and auditory tasks) but also between different tasks in the same sensory modality. Specifically, there is evidence in relation to whole-body movements (Montepare et al., 1999; Ruffman et al., 2009; Spencer, 2016) which differs from facial expression studies insofar as the pattern of deficit and relative preservation appears not to be the same in some important respects as typically reported in relation to faces. In particular, the relatively preserved recognition of happiness by older adults, which is commonly reported in studies involving facial expressions, does not appear to be reflected for bodily expressions of emotion. Conversely, there is evidence from the cited studies that accuracy in categorising fearful body language is impaired in older adults, whereas that is not the case for facial expressions depicting fear.

This gives rise to the possibility that at least some of the age-related deficits in emotion recognition may result not from post-perceptual processes (which may be more equivalent for these different stimulus types conveying equivalent socioemotional information) but from changes in perceptual processing. Importantly, given the findings in Chapter 3 regarding age related deficits in configural processing, and relative preservation in in featural processing, it may be predicted that older adults would exhibit particular difficulties recognising emotions where the emotions are reflected through configural cues.

4.2 Experiment 3 – Affective states

4.2.1 Background

Based on the findings of experiments reported in Chapter 3, it was hypothesised that older adults would exhibit impairments in detecting affective states conveyed primarily through postural information but would be relatively preserved in detecting those conveyed primarily through kinematics. In other words, that they would exhibit impairments when detecting affective states conveyed through the cues that they have relative difficulty perceiving. This hypothesis was examined in Experiment 3 where the ability of older adults to recognise happy, angry and sad affective states from point light displays was assessed.

Previous studies have indicated that the identification of some affective states relies more heavily on kinematic cues such as velocity and acceleration whereas others can be identified more easily from postural information (Gross et al., 2012; Roether et al., 2009). The specific pattern of these dependencies will likely differ depending upon the stimulus set – and certainly also between bodily and facial cues – but previous work in younger adults has revealed much about the sources of information observers use to make affective state judgments in the present stimulus set. Edey et al. (2017) found that velocity cues were of greater importance when detecting anger (rapid, jerky movement) and sadness (slow, sluggish movement) than when detecting happiness in these stimuli, given that judgments were influenced to a greater extent by removal of the cues (see also Barliya et al., 2013; also note that variation in acceleration tracked the variation in velocity). Additionally, when the kinematic cues were removed from these stimuli leaving only postural cues, participants detected happiness more readily than anger or sadness (happiness relative to sadness [$t(86) = 2.8$, $p = 0.006$] and anger [$t(86) = 3.6$, $p = 0.001$]), suggesting that happiness detection in these stimuli relied more upon postural features than anger or sadness detection.

Based on these earlier findings, it was therefore predicted, given the pattern of impaired postural processing alongside relatively preserved kinematic processing from Experiments 1 and 2, that older adults would exhibit impaired detection of happiness based on the relative importance of postural signals in its recognition, and relatively intact detection of anger and sadness, based on the relative importance of kinematics in their recognition. Experiment 3 included 'Affective State' trials, where the described affective state was present and 'Affectively Neutral' trials where a neutral video was shown.

As in other experiments in this thesis and as further explained in Chapter 2, sensitivity to probed stimuli was calculated as *d',* which indicates the extent to which participants are more likely to report the presence of a probed stimulus when it is present than when it is absent. In Experiment 3, hit rate (HR) was the proportion of Affective State trials correctly identified, while false alarm rate (FAR) was the proportion of Affectively Neutral trials wrongly identified as Affective State trials; $d' = \theta^{-1}(HR) - \theta^{-1}(FAR)$.

As in Experiments 1 and 2, the hypothesis related to sensitivity, so results focus on *d'* below. However, we also report findings in relation to response bias (*c*) as a feature of the methodology adopted: $c = -0.5\ (\theta^{-1}(HR) + \theta^{-1}(FAR))$. In so doing it is noted that, unlike in Chapter 3 where there was no *a priori* reason to anticipate a systematic difference in response bias between older and younger adults (although doing so remains useful for reasons set out in Chapter 2), previous findings in relation to 'positivity bias' (Carstensen et al., 2012; van Reekum et al., 2011) were potentially relevant to Experiment 3. Depending on how precisely it is specified, a 'positivity bias' account may either suggest older adults have a greater tendency to report the presence either of emotionally valenced signals in general, or *positive* signals (in this case happiness) specifically. Such a bias would, using an accuracy rather than sensitivity measure, tend to overestimate older adults' ability to identify either emotion conveyed by point light displays in general, or specifically positive emotions conveyed in that manner.

4.2.2 Method

Participants

Two groups participated in Experiment 3, 46 younger adults aged 35 or under (M = 27.7, SD = 4.8 years, 32 females and 14 males) and 37 older adults aged 60 or older (M = 71.8, SD = 7.2 years, 23 female and 14 males). The results of three further older adults were excluded because *d'*s could not be calculated due to 100% false alarm rates or 0% hit rates in at least one condition (i.e., extreme bias towards reporting presence of an emotion). It is noted that as set out in Chapter 2 conventional accuracy measures, in similar circumstances, may have recorded those participants as accurately reporting the presence of the emotion in all cases.

Weschler Abbreviated Scale of Intelligence (WASI) scores were obtained for 25 older adults and 30 younger adults in Experiment 3. Raw scores obtained by older adults (M = 70.8, SD = 6.9; FSIQ2 equivalent = 129.0) did not differ significantly from those obtained from younger adults (M = 71.1, SD = 6.8, FSIQ2 equivalent = 121.5; $t(53) = 0.18$, $p = 0.86$).

To ensure the two groups were matched for other traits that may be associated with deficits in emotion recognition, participants also completed questionnaires relevant to the Toronto Alexithymia Scale (TAS-20) and Beck Depression Inventory (BDI). The decision to include these measures was made after testing had begun, so a smaller number of participants undertook these elements - 25 older adults and 18 younger adults. Scores did not differ according to age group in relation to the TAS-20 (older adults M = 45.20, SD = 8.80; younger adults M = 45.39, SD = 7.19; $t(41) = 0.08$, $p = 0.94$) or BDI (older adults M = 7.80, SD = 5.09; younger adults M = 8.72, SD = 6.44; $t(41) = 0.52$, $p = 0.60$).

Stimuli

Affectively Neutral trials presented the same four walkers depicted as point light displays as were used in Experiments 1 and 2 in Chapter 2. Affective State trials presented other stimuli from the same original set (Alaerts et al., 2011), where the actors conveyed happiness, sadness, or anger. In the Alaerts study, participants had been able to recognise affect at above chance levels (54.3% above in the neutral condition, 44.2% for happiness, 45.8% for sadness, and 58.6% for sadness). The sad point light display moved with low velocity and acceleration, taking fewer steps per second than the affectively-neutral walker (sad: mean velocity = 2.03 pixels/frame [SD = .73], mean acceleration = .73 pixels/frame^2 [SD = .09]; neutral: mean velocity = 3.91 pixels/frame [SD = 1.69], mean acceleration = 1.30 pixels/frame^2 [SD = .21]). In contrast, the happy (mean velocity = 5.91 pixels/frame [SD = 2.54]; mean acceleration = 1.99 pixels/frame^2 [SD = .40]) and angry walkers (mean velocity =

6.97 [SD = 2.87]; mean acceleration = 2.49 pixels/frame^2 [SD = .37]) both moved with higher velocity and acceleration, but where the difference relative to affectively neutral walkers was especially exaggerated in the angry point light display.

This combination of two actors, two viewing angles, and equalisation by duration and step cycle, generated eight Affective State videos per affective state, while there were four Affectively Neutral videos.

Procedure

The procedure matched Experiments 1 and 2 in Chapter 3 (see summary of procedure in figure 3.2), except that participants were asked to consider which affective state, if any, was conveyed in the point light display. They were told that this state could be angry, sad, happy, or none of these. After each video, participants were asked either ‘Was the person happy?’, ‘Was the person sad?’ or ‘Was the person angry?’. As in Experiments 1 and 2, participants were asked to confirm their answer but did not receive feedback on whether or not that answer was correct.

Trials were presented to each participant in two blocks of 84 point light display videos (16 Affective State and 12 Affectively Neutral trials per affective state) and presentation order was randomised within each block, so participants were not aware when watching a video which affective state would be probed. Reflecting Experiments 1 and 2, participants saw no videos in Experiment 3 containing a signal other than the target signal, for example trials in which the person was happy and they were asked whether or not they were angry.

4.2.3 Results

One sample t-tests confirmed that *d'* was significantly positive for both younger adults and older adults for all three affective states tested, indicating that both groups were able to distinguish Affective State from Affectively Neutral trials (all *t*s > 2.66, all *p*s < 0.007). A mixed ANOVA was carried out on the *d'* data, with target affective state (happy, sad, or angry) as the within-participants factor and age group as the between-participants factor. Greenhouse-Geisser corrections were applied where appropriate. There was a significant main effect of affective state ($F(2,162) = 138.06$, $p < 0.001$, $\eta_p^2 = 0.63$), with participants across age groups being most sensitive in the sad condition and least sensitive in the happy condition. Importantly, this main effect was qualified by a significant interaction between affective state and age group ($F(2,162) = 9.62$, $p = 0.001$, $\eta_p^2 = 0.11$). Follow-up tests indicated that older adults were significantly less sensitive to happiness than the younger adults ($t(81) = 3.05$, $p = 0.003$) and, interestingly, significantly more sensitive to sadness ($t(81) = -2.20$, $p = 0.03$). There was no significant difference in relation to sensitivity to anger ($t(81)= -1.18$, $p = 0.24$).

Although, at a group level, *d'*s were significantly positive for both groups in all three conditions, the happy condition was most difficult for both groups and some participants had negative *d'* (in addition to the exclusions noted above, 7 younger adults and 12 older adults fell into this category). Since all participants with negative d's in the happy condition had positive *d'*s in the sad and angry conditions as well as overall, it is unlikely that these arose from confusion over the task instructions or failure to engage in with the task. However, it is possible that, while some of those with negative *d'* were insensitive to informative visual cues, others may have been sensitive to the cues but categorised neutral point light displays as happy and vice versa. In other words, *d'*s reflect both sensitivity to the information and the categorisation of that information. However, even excluding all 19 participants with negative *d'*s (all in the happy condition), there remained a significant interaction between age group and target affective state ($F(2,124) = 4.62$, $p = 0.02$, $\eta_p^2 = 0.07$), and follow-up tests indicated older adults remained significantly less sensitive to happy point light displays than younger adults ($t(62) = 2.31$, $p = 0.02$).

In relation to bias, a mixed ANOVA on the response bias (*c*) data, with target affective state (happy, sad, or angry) as the within-participants factor and age group as the between-participants factor. This indicated a significant main effect of affective state ($F(2,162) = 23.69$, $p < 0.001$, $\eta_p^2 = 0.23$). One-sample t-tests confirmed that participants had a tendency towards answering 'yes' to the question 'Was the person happy?' (overall M = -0.586; older adults M = -0.80, SD = 0.82; younger adults M = 0.40, SD = 0.86; $t(82) = -6.06$, $p < 0.001$), while there was a trend in the opposite direction in the angry condition (overall M = 0.18; older adults M = 0.02, SD = 0.97; younger adults M = 0.30, SD = 0.73; ; $t(82) = 1.88$, $p = 0.06$), and there was no sign of a bias in the sad condition (overall M = -0.04; older adults M = -0.06, SD = 0.81; younger adults M = -0.02, SD = 0.80; $t(82) = -0.42$, $p = 0.67$). There was also a trend for older adults to be more likely than younger adults to respond in the affirmative across all three target affective states ($F(1,81) = 3.57$, $p = 0.062$), but no interaction between affective state and age group ($F(2, 162) = 1.29$, $p = 0.27$). This trend of older adults to answer 'yes' to any question may be deemed consistent with previous suggestions of positivity biases in older adults, albeit depending upon exactly how such an account is characterised, and demonstrates the importance of dissociating sensitivity from biases as considered in Chapter 2.

To summarise, older adults were impaired in detecting those affective states thought to be conveyed predominantly through the cues they were shown to be impaired in perceiving in Experiments 1 and 2 (posture; i.e., happiness) but not in detecting those conveyed primarily through the cues they were shown to process similarly to younger adults (kinematics; i.e., sadness and anger). Figure 4.1 summarises the results of Experiment 3.

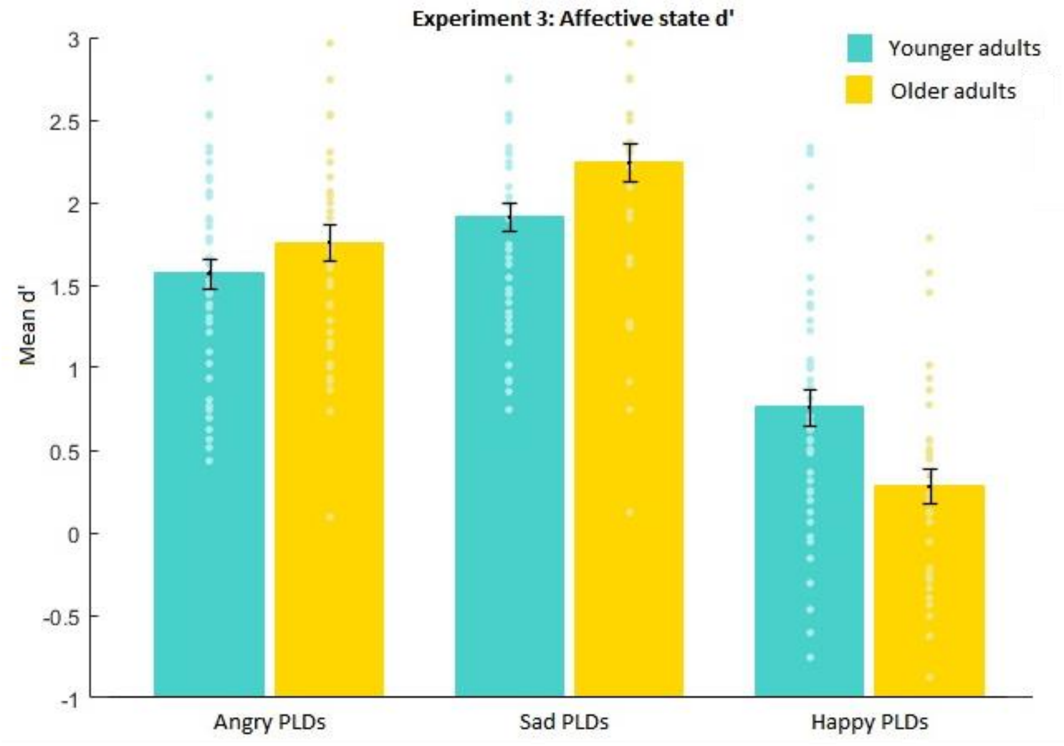

Figure 4.1: Mean sensitivity (d') to angry, sad and happy point light displays in younger and older adults. Bars show group level differences with standard error bars, and dots show individual participants.

4.3 Cross-experiment comparisons

By design, most participants completed all three experiments reported in Chapter 3 and this chapter. This subset included 29 younger adults (M = 27.3, SD = 4.7 years, 21 females and 8 males) and 24 older adults (M = 74.8, SD = 6.8 years, 14 females and 10 males). For these 53 participants, the experiments reported in Chapter 3 and above can be regarded as three tasks within a single experiment.

Among this subset, the patterns of significance (both main effects and interactions) were the same as with the full samples, with the exception of the simple effect of group on sadness recognition where the significant older adult advantage was no longer present and, as with anger recognition, there was no significant difference between age groups (i.e. the age group x emotion interaction was predominantly driven by older adults' deficit in relation to happiness sensitivity). Importantly, there was a task (i.e. Experiment) by age group interaction ($F(1,54) = 5.05$, $p = 0.03$, $\eta_p^2 = 0.09$).

The results in Experiment 3 were consistent with the hypothesis, based upon Experiments 1 and 2, that older adults would exhibit reduced sensitivity to affective states conveyed predominantly through postural cues, and be relatively preserved in detecting those conveyed primarily through kinematics. That hypothesis rested upon the assumption that recognising happiness relies upon postural cues in this stimulus set more than kinematic cues, and anger and sadness detection rely more upon kinematic cues (Edey et al., 2017). However, the hypothesis can also be verified with the present dataset by asking how individual differences in the experiments relate to each other, and therefore disregarding the need for these assumptions. Specifically, individual differences in Experiment 1 should predict individual differences in Experiment 3 in detecting affective states dependent upon postural cues, whereas individual differences in Experiment 2 should predict those individual differences in Experiment 3 in detecting states dependent upon the kinematic cues (importantly, when controlling for age group to ensure that these analyses are not circular with respect to any reported group effects). It is also noted that, in Experiment 3, the condition involving detection of happiness in the point light display was significantly more difficult than those involving detection of anger or sadness, which would be consistent with an account based on general cognitive decline in older adults (Salthouse, 2012; Salthouse, 2005). There are several reasons why this is unlikely, given matched WASI scores, the absolute (as opposed to relative) preservation in two of the conditions, and the absence of an interaction between difficulty and age group in Experiments 1 and 2. However, cross-experiment comparisons may additionally provide relevant evidence that the results of Experiment 3 do not relate primarily to task difficulty.

To this end, partial correlations were carried out between performance in each of Experiments 1 and 2 and detection of the three separate affective states in Experiment 3, controlling for age. Sensitivity (d') to kinematic differences in Experiment 2 was significantly related to d's for both point light displays depicting anger (r =0.31, p = 0.02, 95% CI [0.05, 0.53]) and sadness (r = 0.31, p = 0.03, 95% CI [0.05, 0.53]), but not point light displays depicting happiness (r= 0.06, p = 0.68, 95% CI [-0.21, 0.32]). Conversely, sensitivity to postural differences in Experiment 1 was related to *d'* for point light displays depicting happiness (r =0.31, p = 0.02, 95% CI [0.09, 0.50]) but not point light displays depicting anger (r = 0.11, p = 0.45, 95% CI [-0.12, 0.32]) or sadness (r = 0.05, p = 0.71, 95% CI [-0.18, 0.28]). The same patterns of significance were also found in correlation analyses which did not control for age group, and in partial correlations controlling both for age group and sensitivity in the affectively-neutral task thought to be less related (e.g., controlling for sensitivity to kinematic difference when examining the relationship between posture and happiness detection). These analyses thereby confirm that older adults are indeed impaired in recognising the affective state relying predominantly upon posture information in the present stimulus set – i.e., the cue they are impaired in perceiving.

The results of the cross-experiment comparisons provide evidence that the cue type (posture versus kinematics) underlies the difference in age-related sensitivity to emotionally valenced stimuli in Experiment 3. Figure 4.2 summarises the partial correlation analysis.

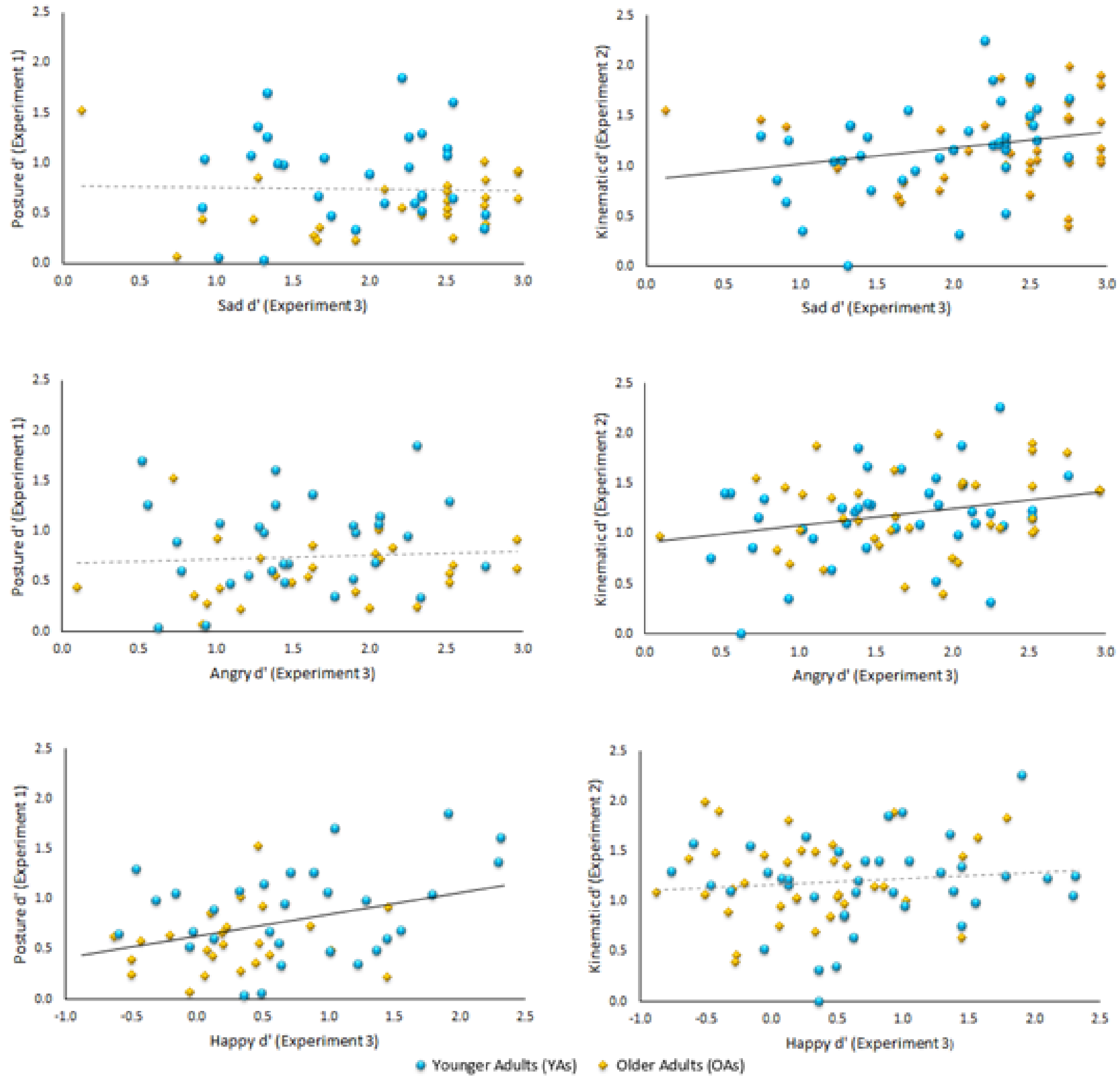

Figure 4.2: Scatter plots illustrating the relationship between sensitivity to sadness, anger and happiness (Experiment 3) and sensitivity to posture (Experiment 1) and kinematics (Experiment 2). Significant predictors are shown by solid lines, and non-significant predictors by broken lines. Individual data points shown for older and younger adults are not residualised.

4.4 Discussion

The experiments reported in Chapters 3 and 4 tested the hypothesis that perceptual disturbances may contribute to previous findings in relation to older adults' deficits in emotion recognition, using 'point light display' body movement stimuli (Dael et al., 2012;

Montepare et al., 1999; Wallbott, 1998). The data demonstrated difficulty processing postural cues in older adults relative to younger adults (Experiment 1), alongside intact processing of kinematic cues (Experiment 2). In support of the hypothesis, older adults also exhibited difficulty recognising only the affective state (happiness) conveyed predominantly through the cue which Experiment 1 had demonstrated them to be impaired in processing (posture). Whilst the hypothesis tested in Experiment 3 made a presumption, based on past findings, as to the types of cue most relevant to judging different emotions, cross-experiment comparison provided supporting evidence that postural sensitivity predicted sensitivity to the point light display depicting happiness (and kinematic sensitivity did not) whereas the opposite pattern applied for point light displays depicting sadness and anger.

These findings are therefore consistent with the hypothesis that difficulties in recognising affective states in older adults relate to reduced sensitivity to the perceptual cues signalling those states. In fact, not only were the emotion recognition deficits larger for those emotions predominantly conveyed by perceptual cues they were impaired in processing, they were absent for emotions predominantly conveyed by intact perceptual cues. This pattern may cast a slightly different light on the hypothesis that deterioration in the ‘social brain’ – involving the orbitofrontal cortex, cingulate cortex and amygdala – is responsible for broad deficits in emotion recognition in older adults (e.g., Ruffman et al., 2008). Given that this is the network implicated in the “accurate perception of the dispositions and intentions of other individuals” (Brothers, 2002), it appears to follow from a strong version of the ‘social brain’ account that problems with emotion recognition are caused directly by problems in post-perceptual mechanisms for computing internal states. Under this interpretation, the specific pattern of impairments in Experiment 3 would not have been predicted. However, given that the account is somewhat underspecified at the cognitive level, it is also possible that one could use the present findings to further specify the account and suggest that the ‘social brain' deteriorates due to reduced perceptual input across age. Additionally, a perceptual account may help to explain some of the inconsistencies between findings on recognition of emotional state. Specifically, in this case, it is possible that age-related deficits in detection of posture may explain why older adults have previously been found to exhibit a deficit in accuracy in recognising happiness conveyed by body language but not faces (although there are alternative explanations for that inconsistency such as ceiling effects in many experiments involving detection of happiness in faces).

As noted in Chapter 3, there are reasons to consider that the deficit older adults show in postural processing is likely to be related to difficulties with visual configural processing. Postural information requires computing the relative position of effectors – in the case of Experiment 1, the position of the dot representing the wrist on one side of the body relative to those representing other body parts – and therefore deficits processing configural information would yield posture perception difficulties. Although perception of kinematic features may often draw on configural processing, the task presented in Experiment 2 likely did not. Specifically, participants could perform the required judgment by focusing on any single point on an arm or leg. Chapter 1 noted some of the possible contributors to configural deficits, but we note that associating postural with configural deficits (and kinematic with featural preservations) is somewhat speculative, and this thesis returns to whether similar patterns are present for faces and other objects in Chapters 5 and 6.

Our findings highlight a methodological issue referred to in Chapter 2 in relation to previous literature suggesting relatively emotion-general deficits in recognition from facial, vocal and bodily cues (e.g., Hayes et al., 2020; Insch et al., 2012; Ruffman et al., 2008; Spencer, 2016; noting that the previous literature has typically found intact recognition of disgust). This literature has not allowed for a specific assessment of sensitivity to the signal, with most studies requiring participants to label the affective state presented, from multiple response options, and calculating the percentage accuracy. Such procedures allow for an inference that individuals have difficulties in correctly labelling emotions, but cannot ascertain whether these difficulties reflect low sensitivity to signals or response biases (see Isaacowitz et al., 2007, for a discussion of this issue). For instance, several studies have indicated intact performance for happiness recognition and, given a possible ‘positivity bias’ in older adults (Carstensen et al., 2012; van Reekum et al., 2011), it is particularly important to dissociate sensitivity from bias effects in this context. Interestingly, Experiment 3 indicated older adults were systematically more biased than younger adults towards reporting signals as emotionally valenced (i.e. errors more often took the form of ‘false alarms’ than ‘misses’), but there was no evidence that this was more pronounced for positive than for negative emotional stimuli. This may be consistent with a version of the ‘positivity bias’ account where the response is positive rather than the underlying reported emotion, although more research would be needed to assess that possibility further. As such, it would not necessarily explain findings of relative preservation in recognition of positive emotions in experiments using accuracy measures, although may indicate underestimation of deficits across the board.

In conclusion, the present findings suggest that difficulties in recognising affective states from bodily cues in older adults may be related to difficulties in perceiving the perceptual cues signalling those states. The findings in Chapter 3 and this chapter demonstrate more widely how it is essential to consider the contribution of perceptual processes to emotion and social perception.

CHAPTER 5: COMPOSITE FACES

5.1 Introduction

Chapters 3 and 4 examined whether a pattern of deficit and preservation in relation to detection of affect in point light displays could be explained, or at least contributed to, by age-related differences in perceptual sensitivity to postural differences. Chapter 3 reported experiments that supported the hypothesis that older adults have impaired perceptual sensitivity in tasks involving detection of postural differences, but relatively preserved perceptual sensitivity in relation to kinematic perception. Based on the logic that judging postural differences in point light displays requires integration of visual information across space whereas identifying kinematic differences does not, Chapter 4 reported an age-related deficit in sensitivity to emotions considered to be conveyed principally by posture in point light displays, and relative preservation in those conveyed by kinematics. These studies therefore provide some initial support for the contribution of differences in perceptual sensitivity to emotional and social perception aberration.

The hypothesis that older adults would exhibit a deficit in relation to sensitivity to postural differences relative to kinematic ones derived from behavioural and neurophysiological evidence that implies configural processing may be particularly disrupted in healthy aging. However, it should be noted that, whilst there are reasons to believe that an important difference between the postural and kinematic tasks in the experiments reported in Chapter 3 is that, in the postural task (Experiment 1) but not in the configural task (Experiment 2), it was necessary to integrate across space in order to judge relative positions of points of light over time, this only constitutes indirect evidence of a configural deficit. In particular, the stimuli presented in Chapters 3 and 4 were dynamic ones, and it is possible deficits related specifically to tracking of movements across space and time.

This chapter seeks to assesses whether older adults exhibit an equivalent pattern of deficit in relation to configural processing of static images of faces to provide a more controlled test of the hypothesis that configural processing is impaired in healthy aging. Additionally, as noted in Chapter 1, much of the research into social cognition from visual cues in healthy aging has focused on images of faces. As such, whilst it is useful to look at body language as an important and less extensively researched source of social cues, it is relevant also to assess the extent to which low level perceptual deficits may or may not contribute to the patterns of apparently social impairment and preservation found in relation to faces.

This chapter seeks to assess configural impairments through the composite face illusion (Young et al., 1987). Within psychophysical studies, illusions have long been seen as useful as a means to probe how visual mechanisms establish ‘normal’ percepts, by structuring stimuli to elicit illusory effects on the basis that the same mechanisms that underlie veridical judgments in typical circumstances can produce illusory ones in other situations (Todorović, 2020). There is evidence that older adults may show reduced susceptibility to certain types of visual illusion, including the Ebbinghaus illusion whereby a central, target stimulus appears smaller when surrounded by larger distractors (Mazuz et al., 2024) and the rotating tilted lines illusion whereby illusory motion is seen in a static presentation of tilted lines (Billino et al., 2009).

This composite face paradigm involves presentation, simultaneously or sequentially, of two faces each composed of the top and bottom half of two separate images. Participants are required to focus on either the top or bottom halves of the images, and to make judgments based on whether the 'target' halves of the two faces are the same or different, ignoring the 'distractor' half. In some presentations, the halves are spatially aligned to give the impression of forming a single face, and in others they are misaligned. Alignment tends to impede rapid and accurate responses where the similarity or difference in the distractor halves are incongruent with the target halves (i.e. where the distractor halves differ whilst the target halves are the same, or the distractor halves are the same while the target halves differ). Similarly, alignment tends to facilitate correct responses when the similarity or difference of the distractor halves are congruent with the target halves (i.e. where both the distractor and target halves differ between images, or where both are the same). Whilst many composite faces studies have been based on composites formed from different people's faces, the effect has also been shown in composites formed from different images of the same person exhibiting different emotions (Calder et al., 2000; Tanaka et al., 2012).

In the original version of the composite faces task, the distractor half of the face is always different between the two presentations, providing two conditions ('incongruent same' where the target halves are identical, and 'congruent different' where they are not). However, this entails a risk that a response bias towards reporting a difference would lead to underestimation of the composite face effect as alignment would only be expected to impede a correct response when the target half of the face is the same in each image (Richler & Gauthier, 2014). Consequently, the complete design is used in this chapter where the distractor halves in the two presentation can be the same, providing two further conditions ('incongruent different' where the target halves differ between the two images but the distractor halves do not, and 'congruent same' where neither half differs between presentations). Figure 5.1 illustrates the complete design of the composite face task, together with an example from Experiment 5.

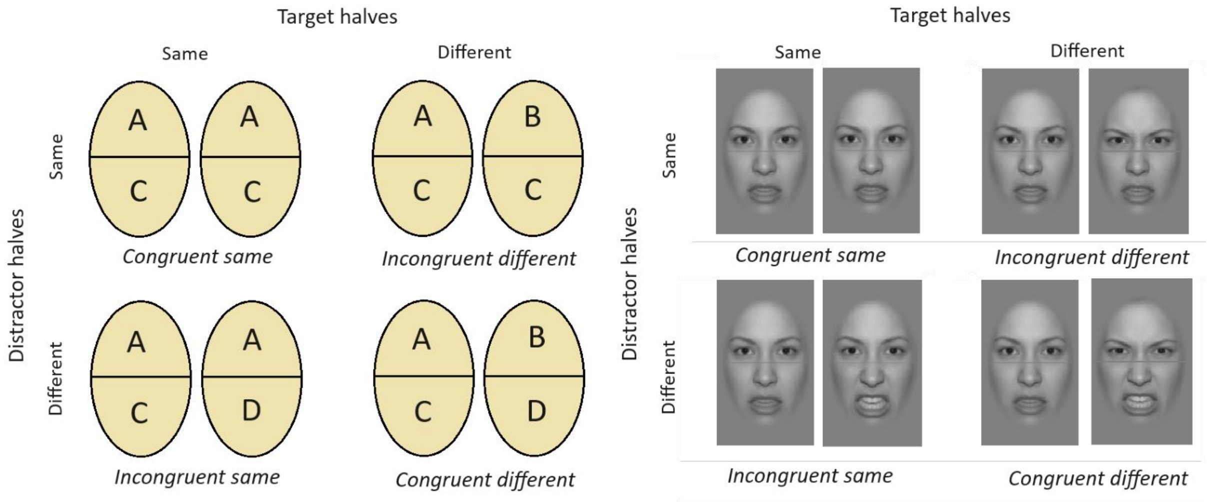

Figure 5.1: Left panel shows the complete design for the composite faces paradigm, and right panel shows an example from Experiment 5. In both panels: (i) target and distractor halves are the same in both images in 'congruent same' condition (top left); (ii) target half differs but distractor half is the same not in 'incongruent different' condition (top right); (iii) target half is the same but the distractor half differs in 'incongruent same' condition (bottom left); and (iv) target and distractor halves differ in 'congruent different' condition.

The composite face reveals a tendency to integrate visual information from disparate regions of the face (Murphy & Cook, 2017) which has been argued to arise from the creation of a novel configuration of parts (Hancock et al., 2000). Additionally, there is some evidence that priming participants via the Navon task to focus on global form in preference to local detail increases the magnitude of the composite face effect. Consistent with the approach in Chapters 3 and 4, this provides a basis to hypothesise that older adults will be less susceptible to the composite face illusion due to impaired integration of information across the visual field and increased reliance on local features.

Each trial within Experiment 4 presented participants, sequentially, with two composite face images formed from the top and bottom halves of pictures of the face of the same person, with a faint horizontal line separating the two halves. In half of the trials, the top and bottom halves of the face were aligned in both images presented, and in the other half they were misaligned. Participants were informed before each block of trials whether they would be asked about the top or bottom halves of faces presented and, after each presentation, were asked whether the target half of the face was the same or different in the two images presented.

As in previous chapters, sensitivity was calculated as *d'* which, as set out in Chapter 2, indicates the extent to which participants are more likely to report the presence of a difference between the target halves of the two images when there is a difference than when there is not. As noted above, use of the complete design addresses the risk that a response bias towards reporting a difference would lead to an underestimation of the composite face effect by ensuring alignment would be expected to impede a correct response in as many trials where the correct response would be 'same' as trials where it would be 'different'.

Within the complete design of the composite face paradigm, alignment should result in increased d' in congruent conditions (whether 'congruent same' or 'congruent different') but reduce d' in incongruent conditions (whether 'incongruent same' or 'incongruent different'), in both cases compared with misaligned trials. The hypothesis was that there would be an interaction between congruency, alignment and age group, such that older adults would show a smaller congruency x alignment interaction – i.e., a smaller composite face effect.

5.2 Experiment 4 – Composite faces

5.2.1 Method

Participants

Two groups participated in Experiment 4, 30 younger adults aged 35 or under (M = 25.7, SD = 4.7, 18 females and 12 males) and 30 older adults aged 60 or older (M = 69.4, SD = 6.4, 20 females and 10 males). The sample size was determined such that we would have at least 80% power to detect a medium-sized group x condition interaction effect (η_p^2 = 0.06, alpha = 0.05). This requirement led to the calculation that we would require at least 24 in each group to detect effects. However, given the difficulties of recruiting older participants and risk of non-attendance, all older participants responding to the recruitment drive were invited to take part, and a matching number of younger participants were also recruited.

Participants had normal or corrected-to-normal vision. Older adults were screened for mild cognitive impairment using the Montreal Cognitive Assessment (Nasreddine et al., 2005) and no participants were excluded on the basis of such an impairment.

Experiments 4 and 5 in this chapter were carried out in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki and approved by the Birkbeck, University of London Ethics Committee. Experiments were pre-registered via “As Predicted”: https://aspredicted.org/g7k7m.pdf. Note that experiments reported in Chapters 3 and 4 were not preregistered because they were carried out before it became widespread.

Stimuli

In Experiment 4 (and Experiment 5 below) stimuli were derived from a set of 14 grayscale face images derived from the Radboud Faces Database (Langner et al., 2010). These showed one male and one female actor each depicting six emotions (happiness, sadness, anger, fear, surprise and disgust) or with a neutral expression. Morpheus Photo Morpher v3.11 (Morpheus

Software, Indiana) was used to reduce emotional intensity to 50% following piloting, with a view to ensuring the task's difficulty level was such as to limit the risk of ceiling effects.

Each pair of composite faces featured the same actor in the target and distractor halves, and each featured some combination of neutral and emotionally expressive faces, with only a single emotion featured within each trial. Specifically, in 'congruent same' trials both images had a neutral target half paired with identical emotional distractor halves; in 'incongruent same' both images had a neutral target half but the distractor half was neutral in one and emotional in the other; in 'congruent different' trials one image had a neutral target half and emotional distractor half and the other an emotional target half and neutral distractor half; and in 'incongruent different' trials both images had an emotional distractor half but the target half was neutral in one and emotional in the other. In all images, a thin, two-pixel line separated the top and bottom halves of the composite faces. Composites subtended approximately 6° vertically when viewed at 50 cm. In the misaligned condition, target and distractor halves were offset horizontally by approximately 3°.

The combination of six mildly emotional facial expressions with the neutral image for each actor, across the four trial types and either aligned or misaligned, resulted in 96 different trials, each of which was presented four times over the course of the experiment (384 trials in total).

Procedure

In Experiment 4, participants were seated in a dimly lit room at an approximate distance of 50 cm from a 24 inch LCD computer monitor (resolution = 1920 x 1200 pixels; refresh rate = 60 Hz). The experiment was conducted in MATLAB® using the Cogent graphics toolbox.

The experimenter was present whilst participants read the on-screen instructions and undertook practice trials in order to answer any questions about the procedure. The instructions told participants that they would be presented, sequentially, with pairs of composite images of faces in quick succession, that each pair of images would be of the same individual, but that their facial expression may or may not vary between the images. Participants were informed that the top and bottom halves of the face would either be aligned or misaligned and were shown examples of how this would look on screen, using faces not featured in the experiment itself. They were told that they would be required to focus on either the top half of the face only, or the bottom half only, and to judge whether it was the same or different in the two images, ignoring the other halves of the faces. Participants were then presented with four practice trials, all involving judging expression from the top half of the pairs of faces, before being asked if they were ready to begin.

The 384 recorded trials were split into 24 blocks of 16 trials. Before each block, participants were told whether they would be asked about the top or bottom of the face in that block, and the question at the end of each trial also included a reminder of the target face half, with participants asked to press the left key if that half of the face was the same in each presentation, or the right key if it was different. No feedback was provided on whether a response was correct. Each trial involved presentation of a fixation cross for 300ms, the first image for 300ms, a noise mask for 300ms, and the second image for 300ms, before the question appeared on screen until answered. Between each presentation, the screen was blank for 100ms. Blocks alternated in relation to target half (with the starting target half being counterbalanced between participants) and the presentation order of trials within blocks was fully randomised. Figure 5.2 summarises the procedure for both Experiments 4 and 5.

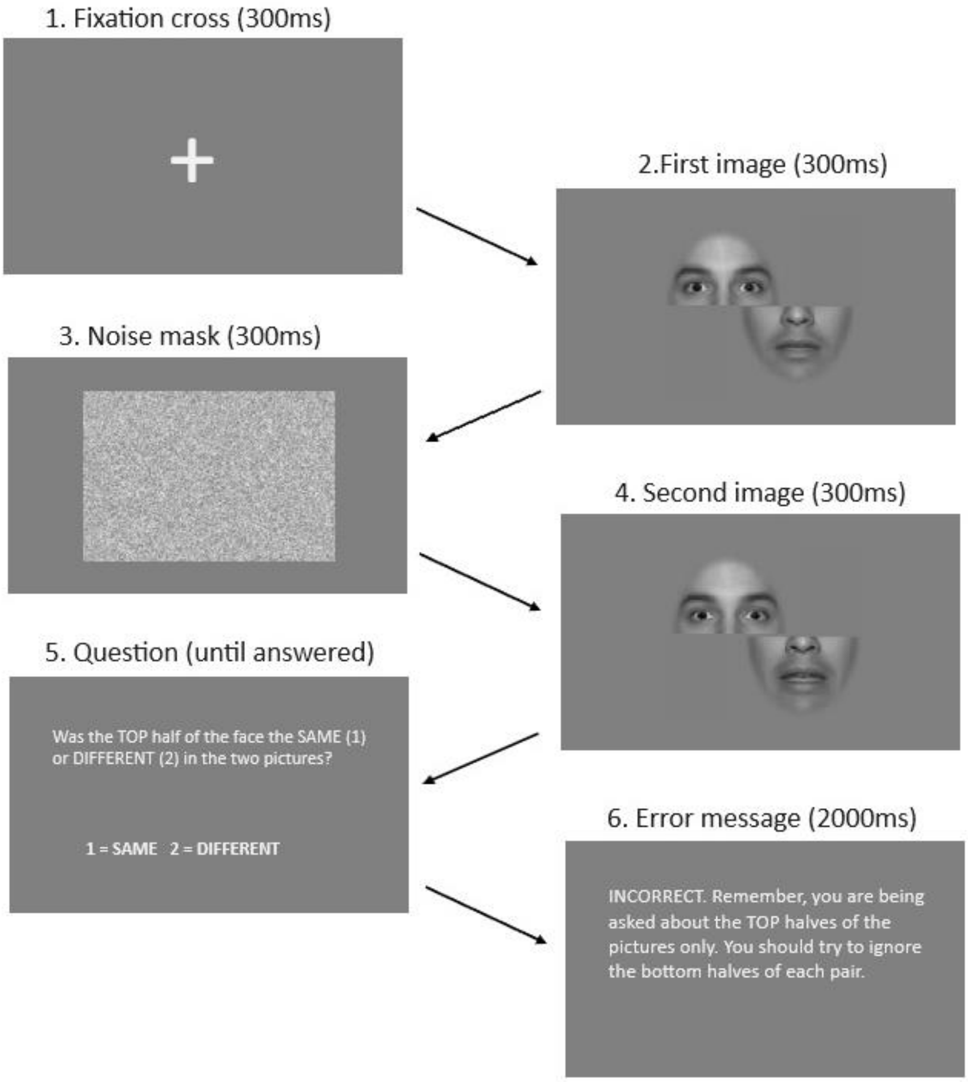

Figure 5.2: Procedure for Experiments 4 and 5. Note that the images used are from Experiment 5 (top half as target, incongruent same condition, misaligned), and that as explained in the procedure, the error message appeared in Experiment 5 only.

5.2.2 Results

One sample t-tests confirmed that *d'* was significantly positive for both younger adults (M = 1.47, SD = 0.66; $t(29) = 12.15$, $p < 0.001$) and older adults (M = 1.29, SD = 0.57; $t(29) = 12.48$, $p < 0.001$), indicating that both groups were able to detect whether target halves of composite faces were the same or different at above chance levels. Additionally, no individual participant exhibited negative *d'* across the experiment as a whole, indicating that they understood the requirements of the task.

A mixed ANOVA was carried out on the *d'* data with congruency and alignment as within-participants factors (each with two levels), and age group as a between-participants factor. Unsurprisingly, in line with the composite face effect, there was a significant interaction between alignment and congruency ($F(1,58) = 58.81$, $p < 0.001$, $\eta_p^2 = 0.50$) with sensitivity significantly increased by alignment in the congruent condition and significantly reduced by alignment in the incongruent condition. There was not, however, a significant three-way interaction between alignment, congruency and age group ($F(1,58) = 2.96$, $p = 0.091$), nor was there a two-way interaction between congruency and age group ($F(1,58) = 3.76$, $p = 0.057$) or between alignment and age group ($F(1,58) = 3.02$, $p = 0.087$).

Whilst no significant three-way interaction was found, the trend was in the predicted direction (i.e. towards a less pronounced composite face effect in older adults). Further, whilst again not at the level of statistical significance, it is noted that there was a trend towards a two-way interaction between congruency and age group (with older adults tending to be less adversely affected by incongruency than younger adults) and between alignment and congruency (with older adults tending to be more adversely affected by misalignment).

Further post-hoc analysis also indicated potential differences in performance towards the older end of the older age group within the sample in Experiment 4. In particular, splitting the older age group into those aged between 60 and 69, and those aged over 70 (15 participants in each group), and comparing *d'*s in misaligned incongruent and aligned incongruent conditions via paired sample t-tests, both 60-69 year olds and younger adults were similarly adversely affected by alignment (younger adults $t(29) = 4.72$, $p < 0.001$; 60-69 year olds $t(14)$

= 2.51, p = 0.013) whereas there was no effect of alignment for those aged 70 or over (t(14) = 0.12, p = 0.453). Although the sample sizes of the two older groups were underpowered, and it should be emphasised that the additional analysis was unplanned and exploratory, the trends suggested scope for further work. Figure 5.3 summarises the results of Experiment 4 – as can be seen, the trend was driven primarily by older adults being less impaired than younger adults by alignment in the incongruent condition (left panel).

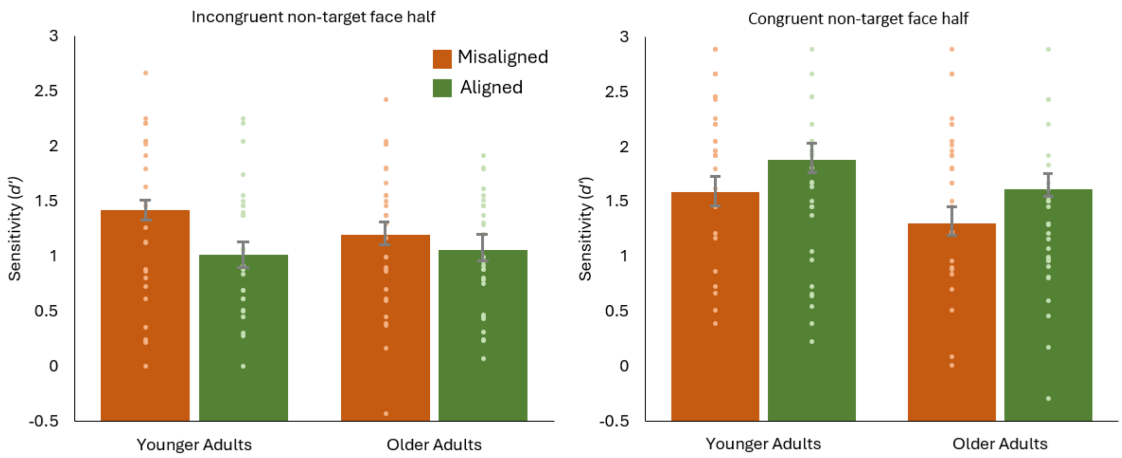

Figure 5.3: Mean sensitivity (d') of younger and older adults to difference/similarity between sequentially presented faces in Experiment 4. Left panel shows incongruent condition, where the alignment would be expected to impair performance. Right panel shows congruent condition, where alignment would be expected to facilitate performance. Bars show group level differences with standard error bars, and dots show individual participants.

5.3 Experiment 5 – Composite faces (replication)

5.3.1 Background

In common with many studies of group-level differences in cognition in healthy aging, most experiments reported in this thesis define older adults as over 60, with comparator younger groups defined as under 35. However, this is a somewhat arbitrary cut-off point, and it is recognised that the physiological and neurophysiological changes outlined in Chapter 1 follow differing typical trajectories over time. As noted in Experiment 4 in this chapter, a trend was apparent (albeit with an underpowered sample) towards participants at the upper end of the older group exhibiting reduced susceptibility to the composite face illusion. Experiment 5 therefore sought to replicate Experiment 4, but recruiting three age groups rather than two (under 35s, 60 to 69 year olds, and over 70s).

Experiment 5 also sought to make other methodological adjustments based on the findings from Experiment 4. Firstly, the methodology described in Experiment 4 meant that participants were more exposed to face halves with a neutral expression. In particular, all 'different' trials in Experiment 4 involved one presentation having emotional valence in the target half of the face whereas the target half was neutral throughout in all 'same' trials. It is therefore conceivable that a statistical association could be learnt over the course of the experiment such that the appearance of an emotion in the target half of a face on either presentation denoted the correct response was 'different' (regardless of whether a difference was recognised between the two presented images), and that there could be group level differences in recognition of that association. Secondly, Experiment 5 included a message following incorrect responses, serving as a reminder as to whether the target half of the face was the top or bottom within the particular block, and encouraging continued attention to the task given such a message delays completion of the task.

It should be noted that Experiment 5 was conducted during the COVID19 pandemic, and so a decision was made to recruit participants and conduct the experiment online. Whilst this provided advantages in terms of rapid collection of results, it also entailed some loss of control over screening and the environment in which the experiment was carried out.

5.3.2 Method

Participants

Three groups participated in Experiment 5, 30 adults aged 35 or under (M = 23.2, SD = 3.7, 10 females and 20 males), 30 adults aged between 60 and 69 (M = 62.6, SD = 2.6, 17 females and 13 males), and 30 adults aged 70 or over (M = 76.9, SD = 2.7, 15 females and 15 males). Sample size was determined for consistency with Experiment 4. Participants were recruited using Prolific (www.prolific.co) and were selected on the basis of age group, having normal or corrected-to-normal vision, and having English as a first language.

Stimuli

Stimuli were derived from the same set of face images derived from the Radboud Faces Database as used in Experiment 4. However, as noted above, there were changes to ensure all images were used equally through the course of the experiment, and guard against the risk of statistical associations being learned. Specifically, all composites were formed from target and distractor halves displaying the same emotion but, in 'different' trials with a different intensity (either 100% or reduced to 50% via morphing in the same way as in Experiment 4). In 'congruent same' trials both images had identical emotional valence and intensity in target and distractor halves; in 'incongruent same' both images had a target halves were identical but the distractor half differed in emotional intensity; in 'congruent different' trials the two images differed in emotional intensity in both the target and distractor halves; and in 'incongruent different' trials the distractor halves were identical but the target halves varied in emotional intensity. As in Experiment 4 a thin, two pixel line separated the top and bottom halves of the composite faces.

The combination of emotional facial expressions at two different intensities for each actor, across the four trial types and either aligned or misaligned, resulted in 96 different trials, each of which was presented four times over the course of the experiment (384 trials in total – the same as Experiment 4).

Procedure

The experiment was created and hosted using the Gorilla Experiment Builder (www.gorilla.sc, Anwyl-Irvine et al., 2020). Given the constraints of online recruitment, it was not possible to control the specifics of stimulus display and conditions in which participants undertook the experiment as closely as in Experiment 4, nor to make the experimenter available for questions of clarity on the instructions. However, the stimuli were designed to appear similar to Experiment 1, participants were required to use a desktop or laptop computer and were instructed to complete the tasks while sitting. Data on device used, screen resolution, and overall completion times were consistent with participants following these instructions.

Similarly to Experiment 4, on-screen instructions told participants that they would be presented, sequentially, with pairs of composite images of faces in quick succession, that each pair of images would be of the same individual, but that their facial expression may or may not vary between the images. They were informed that the top and bottom halves of the face would either be aligned or misaligned, and were shown examples of how this would look on screen, using faces not featured in the experiment itself. They were told that they would be required to focus on either the top half of the face only, or the bottom half only, and to judge whether it was the same or different in the two images, ignoring the other halves of the faces. Unlike in Experiment 4, they were informed that a message would be displayed following incorrect responses, meaning completion time would depend on both speed and accuracy. They were then presented with four practice trials, all involving judging expression from the top half of the pairs of faces.

As in Experiment 4, the 384 recorded trials were split into 24 blocks of 16 trials. Before each block, participants were told whether they would be asked about the top or bottom of the face in that block, and the question at the end of each trial also included a reminder of the target face half, with participants asked to press the left key if that half of the face was the same in each presentation, or the right key if it was different. Presentation order and timing matched Experiment 4 except that, where an incorrect response was made, a message appeared on screen for 2000ms informing the participant of the error and reminding them of the target half in that block. Blocks were randomised as to whether they involved the top or bottom half being the target half, and of presentation order of trials within blocks was fully randomised. Figure 5.2 sets out the procedure used for both Experiments 4 and 5.

5.3.3 Results

One sample t-tests confirmed that *d'* was significantly positive for under 35s (M = 1.13, SD = 0.21; $t(29) = 29.34$, $p < 0.001$), those aged between 60 and 69 (M = 1.06, SD = 0.29; $t(29) = 20.16$, $p < 0.001$), and those aged over 70 (M = 0.89, SD = 0.24; $t(29) = 22.31$, $p < 0.001$), indicating that all groups were able to detect whether target halves of composite faces were the same or different at above chance levels. One participant in the 60-69 age group had a marginally negative d' across the experiment as a whole (d' = -0.02), but there was no indication from the data that this related to a misunderstanding as to the requirements of the task or wilful decision not to engage (e.g. repeatedly giving the same response). Since a d' at or around zero is consistent with low levels of sensitivity, it was not considered appropriate to exclude the participant (and doing so would not materially have altered reported results).

A mixed ANOVA was carried out on the d' data with congruency and alignment as within-participants factors (each with two levels), and age group as a between-participants factor. Unsurprisingly, in line with the composite face effect, there was a significant interaction between alignment and congruency ($F(1,87) = 38.74$, $p < 0.001$, $\eta_p^2 = 0.31$), with sensitivity significantly increased by alignment in the congruent condition and significantly reduced by alignment in the incongruent condition. There was not, however, a significant three-way interaction between alignment, congruency, and age group as hypothesised and suggested by the trend in Experiment 4 ($F(1, 87) = 1.13$, $p = 0.327$). Nor were trends observed in Experiment 4 in relation to a possible two-way interaction between congruency and age group or alignment and age group reflected in Experiment 5 (congruency x age group: $F(1,87) = 1.12$, $p = 0.331$; alignment x age group: $F(1,87) = 0.48$, $p = 0.621$). Figure 5.4 summarises the results of Experiment 5.

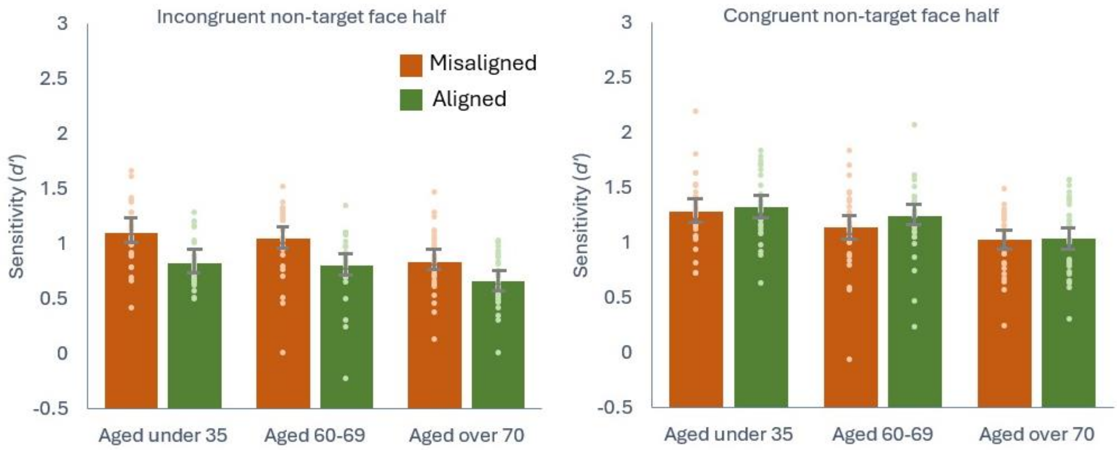

Figure 5.4: Mean sensitivity (d') of younger and older adults to difference/similarity between sequentially presented faces in Experiment 5. Left panel shows incongruent condition, where the alignment would be expected to impair performance. Right panel shows congruent condition, where alignment would be expected to facilitate performance. Bars show group level differences with standard error bars, and dots show individual participants.

5.4 Discussion

Experiment 4 suggested a trend towards reduced susceptibility to the composite face illusion in older adults in the context of composite face stimuli where target and distractor halves differed by emotional valence (but not by identity), particularly towards the upper end of the age range. However, Experiment 5 did not find significant age-related differences in the composite face effect. There are several reasons why experiments reported in this chapter may not have supported the hypothesis.

Firstly, the hypothesis in this chapter was premised on the composite face illusion (an alignment x congruency interaction in d') primarily reflecting the extent of visual configural processing. This provided reason to suggest that the evidence in Chapter 3 for configural processing deficits in the context of point light representations of bodies by older adults, and relative preservation in featural processing, would translate to a reduced composite face effect in older adults. However, there is debate as to whether alignment in the composite face task impedes configural processing by creating a novel configuration that hinders recognition of constituent parts or features (Hancock & Burton, 1996) or whether, at least in the context of faces, features and configurations form a single, holistic “Gestalt” representation and that alignment alters perception of feature shape as well as configuration (Farah & Wilson, 1998). In support of this latter idea, there is some evidence that the composite face effect distorts perception of aspects of features (Hayward et al., 2016, where the same/different judgment related to darkness of eyebrows). Nevertheless, if older adults are unimpaired in featural processing, this may be why no reduced composite face effect was reliably demonstrated in these studies.

Secondly, the experiments reported in this chapter are based on recognition of differences in affect as, within each trial, the composites were made up of different photographs of the same model. Evidence is mixed as to the extent to which emotion recognition is dependent on configural as opposed to featural information. Whilst some studies indicate a configural rather than featural processing is central to emotion processing (Bombari et al., 2013) findings tend to be based on the presumption that inversion effects cause greater disruption in configural than featural processing, and research involving eye-tracking has indicated featural processing is important in tasks involving emotion recognition (Calvo et al., 2010). If, as some studies suggest, sensitivity to emotional affect in faces is in fact based more on featural than configural information then, in the task described in this paper where face halves differed in affect, older adults would primarily be expected to differ from younger adults only to the extent they exhibit featural processing deficits. Experiments reported in Chapter 3 relate to *relative* patterns of deficit and preservation in postural and kinematic processing in younger and older adults and do not exclude that older adults may have *absolute* deficits in both respects. However, Experiment 5 in Chapter 3 not only provided no significant evidence of a deficit in kinematic processing in older adults, but no trend at all in that direction.

Thirdly, and related to both the above points, the experiments reported in this chapter may have been underpowered to detect an effect. As noted above, sample sizes were chosen with a view to detect medium sized effects. To the extent that the composite face effect is only partially driven by disruption of configural processing, either because information from features is of primary importance and configural processing is less relevant to judgments of emotional state in faces than it is to identity, or because the composite face effect primarily disrupts holistic processing as distinct from configural processing, any effect size might be expected to be more modest. Consistent with this, Experiment 4 found a trend in the predicted direction which may indicate a larger sample would find a small effect (albeit this was not replicated in Experiment 5).

CHAPTER 6: CONFIGURAL AND FEATURAL PROCESSING IN FACES

6.1 Introduction

Note: The work in this chapter draws upon and extends work that has previously been published (Chard et al., 2022).

Chapters 3 and 4 set out how age-related differences in visual perception may have an impact on performance in a task involving recognition of affective state, in the specific context of body language conveyed via point light displays. Specifically, Chapter 3 reported an age-related deficit in sensitivity to postural differences and relative preservation in relation to kinematic differences, and Chapter 4 found evidence that this was predicted sensitivity to emotional valence. Whilst there were theoretical reasons to suggest that the reduced sensitivity to posture reflected a deficit in configural processing in older adults, Chapter 5 did not find significant evidence of a reduced composite face effect as the hypothesised configural processing deficit may suggest would have been the case.

However, as noted in the discussion in Chapter 5, there are several reasons why reduced susceptibility to the composite face illusion may be regarded as an imperfect measure of configural processing deficits, particularly in the context of face images where facial expression but not identity varied. Additionally, whilst experiments reported in Chapter 5 did not find evidence supporting the presence of a configural deficit in older adults, nor did it provide evidence for its absence, and indeed a trend observed in Experiment 4 in the anticipated direction, albeit this was not reflected in Experiment 5.

This chapter reports further experiments (an in-person version and an online replication) aimed at assessing whether older adults have a pattern of deficits in configural processing, and relative preservation in featural processing, that may impact on identifying relevant social information from faces. It does so through a more direct manipulation of features and configurations and compares the position as it applies to faces and to non-face objects. The reported experiments use stimuli developed by Yovel & Kanwisher (2004), consisting of images of faces and houses which are adapted either with featural changes (i.e. replacing either the mouth and eyes of the person, or doors and windows of the house) or configural changes (adjusting distances between eyes and nose/mouth, or between windows and door).

6.2 Experiment 6 – Direct manipulation of configurations and features

6.2.1 Background

To test whether older adults have a relative deficit in configural processing, Experiment 6 presented participants with pairs of face stimuli and required them to judge whether the configurations were the 'same' or 'different'. They also undertook a control task where they made the same judgments about the features themselves. To test the domain-specificity of any impairments, an equivalent task presented participants with house stimuli, as well as inverted versions of all stimulus sets (noting that studies have found featural processing to be disrupted by inversion, in the same way as configural processing; Murphy et al., 2020).

As in previous chapters and as further set out in Chapter 2, a signal detection paradigm was adopted to allow sensitivity to be separated from response bias. It was hypothesised that, compared with younger adults, older adults' sensitivity to differences in configuration would be impaired relative to their sensitivity to featural differences. If this deficit was reflective of a domain-general problem with configural processing, it may be expected to apply across face and house stimuli, and across upright and inverted orientations (e.g., Rossion, 2008; Susilo et al., 2013). The collection of reaction time data in Experiment 6 also enabled the precise nature of group differences is further assessed thorough drift diffusion modelling of the data.

As in other experiments in this thesis, sensitivity to probed stimuli was calculated as *d'* which, as set out in Chapter 2, indicates the extent to which participants are more likely to report the presence of a probed stimulus when it is present than when it is absent, i.e., the difference between the z-scores of the hit rate (HR; proportion of trials where the two images presented were identified as being different) and false alarm rate (FAR; proportion of trials where the two images were reported as being different when they were in fact identical); $d' = \theta^{-1}(HR) - \theta^{-1}(FAR)$.

6.2.2 Method

Participants

Two groups participated, 30 younger adults aged 35 or under (M = 23.50, SD = 4.27, 20 females, 10 males) and 30 older adults aged 60 or older (M = 71.07, SD = 6.32, 23 females, 7 males). As with experiments reported in previous chapters, sample size was determined such that the experiment would have at least 80% power to detect a medium-sized group x visual difference interaction effect ($\eta_p^2 = 0.06$, $\alpha = 0.05$). As in previous experiments, this requirement led to the calculation that we would require at least 24 in each group to detect effects. However, given the difficulties of recruiting older participants and risk of non-attendance, all older participants responding to the recruitment drive were invited to take part, and a matching number of younger participants were recruited. Participants had normal or corrected-to-normal vision.

Weschler Abbreviated Scale of Intelligence (WASI) scores were obtained for two subtests (matrix reasoning and vocabulary) for all participants. Raw scores achieved by older adults (M = 75.34/100, with each test standardised to /50; SD = 8.45) did not differ from raw scores achieved by younger adults (M = 72.60/100, SD = 5.07), $t(58) = 1.52$, $p = 0.13$, indicating that any deficits observed in older adults in the main task are unlikely to have arisen from a decline in overall intellectual capabilities (note that raw scores provide a more appropriate comparison in the present context because FSIQ2 scores are normalised by age).

The experiment was carried out in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki and approved by the local Ethics Committee.

Stimuli

Stimuli consisted of a set of nine images of faces and nine of houses, all based on the same two original images (stimulus set mirrored precisely that used by Yovel & Kanwisher, 2004). From each base image, four additional versions were produced in which the features (eyes and mouth in the case of faces; windows and door in the case of houses) were replaced with those from other images while retaining the same second-order configuration. Four additional images were produced where the features were unchanged from the original image, but their second-order configuration was altered (by increasing or reducing the horizontal distance between the eyes and vertical distance between the mouth and nose for faces; and by the equivalent manipulation between windows and the door for houses). All face stimuli had a neutral expression. Figure 6.1 shows examples of stimuli alongside experimental results (albeit the faces are illustrative as permission was not obtained from the original model for use of the images in publications).

In Signal Absent trials, participants were presented with two identical images. In Signal Present trials, images differed either in respect of features or configuration. Given the number of images as described above, there were ten possible pairings of faces (and ten of houses) that differed in configuration, and a further ten that differed in features.

Procedure

Participants were seated in a dimly lit room at an approximate distance of 50 cm from a 24 inch LCD computer monitor (resolution = 1920 x 1200 pixels; refresh rate = 60 Hz). Given the on-screen size of the stimuli and seating position, the visual angle was approximately 10**°.** The experiments were conducted in MATLAB® using the Cogent graphics toolbox. Before taking part, participants were informed of the basic procedure and were told that, where the images differed, they would do so only subtly. They were not, however, told anything about the nature of the differences that they may see. The task was calibrated via piloting by Yovel and Kanwisher (2004) to seek to achieve performance above chance levels whilst avoiding ceiling effects, and so involved relatively rapid presentation of images. In each trial, participants were shown a fixation dot in the centre of the screen (500 ms) followed by a blank screen (100 ms). The first image then appeared (250 ms), followed by a fixation dot (500 ms), blank screen (100 ms), and second image (250 ms). Finally, they were asked whether the images were the 'same or different'. Participants responded using left and right keys, respectively. Participants received no feedback about whether individual responses were correct.

Participants completed 320 trials in total, consisting of 80 trials of each condition (upright face, inverted face, upright house and inverted house). Within each condition, 40 of the trials were Signal Present, of which half differed featurally and half configurally, and the remainder were Signal Absent. Half of the participants were presented with face blocks followed by house blocks, and the other half undertook the house blocks first. They undertook six trials before each new stimulus type to provide the opportunity to ask questions of the experimenter. These were randomly selected from the experimental set. Each block of 160 trials (houses or faces) was further divided into eight mini-blocks of 20 trials. Before each mini-block, participants were told whether images would appear upright or inverted. The start of each new block was controlled by the participant, enabling them to rest their eyes as required before continuing. Whether the first block was upright or inverted was counterbalanced between participants and thereafter the orientation of blocks alternated. Within the constraints described, presentation order was random. No feedback on participant performance was provided at any point in the experiment.

6.2.3 Results

A mixed ANOVA was conducted on the *d'* data (all ps > 0.17 in Levene's tests) with stimulus type (face or house), inversion (upright or inverted), and visual difference (featural or configural) as within-participants factors, and age group (younger adult or older adult) as a between-participants factor.

A small number of participants had negative d's in certain conditions, noting that average performance was low, particularly in inverted face conditions, with d' < 1 indicative of a challenging task. However, all participants had positive d's across the experiment as a whole and no patterns such as very fast reaction times or multiple repeated answers that would indicate inattentiveness. On that basis, there was no evidence to exclude based on task confusion or inattentiveness, and instances of negative d's were consistent with low sensitivity in some conditions.

We found some age-independent stimulus effects. Namely, there were significant main effects of stimulus type ($F(1,58) = 39.69$, $p < 0.001$, $\eta_p^2 = 0.41$) and inversion ($F(1,58) = 120.30$, $p < 0.001$, $\eta_p^2 = 0.68$), qualified by an interaction between stimulus type and inversion ($F(1,58) = 77.02$, $p < 0.001$, $\eta_p^2 = 0.57$). Specifically, while sensitivity for upright faces and houses did not differ ($t(59) = 1.27$, $p = 0.21$), sensitivity towards inverted faces was lower than towards inverted houses ($t(59) = 9.36$, $p < 0.001$).

There was also a significant main effect of age group ($F(1,58) = 19.82$, $p < 0.001$, $\eta_p^2 = 0.26$), and a borderline interaction between age group and inversion ($F(1,58) = 4.00$, $p = 0.05$, $\eta_p^2 = 0.06$), but no three-way interaction between stimulus, age group, and inversion ($F(1,58) = 0.02$, $p = 0.89$). Specifically, whilst older adult sensitivity was lower for both upright stimuli ($t(58) = 2.81$, $p = 0.01$) and inverted stimuli ($t(58) = 5.24$, $p < 0.001$), the impairment was relatively greater for inverted stimuli.

Most importantly for our hypotheses, there was an interaction between age group and visual difference ($F(1,58) = 10.99$, $p < 0.001$, $\eta_p^2 = 0.16$). Whilst older adult sensitivity was lower for both featural differences ($t(58) = 2.76$, $p = 0.01$) and configural differences ($t(58) = 5.06$, $p < 0.001$), older adults showed greater impairment in the configural task. There were no higher order interactions involving age group and visual difference (all Fs < 2.13, all ps > 0.15). Figure 6.1 summarises the results of Experiment 6.

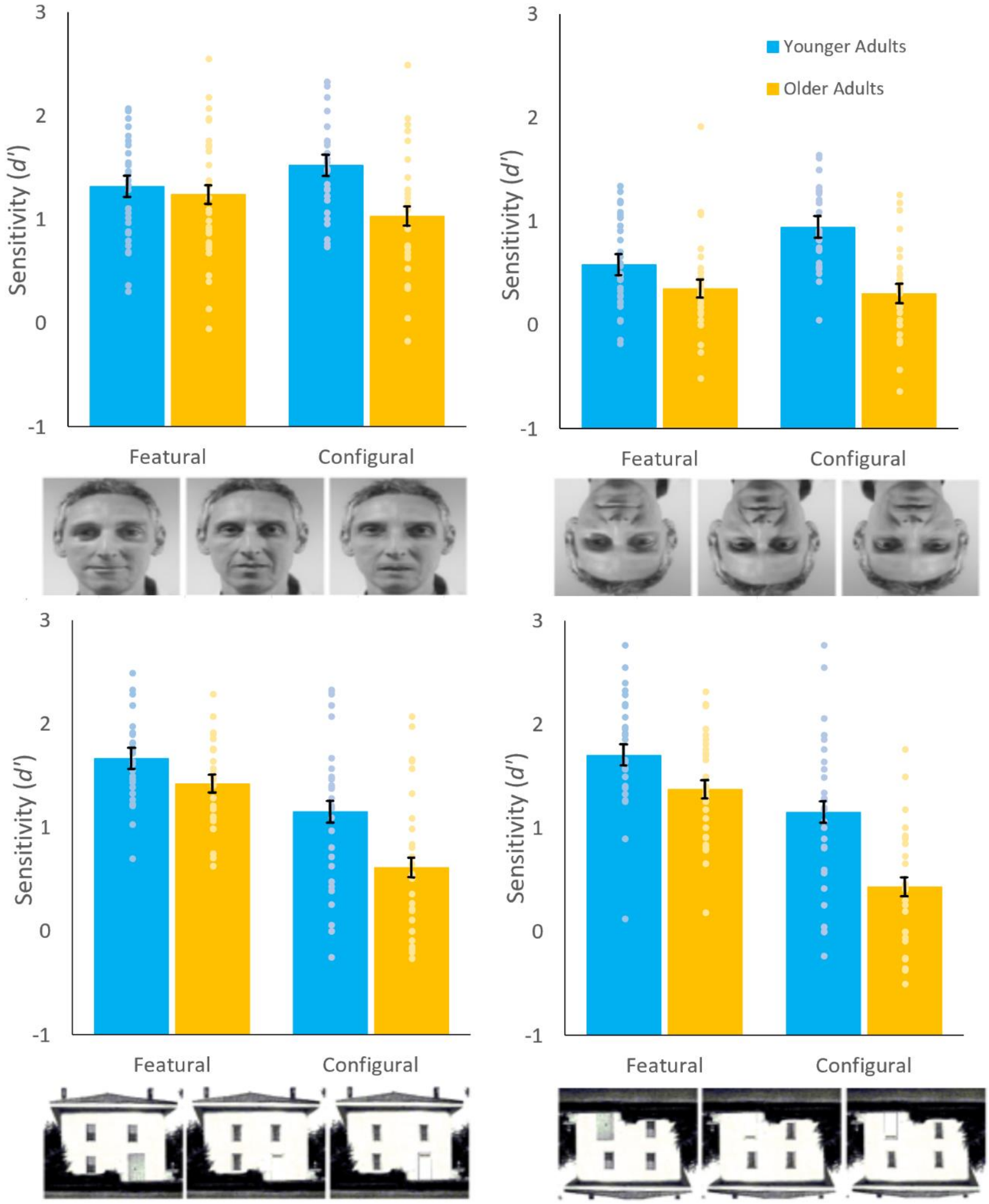

Figure 6.1: Sensitivity (*d'*) in Experiment 6 of younger adults and older adults to featural and configural differences in (clockwise from top left): (i) upright faces; (ii) inverted faces; (iii) inverted houses; (iv) upright houses. Bars show group level differences with standard error bars, and dots show individual participants. Example stimuli are shown below each chart, with the base image in the centre, featurally different image to the left and configurally different image to the right. The stimulus set was originally developed

by Yovel & Kanwisher, 2004 (the face stimuli are illustrative due to lack of written consent for the use of images from the original model in publications).

A mixed ANOVA was also conducted on the bias (*c*) data with stimulus type, inversion, and visual difference as within-participants factors, and age group as the between-participants factor. There were significant main effects of age group ($F(1,58) = 12.28$, $p < 0.001$, $\eta_p^2 = 0.18$), stimulus type ($F(1,58) = 8.92$, $p = 0.004$, $\eta_p^2 = 0.13$), inversion ($F(1,58) = 9.80$, $p = 0.003$, $\eta_p^2 = 0.15$), and visual difference ($F(1,58) = 14.88$, $p < 0.001$, $\eta_p^2 = 0.20$). These were qualified by interactions between visual difference and age group ($F(1,58) = 7.67$, $p = 0.008$, $\eta_p^2 = 0.12$), visual difference and stimulus type ($F(1,58) = 39.17$, $p < 0.001$, $\eta_p^2 = 0.40$), and inversion and stimulus type ($F(1,58) = 5.90$, $p = 0.018$, $\eta_p^2 = 0.09$). As pointed out in Chapter 2, care is required in the interpretation of bias, particularly in cases where sensitivity is low in some conditions as this may give rise to more extreme biases (Lynn & Barrett, 2014; Pastore et al., 2003). As noted above, low sensitivity (*d'* < 1) is reported in several conditions with notable differences in d' between conditions, and this may be expected to influence results in relation to bias.

As noted in Chapter 2, sensitivity differences in a signal detection paradigm could reflect a range of different perceptual processes. In particular, reduced sensitivity may reflect less efficient accumulation of evidence resulting in a greater number of incorrect responses (whether 'misses' or 'false alarms'). Alternatively, it may reflect a lower confidence threshold for decision making (i.e. a willingness to respond based on a lesser degree of confidence). Hierarchical drift diffusion modelling was used to distinguish these possibilities. As noted in Chapter 2, drift diffusion models (Ratcliff et al., 2016) treat decision making in a two-alternative forced choice procedure as involving sequential sampling of sensory evidence to compute a decision variable. When this accumulated decision variable meets a response boundary, the appropriate response is triggered.

A hierarchical drift diffusion model was applied to responses using a package implemented in Python (Wiecki et al., 2013). This approach treats model parameters for each participant as being drawn from group level distributions, and uses Bayesian Markov Chain Monte Carlo (MCMC) sampling to estimate group and participant level parameters simultaneously. It parameterises drift rate (v), representing efficiency of evidence accumulation; threshold (a), representing the extent of separation of decision-making boundaries; and non-decision time (t), representing processes not directly involved in stimulus discrimination, such as motor preparation to press the relevant response key. These parameters were allowed to vary based on age group and whether differences were featural or configural. Models were estimated with 30,000 samples ('burn in' = 7500), and models were compared using deviance information criteria as an approximation of Bayesian model evidence. Estimated parameters were then compared using a Bayesian significance test implemented in the hierarchical drift diffusion model, which computes the posterior probability that group level parameters differ across conditions.

In both configural and featural trials, older adults exhibited lower drift rates, as well as greater boundary separation and non-decision time (all posterior probabilities for group differences > 0.99; higher values indicate a greater difference between conditions). Older adults exhibited a slower rate of accumulation of evidence relative to younger adults, but this was particularly marked for the configural task (mean drift rates: older adult configural = 0.402; younger adult configural = 0.998; older adult featural = 0.459; younger adult featural = 0.636). This slower evidence accumulation resulted in lower *d'*s despite more conservative decision thresholds, and longer non-decision times (noting that more conservative thresholds would tend to increase *d'* in this model). Furthermore, a partial correlation analysis showed a significant relationship between sensitivity and drift rate in the configural task, controlling for age and sensitivity and drift rate in the featural task ($r = 0.596$, $N = 60$, $p < 0.001$; see Figure 6.2, and note that a correlation of the featural-configural difference between these parameters was similarly strong; $r = 0.626$, $N = 60$, $p < 0.001$). In other words, the *d'* deficits reported in older adults reflect lower efficiency of extracting the perceptual evidence, rather than closer decision boundaries (which would have indicated greater prioritisation of speed than accuracy in the task).

To examine further whether the age-related configural deficit was likely domain-general, correlation analyses were conducted to investigate how individual differences in each condition related to each other. Demonstrating that perceptual sensitivity towards configural differences in one condition related to that in others, there was a correlation between sensitivity towards configural differences in faces and in houses, when controlling for age and sensitivity towards featural differences in both stimulus types ($r = 0.485$, $N = 60$, $p < 0.001$). There was also a correlation between sensitivity to configural differences in upright and inverted stimuli, when controlling for age and sensitivity towards featural differences in both orientations ($r = 0.785$, $N = 60$, $p < 0.001$). Figure 6.2 sets out scatter charts relating to the correlation analysis indicating the position of individual older and younger participants, together with a panel summarising the drift diffusion methodology.

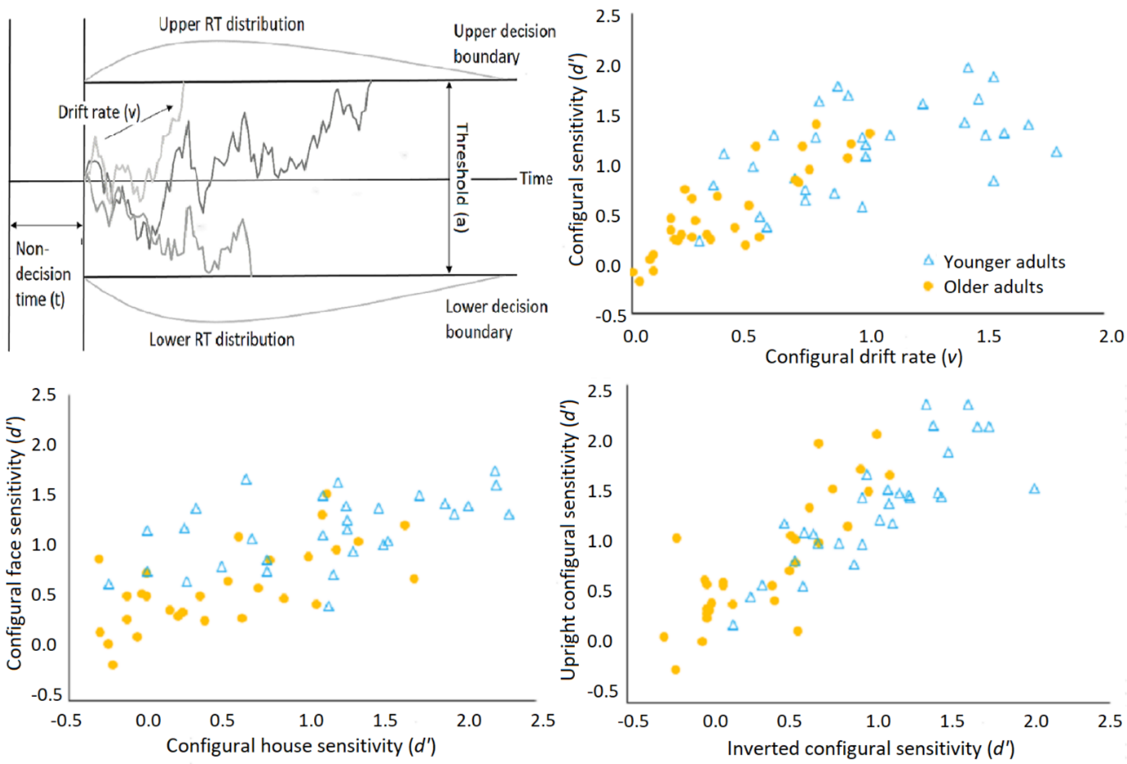

Figure 6.2: The top left panel illustrates the drift diffusion model parameters. The top right panel shows the correlation between sensitivity (d') and drift rate (v) towards configural differences in Experiment 2. The bottom left panel shows the correlation between sensitivity towards configural differences in faces and houses. The bottom right panel shows the correlation between sensitivity towards configural differences in upright and inverted stimuli.

6.3 Experiment 7 – Direct manipulation of configurations and features (replication)

6.3.1 Background

Experiment 6 demonstrated lower sensitivity towards second-order configurations between features in older relative to younger adults, which was accounted for by reduced evidence accumulation in this group rather than narrower response boundaries. Experiment 7 was mainly designed to ensure the findings in Experiment 6 were robust. It also aimed to determine that a particular feature of the trial ordering in Experiment 6 was not responsible for the absence of face-specific deficits.

Specifically, in Experiment 6, trials were blocked such that participants either completed all 160 trials with the house stimuli or all 160 with the face stimuli first. While the block type undertaken first was counterbalanced, it is theoretically possible that there is a domain-specific impairment to be found in older adults but that it is hard to detect in Experiment 6 due to differential fatigue or practice effects between groups. Experiment 7 therefore altered the procedure to involve short mini-blocks containing each stimulus type. It was carried out online due to the COVID pandemic at the time.

6.3.2 Method

Participants

Two groups participated, 30 younger adults aged 35 or under (M = 24.17, SD = 4.16, 17 females) and 30 older adults aged 60 or older (M = 68.00, SD = 4.76, 21 females). Participants were recruited using Prolific (www.prolific.co) and were selected on the basis of age group, having normal or corrected-to-normal vision, and having English as a first language. Data on ethnicity and cultural background were not collected.

Stimuli

Stimuli were identical to those used in Experiment 6.

Procedure

The experiment was created and hosted using the Gorilla Experiment Builder (www.gorilla.sc, Anwyl-Irvine et al., 2020). Given the constraints of online recruitment, it was not possible to control the conditions in which participants undertook the experiment as closely as in Experiment 6, but participants were required to use a desktop or laptop computer and were instructed to complete the tasks in one sitting. Data on device used, screen resolution, and overall completion times were consistent with participants following these instructions. In relation to the reaction time data used for drift diffusion modelling, studies have indicated that online platforms including Gorilla provide a reliable measure (Anwyl-Irvine et al., 2021; Bridges et al., 2020).

The instructions and procedure for Experiment 7 reflected Experiment 6 except that practice trials were not included due to no experimenter being present to answer questions, and the 16 blocks of 20 trials were in a random order for each participant – with a message being shown before each block to inform participants whether the block would feature upright faces, inverted faces, upright houses, or inverted houses.

6.3.3 Results

The results of Experiment 7 were analysed in the same way as those of Experiment 6, namely carrying out a mixed ANOVA with stimulus type, inversion, and visual difference as within-participants factors, and age group as a between-participants factor (see Figure 6.3; all *p*s > 0.20 in Levene's tests). The first point of note is that the *d*'s were globally similar to those in Experiment 6 ($t(118) = 0.31$, $p = 0.76$), suggesting that differences between the in-person and online contexts did not exhibit a major impact on participants' sensitivities. This differed from Experiments 4 and 5, which were also conducted in person and online respectively, and where there were significantly lower d's in the online version. However, there were also methodological changes in Experiment 5, as explained in Chapter 5.

As with Experiment 6, a number of participants exhibited negative *d'*s in some conditions. However, all participants had positive d's overall and there was no evidence of task confusion or inattentiveness. Therefore, the results were consistent with low levels of sensitivity in those cases, and exclusions were not made on that basis.

Replicating Experiment 6, there were significant main effects of stimulus type in Experiment 7 ($F(1,58) = 36.18$, $p < 0.001$, $\eta_p^2 = 0.38$) and inversion ($F(1,58) = 77.96$, $p < 0.001$, $\eta_p^2 = 0.57$), qualified by an interaction between stimulus type and inversion ($F(1,58) = 31.79$, $p < 0.001$, $\eta_p^2 = 0.35$). Specifically, while sensitivity for upright faces and houses did not differ ($t(59) = 0.66$, $p = 0.51$), sensitivity towards inverted faces was lower than towards inverted houses ($t(59) = 9.08$, $p < 0.001$).

There was also a significant main effect of age group ($F(1,58) = 14.33$, $p < 0.001$, $\eta_p^2 = 0.21$). There was a trend towards an interaction between age group and inversion ($F(1,58) = 3.35$, $p = 0.07$), similar to that seen in Experiment 6.

Most importantly for the hypothesis under consideration in this chapter, and again replicating Experiment 6, there was an interaction between age group and visual difference ($F(1,58) = 80.15$, $p < 0.001$, $\eta_p^2 = 0.58$). Sensitivity towards featural differences did not differ between age groups ($t(58) = 0.638$, $p = 0.64$) but older adults were significantly less sensitive than younger adults to configural differences ($t(58) = 6.68$, $p < 0.001$). It is noted that although the relative deficit was the same as in Experiment 6, that experiment reflected older adults having a deficit in the featural conditions and a larger deficit in the configural condition whereas, in

Experiment 7, older adults showed no featural deficit. Speculatively, this may be because older adults in the online study have more experience with computer-based tasks than many of their peers. Alternatively, it is possible that differences in viewing conditions in the online version (where the participants themselves determined elements like screen position and lighting) may have enabled older adults to improve their sensitivity, which removed the weaker featural deficit while leaving the interaction of interest intact. Regardless of the nature of this difference, the core questions relate to the relative difference between featural and configural processing between groups – which is the same in Experiments 6 and 7. There were no significant higher order interactions involving age group and visual difference (all Fs < 3.45, all ps > 0.06). Figure 6.3 summarises the results of Experiment 7.

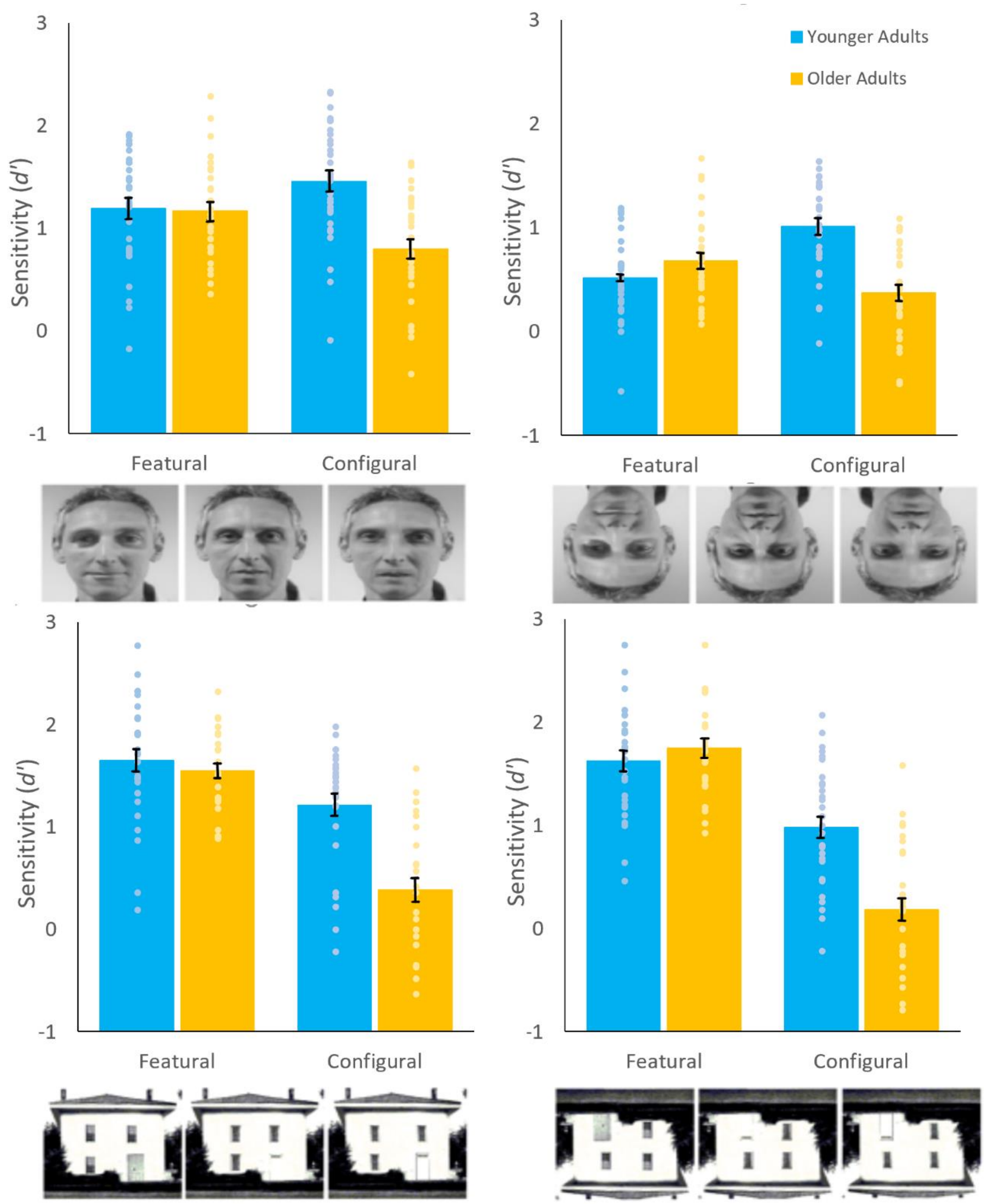

Figure 6.3: Sensitivity (*d'*) in Experiment 7 of younger and older adults to featural and configural differences in (clockwise from top left): (i) upright faces; (ii) inverted faces; (iii) inverted houses; (iv) upright houses.

A mixed ANOVA was also conducted on the bias (c) data with stimulus type, inversion, and visual difference as within-participants factors, and age group as the between-participants factor. There were significant main effects of stimulus type ($F(1,58) = 17.12$, $p < 0.001$, $\eta_p^2 = 0.23$), inversion ($F(1,58) = 44.14$, $p < 0.001$, $\eta_p^2 = 0.43$), and visual difference ($F(1,58) = 116.17$, $p < 0.001$, $\eta_p^2 = 0.67$), but not of age group as was the case in Experiment 6, albeit there was a trend in that direction ($F(1,58) = 3.88$, $p = 0.054$). These were qualified by interactions between stimulus type and age group ($F(1,58) = 19.30$, $p < 0.001$, $\eta_p^2 = 0.25$), visual difference and age group ($F(1,58) = 80.15$, $p < 0.001$, $\eta_p^2 = 0.58$), visual difference and stimulus type ($F(1,58) = 97.67$, $p < 0.001$, $\eta_p^2 = 0.63$), and a three-way interaction between inversion, stimulus type and visual difference ($F(1,58) = 19.73$, $p < 0.001$, $\eta_p^2 = 0.25$). As noted in relation to Experiment 6, caution is needed in the interpretation of bias in the context of low sensitivity between conditions and variability in sensitivity.

A hierarchical drift diffusion model was fitted to responses using the same parameters as described in Experiment 6. As in Experiment 7, older adults' slower rate of evidence accumulation was particularly marked for the configural task (mean drift rates: older adult configural = 0.483; younger adult configural = 1.151; older adult featural = 1.047; younger adult featural = 1.098) resulting in lower *d'*s despite more conservative decision thresholds and longer non-decision times. A partial correlation analysis showed a significant relationship between sensitivity and drift rate in the configural task, controlling for age and sensitivity and drift rate in the featural task (r = 0.841, N = 60, p < 0.001. Figure 6.4 sets out the scatter plots under the correlation analysis.

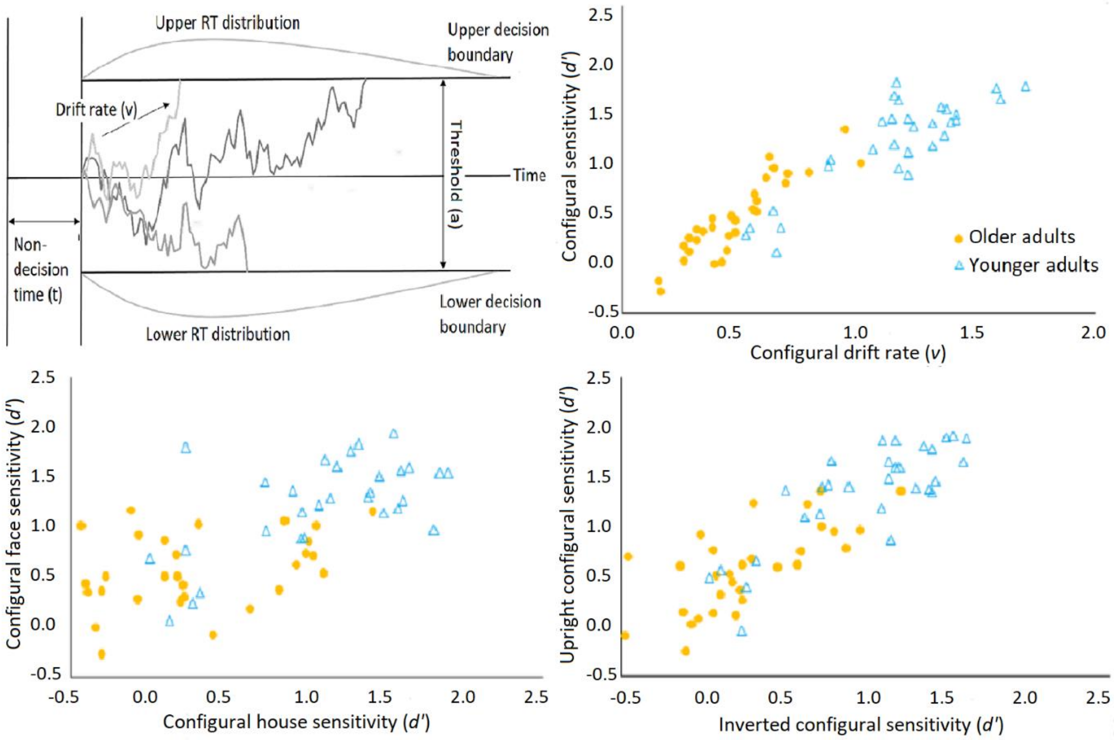

Figure 6.4: The top left panel illustrates the drift diffusion model parameters. The top right panel shows the correlation between sensitivity (d') and drift rate (v) towards configural differences in Experiment 7. The bottom left panel shows the correlation between sensitivity towards configural differences in faces and houses. The bottom right panel shows the correlation between sensitivity towards configural differences in upright and inverted stimuli. Individual data points shown for older and younger adults are not residualised.

6.4 Discussion

Experiments 6 and 7 in this chapter provide more direct evidence of difficulties in processing stimulus configurations in healthy aging based on tasks directly manipulating those elements. These difficulties were found across perception of faces and houses, and across upright and inverted orientations. They were also observed in the context of relatively intact processing of features of both faces and houses. Drift diffusion modelling suggested that deficits in configural sensitivity arose from less efficient evidence accumulation rather than from more liberal decision thresholds.

The results of Experiments 6 and 7 were also consistent with the results of Experiments 1 to 3 (reported in Chapters 3 and 4) being indicative of a general age-related deficit in relation to visual processing of global configurations, and relative preservation in relation to perception of local features, rather than specific to posture and kinematics conveyed by body movement. As such, although the tasks did not extend to asking specific questions of a socio-cognitive nature, they illustrate the importance of considering whether patterns of age-related deficits and preservations in tasks that have tended to be associated with the ‘social brain’ or other higher level cognitive processes, may either be explained by or contributed to by low-level perceptual deficits. That is, the results indicate how visual perception deficits could give rise to a particular pattern, rather than merely resulting in similarly reduced performance in a range of visual tasks.

The results reported in this chapter concur with observations that older adults exhibit difficulties determining the distance between facial features (e.g., Slessor et al., 2013) and determining horizontal compared with vertical spatial manipulations (Chaby et al., 2011). The present findings suggest that perceptual difficulties may emerge through impaired processing of the spatial configuration of features, rather than in generalised decline in visual processing that would be seen also when detecting featural aspects of images (see also Lux et al., 2008). The modelling further demonstrates that the atypicalities result from difficulties in evidence accumulation for configural features, rather than differential decision boundaries. The fact that the deficit was similar with houses suggests that the problem with processing configurations is not specific to faces, and also reduces the likelihood that specific features of the face stimuli determined effects – given that variation between faces and houses is greater than that within the category of faces.

Observation of the deficit across upright and inverted images is consistent with evidence that faces can recruit qualitatively similar perceptual processing in both orientations (Murphy & Cook, 2017; Susilo et al., 2013). This effect is also consistent with the idea that late-myelinated white matter is particularly vulnerable to age-related decline (Brickman, 2013), such that degeneration of the inferior longitudinal fasciculus connecting occipital and temporal regions may impact configural perception across domains. In this context, it is noted that there is evidence that configural and featural processing recruit different neural networks, with that fMRI and TMS evidence that configural processing networks extend into the right frontal cortex (Maurer et al., 2007) and that processing configuration involves greater functional connectivity between the right fusiform face (FFA) and areas of the dorsal stream associated with spatial processing, whereas feature recognition involves connections between right and left FFA (Zachariou et al., 2016). Further research into the pattern and rate of decline in configural processing across age, rather than simply comparing younger and older groups, could help in characterising the nature of the identified deficit.

There are some limitations to the present studies that should be noted. First, Experiment 7 was conducted online, which gives little control over viewing conditions. In principle, the lack of a featural deficit in older adults in Experiment 7 may be due to differences in viewing conditions between Experiments 6 and 7. Nevertheless, the broad pattern of results of interest for our hypotheses was replicated across in-person and online studies, supporting a growing body of evidence that online testing can be used effectively in cognitive science – even for challenging psychophysical studies (Anwyl-Irvine et al., 2021; Bridges et al., 2020). Second, all stimuli were Caucasian and we did not collect ethnicity data pertaining to our participants. It is therefore important for future research to replicate these results with diverse face stimuli and diverse samples of younger and older adults. Importantly however, deficits in configural processing in the present studies were seen for objects (houses) and faces, and across orientations, and there was no reason to assume systematic differences in ethnicity between our older and younger adult groups, so it is unlikely, for instance, that our findings are products of the so-called ‘other race effect’ (Sangrigoli et al., 2005).

In conclusion, older adults exhibit reduced sensitivity to visual configurations in faces and objects, reflecting reduced evidence accumulation for such information. Given evidence that configural processing plays a particular role in identity and emotion recognition from faces, the contribution of low-level visual deficits to social difficulties in healthy aging merits further examination.

CHAPTER 7: SENSE OF AGENCY

7.1 Introduction

Based on previous evidence of age-related impairments in integrating visual information across space, Chapter 3 hypothesised that older adults would exhibit impaired sensitivity to postural cues in point light displays of figures walking (Experiment 1), alongside relative preservation in relation to kinematics in the same stimulus set (Experiment 2) and found evidence for such a pattern. Chapter 4 applied the findings of Chapter 3 to detection of emotional state in point light displays, with the results of Experiment 3 and cross-experiment comparisons supporting a conclusion that patterns of deficit and preservation in low-level visual processing may account, at least in certain circumstances, for findings in relation to sociocognitive impairments.

Whilst these findings were consistent with age-related configural impairments deriving from difficulties in integrating across space, they did not provide direct evidence that this aspect of visual processing accounted for the deficit observed in Experiment 1 in relation to postural differences, nor in Experiment 3 in relation to the point light display intended to depict 'happy' affect. Chapter 5 sought to test whether the findings reported in Chapters 3 and 4 were reflected in older adults having reduced susceptibility to the composite face illusion, as a specific configural deficit would suggest. Although Experiment 4 found a trend in the predicted direction, this was not reflected in Experiment 5. Recognising the limitations of the methodology used in Chapter 5 and competing interpretations of the composite face effect, Chapter 6 tested the hypothesised deficit in sensitivity to configural differences, and relative preservation in relation to sensitivity to featural differences, in a paradigm involving more direct and controlled manipulation of configurations and features in images of faces and non-face objects. When doing so, it found significant evidence in support of the hypothesis in

Experiments 6, which was replicated in Experiment 7. Hierarchical drift diffusion modelling supported an interpretation that sensitivity differences were driven by lower evidence accumulation by older adults, rather than more liberal response thresholds.

One possibility is that the pattern of findings indicated by previous chapters may relate specifically to decline in the visual system which may impair integration across space whilst leaving sensitivity to local detail relatively preserved. For example, as noted in Chapter 1, there is evidence of a differential degree of cortical thinning in areas of the primary visual cortex related to peripheral visual field representations in healthy aging (Griffis et al., 2016). Such a conclusion would be relevant in interpreting and designing studies based on visual stimuli, including in relation to social cognition, in older adults, but may not be generalisable beyond the visual system.

However, alternatively or additionally, there is evidence of age-related declines in white matter integrity more broadly (Bennett et al., 2010; Branzoli et al., 2016) and, in particular, demylineation impacting negatively on conductive properties (Bartzokis et al., 2010; Peters, 2002b). Previous chapters have focused primarily on sensitivity to visual signals and the extent to which patterns of deficit and preservation may contribute to findings in relation to more explicit judgments, particularly of a social nature. However, as set out in Chapter 1, if this pattern relates to wider connectivity deterioration, this would imply deficits in integration of information between as well as within modalities. Indeed, reduced connectivity may be expected to impact particularly negatively in tasks recruiting widely distributed neural networks because of the extent of their reliance on such connectivity (Filley & Fields, 2016; Peer et al., 2017).

As a starting point in distinguishing these possibilities, this chapter seeks to examine the effect of healthy aging on sense of agency - a complex phenomenon, which there are good theoretical and neurophysiological reasons for believing emerges from intricate integration of function across distributed neural networks as opposed to single structures (Seghezzi et al., 2021). Sense of agency has been described as “the experience of controlling one’s own actions and, through them, the course of events in the outside world” (Haggard, 2017). A range of models have been proposed including top-down inference based on consistency of sensory consequences with conscious will (Wegner, 2003), comparison between predictive signals generated by internalised models in motor planning and observed outcomes (Blakemore et al., 2002), and a balancing of prediction errors converging on probable causation (Friston et al., 2011). Whilst different models differ materially in mechanisms and neural networks, what they share in common is reliance on convergence between efferent and afferent signals generating a subjective experience of agency. Based on this, sense of agency provides an opportunity to test whether older adults exhibit deficits in integrating across motoric and sensory modalities, reflecting those reported earlier in this thesis in relation to integration across space in vision. Agency judgements arguably reflect a function with one of the most crucial intricate requirements for sensitive and accurate integration across modalities. Specifically, if coordination of visual and motoric information ms-by-ms is off even marginally, our sense of agency is likely to be hugely affected - noting evidence of not only of declines in processing speed but also increased variability in processing speed in older adults (Nilsson et al., 2014).

In addition to providing a means to assess integration across modalities, sense of agency in healthy aging is also of particular interest as there is evidence that this changes across the lifespan, and particularly in later life, and may contribute to the cascade of difficulties in social cognition in later life referred to in this thesis (Happé et al., 1998; Luo et al., 2012), particularly given evidence that sense of agency is modulated by affective components (Gentsch & Synofzik, 2014). Some of the evidence derives from self-reported judgments of agency, which indicate older adults are significantly less likely to feel a sense of being in control, with decline in self-reported control from around the age of 50, accelerating into older age (Lachman, 2006; Mirowsky, 1995) and correlating with ill-health (Rodin & Langer, 1977). As noted in Chapter 1, this trend runs counter to evidence that wellbeing, by many measures, tends to improve in later life (Blanchflower & Oswald, 2008; Van Landeghem, 2012), and may contribute to findings suggesting that the generally positive picture of preserved wellbeing in healthy aging ultimately enters substantial decline towards end of life and amongst the oldest individuals (Gwozdz & Sousa-Poza, 2010).

One interpretation of reduced self-reported control is that older adults can less reliably identify where their own intentional action has led to an observed outcome, but have relatively preserved capacity to recognise where conspecifics actions lead to observed outcomes, resulting in a judgment that actual control of outcomes has reduced relative to others' control. Caution is needed, however, in interpreting cross-sectional survey data concerning agency in healthy aging. Surveys asking about the individual's own personal control over the world around them may have entirely plausible sociological rather than psychological explanations. For example, there are respects in which older adults on average objectively have less control over the world around them due to ill-health, the social status of older people in society, or moving from a senior status at work to relative economic inactivity. Whilst there are possible countervailing factors such as greater flexibility to make one's own choices often provided by retirement, and surveys can seek to control for socioeconomic differences, it remains plausible that survey data is not capturing a difference in psychological mechanisms underpinning the sense of having control, but rather a tendency for older adults to in fact have less control. Additionally, self-report is vulnerable to bias, and older adults may conceivably feel expected to downplay the extent to which they feel in control of the world around them in explicit, self-reported surveys. To the extent survey findings are driven by objective fact or bias, they are not necessarily indicative therefore of underlying change in supporting mechanisms. Some surveys, such as Rotter's Locus of Control scale (Rotter, 1966) include questions that are not directly personal to the respondent, i.e. they ask about the functioning of the world as a whole and the extent to which all individuals within it can or cannot shape events. However, it is likely answers are influenced by prior experience, and indeed they explicitly seek to elicit information about prior beliefs, whereas several psychological models characterise sense of agency as more of an emergent property than a top-down, inferential process (e.g., Friston et al., 2011). Further, relevant distinctions have been proposed between the underlying feeling of agency, and self-reported judgment of agency (Synofzik et al., 2008).

There have been fewer studies of sense of agency in healthy aging in an experimental setting, but these have tended to provide evidence of some age-related deficits in older adults' sense of agency. As noted in Chapter 1, decline in sensitivity and increased perceptual noise in different domains may be expected to impact one's sense of agency. Experimental studies have tended to support this, including in tasks requiring explicit judgment of agency which indicate older adults have reduced susceptibility to illusory agency (Cioffi et al., 2017) and to temporal and, importantly given findings reported in previous chapters relating to age-related deficits in configural processing, spatial manipulations (Metcalfe et al., 2010). There is also preliminary evidence from implicit measures of a sense of agency, specifically a reduction in temporal compression or "binding" (i.e. perceived interval between action and outcome predicted by intentional binding) in older groups (Mariano et al., 2024).

The experiment reported in this chapter aimed to isolate the component of a sense of agency that requires determining whether efferent and afferent information match, hopefully therefore somewhat controlling for sociological explanations of differences in questionnaire answers about sense of control. It involves a sense of agency task where participants judged whether or not efferent motor commands matched afferent visual feedback. Specifically, participants produced circular hand movements whilst simultaneously viewing an equivalent movement of a dot on screen, and were asked to judge whether their own movement controlled the movement of the dot. This was compared with performance in a task where participants passively observed an avatar hand performing the same task and were asked whether the avatar controlled the dot movement displayed alongside it. It was hypothesised that, based on required integration across a more distributed neural network implicated in sense of self-agency, in a context where ms-by-ms comparison of signals is needed, older adults would exhibit a relatively greater deficit in judging their own agency compared with a control task involving passive observation of visual stimuli, if degeneration in effective connectivity more broadly underpins integration problems observed in earlier chapters. To assess any association with surveys indicating changes in self-reported sense of control, participants also completed control questionnaires.

7.2 Experiment 8 – Sense of own and others' agency

7.2.1 Background

Participants completed two signal detection tasks. The first task (the "Own Agency Task") was designed to assess sensitivity and bias in a task requiring participants to judge correspondence between self-produced motor action and a simultaneous visual representation of that movement. In the Own Agency Task, participants were required to judge whether or not they controlled the movement of a dot on a computer monitor via their own hand movement over an infrared motion tracker. The second task (the "Avatar Task") was a signal detection task requiring participants to judge correspondence between two simultaneously presented, passively observed visual representations. In the Avatar Task, participants saw an avatar hand on one side of the screen and a moving dot on the other and were required to judge whether or not the avatar hand controlled the movement of the dot.

As in other experiments in this thesis and as further explained in Chapter 2, sensitivity was calculated as *d'*, which indicates the extent to which participants are more likely to report the presence of a probed stimulus when it is present than when it is absent. In the Own Agency Task, hit rate (HR) was the proportion of trials where the participant correctly reported they controlled the moving dot, while false alarm rate (FAR) was the proportion of trials where participants incorrectly reported themselves as being in control when they were not. In the Avatar Task, HR was proportion of trials where the avatar was correctly reported as controlling the corresponding dot, while FAR was the proportion of trials where participants incorrectly reported the avatar hand as being in control of the dot when its movement did not in fact correspond with that of the dot; $d' = \theta^{-1}(HR) - \theta^{-1}(FAR)$.

As part of dissociating the possible influence of response bias, experiments also measured the extent to which participants report control in both tasks regardless of its presence; as set out in Chapter 2, $c = -0.5\,(\theta^{-1}(HR) + \theta^{-1}(FAR))$. It is noted that dissociating bias was particularly important in Experiment 8 as both tasks involved an explicit judgment of agency rather than an implicit measure such as temporal compression, and there could be reason to hypothesise age-related differences in bias towards reporting external and internal agency.

In order to assess whether a relative deficit in sensitivity in the Own Agency Task predicted self-reported sense of agency, participants also completed two questionnaires. Firstly, Rotter's general Locus of Control questionnaire (Rotter, 1966), a questionnaire where participants select which of a pair of statements is close to their view. A low score on this questionnaire is taken to indicate an 'internal locus of control', where events in the world are considered by the respondent to be contingent on own action to a large extent. A high score reflects an 'external locus of control', where outcomes are believed to be contingent primarily on others' actions. Secondly, the Sense of Agency scale (Tapal et al., 2017), a questionnaire where participants indicate agreement or disagreement on a Likert scale from 1 (strongly disagree) to 7 (strongly agree). This construct provides two separate scores pertaining to 'sense of positive agency' defined as a subjective sense of control over mind, body environment, and 'sense of negative agency' defined as a subjective sense of lack of control over those things.

7.2.2 Method

Participants

Two groups participated, with 29 younger adults aged 35 or under (M = 25.59, SD = 4.82, 1 females) and 25 older adults aged 60 or older (M = 68.16, SD = 6.28, 17 females) completing the experiment. Initially, the intention was to test 30 in each group, with sample size determined such that the experiment would have at least 80% power to detect a medium-sized age group x task interaction effect (η_p^2 = 0.06, α = 0.05). Whilst 30 participants were recruited in each age group, four older adults and one younger adult did not complete the Experiment due to reporting physical discomfort relating to repeated production of the hand movement required by the procedure (see below). One further adult was unable to complete due to script malfunction. One older participant also completed the Own Agency and Avatar Tasks but declined to complete the questionnaires. The decision was taken to stop testing just short of the planned sample, because two completed participants reported residual discomfort following completion of the task involving repetitive arm movements, and we did not want any risk of injury with future testing.

Participants were right-handed, had normal or corrected-to-normal vision, and no reported physical difficulties that would preventing them from completing the repeated circular hand movement involved in the task. Since our focus was on healthy aging, we screened older adults for mild cognitive impairment using the Montreal Cognitive Assessment (Nasreddine et al., 2005), with no exclusions being made on this basis.

Experiment 8 was carried out in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki and approved by the Birkbeck, University of London Ethics Committee.

The reported experiment and analysis were pre-registered via "As Predicted": https://aspredicted.org/8za8i.pdf.

Procedure

The experiment was conducted in MATLAB® using the Cogent graphics toolbox, and consisted of two experimental tasks, arranged into eight alternating blocks.

Participants were seated approximately 50cm from a monitor with the motion tracker to their right. A 24-inch cathode ray tube monitor (resolution = 1280 x 1024 pixels; refresh rate = 85 Hz) was used to provide a higher refresh rate than the LCD equivalent, slightly improving correspondence between generated and observed movement. Participants wore glasses with an occluded lower half to prevent them from seeing their own hand movement over the motion tracker.

Participants began by completing practice trials intended to allow them to experience the tracking device and produce the required motion in the Own Agency Task. They were instructed to use their right hand for the self-produced movement throughout the experiment, and that in each trial they would be required to use their hand to move a dot on the screen into a small, red-bordered starting zone and hold it there. When they did so the border changed to white. When they had kept the dot within in the zone for two seconds (2000ms), two concentric circles appeared. Participants were instructed that, when this happened, they had two seconds to make an anti-clockwise circular movement, remaining within the ring created by the two circles. They were instructed to move reasonably quickly in order to complete a full circle within the time allowed. The 2000ms began when the participant started their anti-clockwise movement. If the dot moved outside the ring, an error message was shown and the participant was required to repeat the trial. If, however, the movement was successfully completed without leaving the ring, then the screen went blank after the 2000ms elapsed. Participants were required to successfully complete the required movement in ten practice trials in which no question followed the movement.

There were ten further practice trials specifically for the Own Agency Task in which participants were informed that sometimes they would control the dot but sometimes they would be seeing a pre-recorded circular movement. The same procedure as previously described was followed, but after each trial the question, "Did you control the dot?" appeared on screen to which participants responded by pressing "1" for "yes" or "2" for "no" with their left hand. The response was then shown on screen for 500ms, with no feedback as to whether it was correct, for 500ms. Figure 7.1 summarises the procedure in the Own Agency Task in Experiment 8.

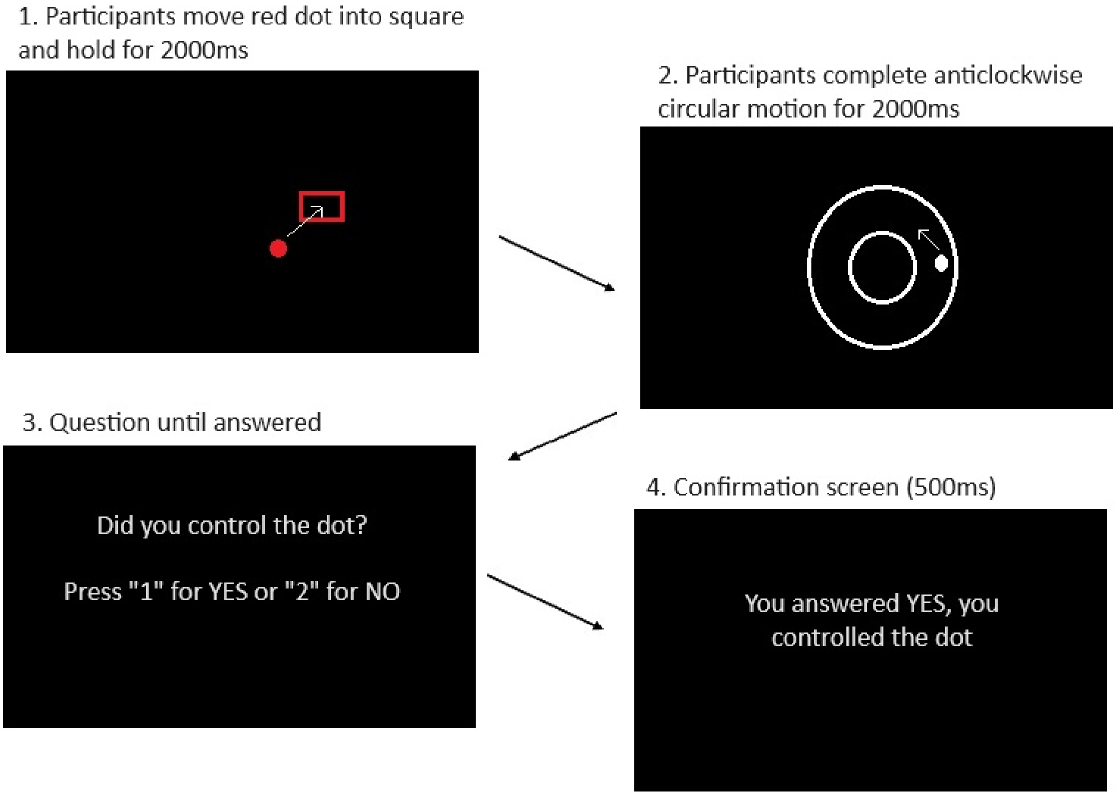

Figure 7.1: Summary of procedure in the Own Agency Task in Experiment 8.

Following the practice trials, participants completed the first of four blocks of 20 Own Agency Task trials. They were then instructed to rest their right arm and began the first block of 20 trials in the Avatar Task. In this task, participants were presented with a fixation cross for 500ms and then required to passively watch a 2000ms video of an avatar hand performing the same task on the right of the screen, with the equivalent dot movement as appeared in the Own Agency Task simultaneously being shown on the left of the screen. They were informed that sometimes the avatar hand would control the dot but sometimes they would be seeing a pre-recorded circular movement. They were then asked the question “Did the avatar hand control the dot?” again by pressing “1” for “yes” or “2” for “no”, with a confirmation screen appearing. Figure 7.2 summarises the procedure in the Avatar Task in Experiment 8.

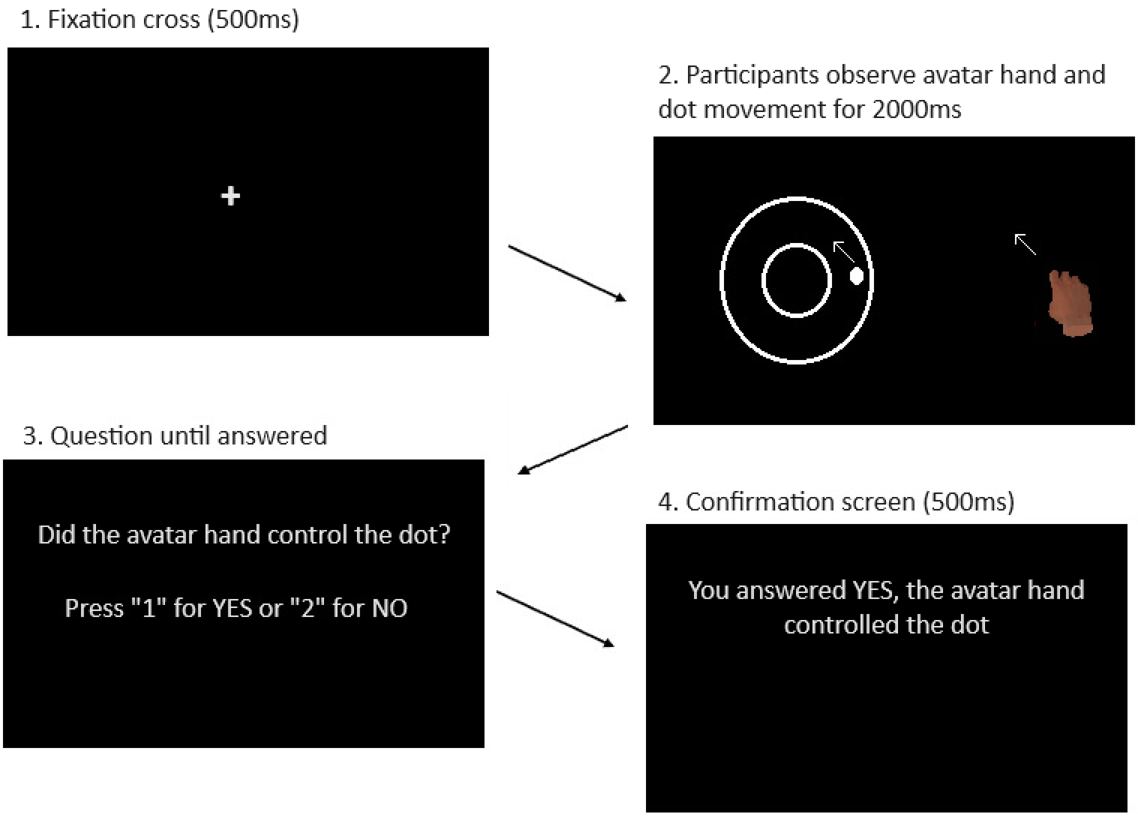

Figure 7.2: Summary of procedure in the Avatar Task in Experiment 8.

Although participants were unaware of this, the movement of the dot in those Own Agency Task trials where the participant was not in control, and of both the dot and avatar hand in the Avatar Task, were derived recordings of the participant's own earlier movements in either the practice or the main experiment. This was to ensure that, on average, the variability of movement kinematics was matched between the Own Agency Task and Avatar Task for each participant. Therefore, although those participants producing smoother and more consistent movements typically had less signal in "no control" trials than those with more erratic movement (i.e. there was typically less variation between the visual and proprioceptive signals in the Own Agency Task or two visual signals in the Avatar Task), for each participant the average signal was closely matched in the Own Agency and Avatar Tasks. That is, whilst the design did not allow difficulty to be matched between participants because movements were self-initiated, it remained meaningful to compare participants' relative performance in the two tasks.

Participants completed 160 trials in total, half in the Own Agency Task and half in the Avatar Task, divided into eight alternating blocks of 20 trials. Participants completed Rotter's general Locus of Control questionnaire (Rotter, 1966) and Tapal's Sense of Agency questionnaire (Tapal et al., 2017) following the completion of the experimental tasks via an online form, with all results anonymised. Because the task was relatively complex and relied on proper completion of hand movements and use of the partially occluded glasses to ensure that the Own Agency Task was a visual-motor rather than potentially visual-visual task, the experimenter remained with participants whilst they completed the experiment.

7.2.3 Results

As in previous experiments reported in this thesis, a small number of negative d's were recorded, although all participants had positive d's across Experiment 7, which is a pattern which is consistent with low sensitivity. There was no evidence from reaction times, patterns of responses, or experimenter observation (noting that the experimenter remained with participants) of inattentiveness or task confusion.

A mixed ANOVA was conducted on the sensitivity (d') data with task (Own Agency Task or Avatar Task) as the within-participants factor, and age group as the between-participants factor.

Most importantly for our hypotheses, there was an interaction between age group and task (*F(*1,52) = 30.34, $p < 0.001$, $\eta_p^2 = 0.37$). Older adults' sensitivity was significantly lower than younger adults' sensitivity in the Own Agency Task ($t(52) = -2.73$, $p = 0.009$) but significantly higher than younger adults' sensitivity in the Avatar Task (t(52) = 2.92, p = 0.005). There was also a significant main effect of task (*F(*1,52) = 25.35, $p < 0.001$, $\eta_p^2 = 0.33$), although this was a result of the difference in older adults' performance in the tasks (t(52) = -9.89, p < 0.001) whereas younger adults' sensitivity was closely matched at a group level across tasks (t(52) = 0.29, p = 0.771), which was intentional and resulted from earlier piloting with different younger participants to calibrate the two tasks. There was no main effect of age group (*F(*1,52) = 0.30, $p < 0.59$). Figure 7.3 summarises the results of Experiment 8 in relation to sensitivity (d').

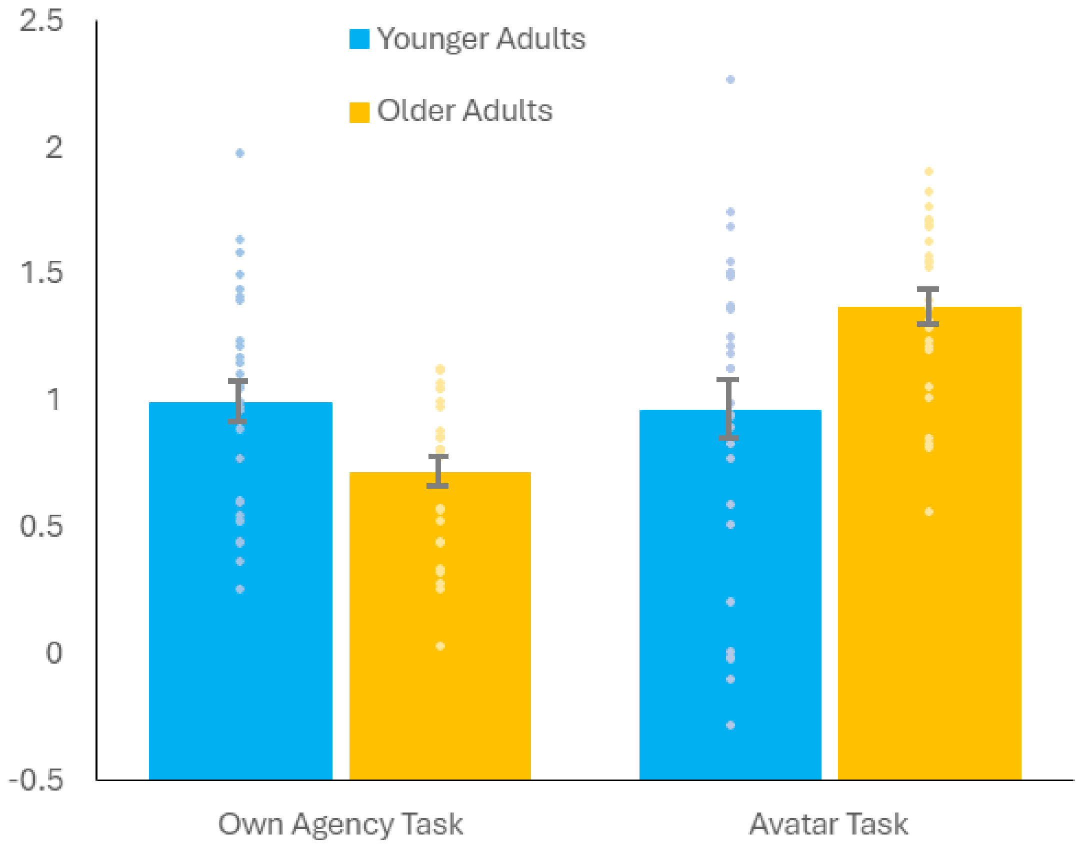

Figure 7.3 Sensitivity (*d'*) in Experiment 8 of younger adults and older adults in the Own Agency Task and Avatar Task.

A mixed ANOVA was also conducted on the bias (c) data with task (Own Agency Task or Avatar Task) as the within-participants factor, and age group as the between-participants factor. There was no significant main effect of task ($F(1,52) = 0.20$, $p = 0.654$) or age group ($F(1,52) = 0.20$, $p = 0.654$) and no interaction ($F(1,52) = 1.36$, $p = 0.248$).

A partial correlation was carried out on the relationship between questionnaire scores and sensitivity (d') in the Own Agency Task, controlling for d' in the Avatar Task and for age. In relation to Rotter's Locus of Control scale, we found a partial correlation: r = -0.403, p = 0.007. It is noted that a low score on this scale indicates an internal locus of control, so the negative correlation indicates higher sensitivity in the Own Agency Task in Experiment 8 predicted increased tendency to report that outcomes were contingent on own action on the Locus of Control scale, controlling for age and sensitivity in the Avatar Task. This result appears to be primarily driven by younger adults rather than older adults (YA: r = -0.508, p = 0.007; OA: r = -0.136, p = 0.643) although it is noted that sample sizes when dividing into age groups were low. Equivalent partial correlations were also significant, on a one-tailed test, for sense of negative agency (r = -0.259, p = 0.035) and sense of positive agency (r = 0.275, p = 0.027).

A partial correlation was also carried out on the relationship between questionnaire scores and bias (c) in the Own Agency Task, controlling for c in the Avatar Task and for age. No significant partial correlations were found (Rotter's: r = -0.069, p = 0.632; Sense of negative agency: r = -0.123, p = 0.395; Sense of positive agency: r = -0.096, p = 0.509).

It is noted that all correlations reported are based on two-tailed tests; the pre-registration for Experiment 8 noted secondary correlational analysis would be carried out but did not specify a directional hypothesis. Figure 7.4 illustrates the relationship described above in relation to sensitivity and Locus of Control.

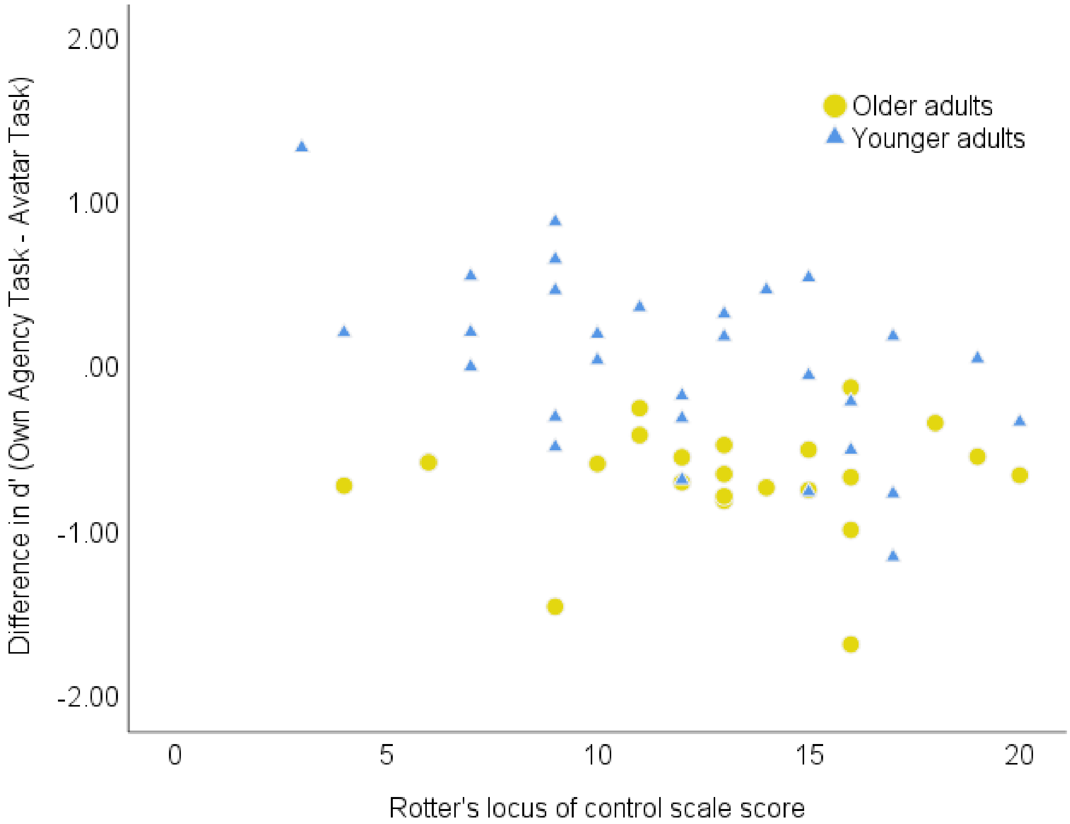

Figure 7.4: Scatter plot showing difference in sensitivity between tasks (Own Agency Task d' - Avatar Task d') in Experiment 8 and scores on Rotter's Locus of Control scale. Points above zero on the y-axis relate to participants with higher sensitivity in the Own Agency Task than in the Avatar Task. Individual data points shown for older and younger adults are not residualised.

7.3 Discussion

The primary hypothesis motivating Experiment 8 was that older adults would exhibit a relatively greater deficit in judging their own agency compared with a control task involving passive observation of visual stimuli, and the significant interaction between task and age group, alongside effect of age in the Own Agency task, supports that conclusion. The result is consistent with experimental studies finding reduced sense of agency in older adults via explicit (Cioffi et al., 2017; Metcalfe et al., 2010) and implicit, temporal binding measures (Mariano et al., 2024).

Importantly in the context of this thesis, these findings suggest that age-related deficits in tasks involving relatively low-level configural judgments reported in earlier chapters (i.e. visual integration across space) may represent one aspect of a wider deterioration in connectivity impacting on performance in a range of domains. This may not only generalise but be magnified in more complex phenomena rather than being specific to the visual system. In particular, both the Own Agency Task and Avatar Task involve perceiving the spatial position and kinematics of a point on screen such that an age-related deficit in visual perception only would be expected to result in equivalent changes in performance in both tasks. Whilst this remains speculative and further research would be needed, possible explanations would include deterioration in integrity of white matter tracts, in particular having an impact on conductive properties (Bartzokis et al., 2010; Peters, 2002b) as well as increased neural noise disrupting communication and synchronisation between regions (Dave et al., 2018; Voytek et al., 2015). Such deterioration would be expected to impact on patterns of deficits within a sensory domain as set out in previous chapters, but may be anticipated to be more pronounced for more complex tasks requiring integration across information in a wider neural network; in the case of Experiment 8, the Own Agency Task required integration of efferent motor commands (and potentially afferent proprioceptive signals) with visual feedback whereas the Avatar Task was based on passive observation.

The major theoretical frameworks in relation to sense of agency share in common a subjective experience of agency which emerges from the convergence between perceived efferent and afferent signals. Such models would each imply recruitment of more widely distributed neural networks in the Own Agency Task since the efferent signal is generated by motor planning and afferent signals involve proprioceptive and visual feedback, whereas the Avatar Task involves passive observation of side-by-side visual stimuli. As such, Experiment 8 does not necessarily provide support for a particular model of sense of agency. However, it is relevant to note that the signal detection paradigm sought to distinguish sensitivity from response bias. Top-down inference based on prior beliefs might be expected to manifest itself in response bias (e.g., a tendency for a participant who assumes a high level of control over external events to show a high ratio of false alarms to misses) but the significant effects reported above relate to sensitivity. This does not exclude a role for prior beliefs, but the results reported here appear more likely to be driven by declines in connectivity and increases in neural noise.

It is noted that, although the reported interaction in Experiment 8 was as predicted, that hypothesis was driven primarily on the anticipation of an age-related deficit in the Own Agency Task based on theoretical frameworks of sense of agency relying upon connectivity between widely distributed neural networks involved in motor planning and in visual perception of outcomes, and evidence that healthy aging impacts negatively on connectivity. Whilst there was significantly lower sensitivity amongst older adults in the Own Agency Task, the interaction was additionally driven by significantly higher sensitivity in the Avatar Task. This finding is surprising in the context of previous chapters because the Avatar Task required side-by-side comparison of two visual stimuli (an avatar hand and moving dot). Therefore, a strategy participants might have been anticipated to use would be simultaneous comparison of the on-screen position of the dot and avatar hand. Given the relative deficits in configural processing noted in earlier chapters, it was anticipated that the older adults would still find this task more difficult than the younger adults, because it requires integration across space, but to a lesser extent than in the Own Agency condition.

Speculatively, I therefore consider here some different explanations for the performance in the Avatar Task apparently being enhanced rather than merely impaired to a lesser extent. The experimental design does not distinguish between these accounts, but they could provide interesting avenues for future research. Firstly, participants may sequentially sample the kinematic profile of the avatar hand and moving dot, noting that Experiment 2 found no evidence of a deficit in a task involving sensitivity to kinematic differences in older adults. That is, they may not be judging similarity of the profiles by integrating visual information across space, but rather, e.g., determining speed in one profile at time point t, and comparing this against speed in the other at time point t+1. One could arguably perform the task this way. Secondly, differences in recruitment of participants may have resulted in older participants being more motivated across tasks such that the apparent absolute advantage in the Avatar Task was not representative of the broader population. A statistically significant older adult advantage was also apparent in relation to sensitivity to the point light display conveying sadness condition in Experiment 3, albeit the effect size was larger in the present case and the recruitment approach did not differ in Experiment 8 compared with other reported experiments. Finally, Experiment 8 differed from other experiments reported in this thesis in that the visual stimuli were, in all cases, self-generated (i.e. videos were either generated from simultaneous action by the participant, or from previously recorded movements by that participant). This meant that participants with more variability of movement in the Own Agency Task had a larger 'signal' on average in terms of making a decision. Whilst this was useful in terms of observing relative differences in sensitivity between tasks (as, for each participant the tasks were matched in terms of variability in 'not in control' cases), it means less can be read into absolute differences. There is evidence of reduced fine motor control in older adults (Ranganathan et al., 2001), such that they may be expected to produce less smooth and consistent fine motor movement in the Own Agency Task. Therefore, their task may have been easier in the Avatar Task, because there was, on average, a greater difference between the profiles being compared. This is perhaps the most likely explanation. Of note, it would similarly generate a greater difference between the profiles in the Own Agency condition, such that the relative difference between conditions would be unaffected by such variability, and impaired performance in the Own Agency condition may therefore arguably be underestimated.

The significant negative partial correlation between sensitivity in the Own Agency Task and scores on Rotter's Locus of Control scale, controlling for age and sensitivity in the Avatar Task, is striking (with a similar result for other questionnaire measures). Although the inclusion of questionnaire measures was motivated by previous findings in relation to declines in self-reported sense of control in older adults, there is a substantial level of abstraction between 'sense of agency' as a subjective experience of being in control of a specific motor action and the content of questionnaires asking more broadly about the relationship between the individual and the world around them. As noted above, questionnaire data may be expected to be influenced by a wide range of socioeconomic factors and a behavioural study with a relatively small sample size, which was chosen with a view to detect task/age group interaction in the relatively controlled Own Agency and Avatar Tasks, may therefore have been expected to be underpowered to detect any relationship between sensitivity in the experimental tasks reported in this chapter and questionnaire measures.

It is also noted that the negative partial correlation was found in relation to sensitivity (d') rather than bias (c). That would be consistent with an account where older adults have a diminished sense of whether or not their willed action results in an observed outcome, but a preserved sense of whether actions of conspecifics do so. Alternatively, it is possible that attentional differences are relevant to the correlation findings – i.e., that individuals with an internal Locus of Control attend more carefully in tasks involving own agency.

CHAPTER 8: GENERAL DISCUSSION

8.1 Thesis summary

This thesis sought to investigate the possible contribution of perceptual deficits to patterns of decline and relative preservation in social cognition in healthy aging. Such patterns have tended to be attributed to neurophysiological changes in a postulated 'social brain' network involving regions such as the orbitofrontal cortex, cingulate cortex and amygdala (Fischer et al., 2010; Ruffman et al., 2008; Ziaei et al., 2019). However, whilst there is evidence of age-related change in such regions, this forms part of a wider pattern of physiological and neurophysiological change in healthy aging, differing widely in onset, rate and trajectory. Such changes include reduction in grey matter volume which varies substantially in extent between anatomical networks (Hafkemeijer et al., 2014) and both in white matter volume (Allen et al., 2005) and its structural integrity, particularly in terms of deterioration of myelin sheaths with an impact on conductive properties (Bartzokis et al., 2010; Peters, 2002b). A challenge within study of aging is that physiological and neurophysiological change is widespread, similar between individuals, and tends to follow a similar path of deterioration. Additionally, the availability of 'scaffolding' responses, updating cognitive strategies in response to decline (Park & Reuter-Lorenz, 2009) makes it difficult to draw inferences by mapping neurophysiological change onto behavioural findings.

Although there are good reasons to consider the postulated 'social brain' network based on well-established patterns of activation (see Adolphs, 2009 for a review), there is some risk that other mechanisms which could account for or contribute to patterns of deficits and preservation in healthy aging may be overlooked. Additionally, lower level perceptual deficits are sometimes seen as being either capable of correction (e.g. by prescription glasses or lenses in the case of visual perception) or liable to manifest themselves in general decline in task performance, rather than a specific pattern of relative preservation as well as deficit. In turn, this may lead to misinterpretation of patterns of data, or of apparent inconsistencies in findings using different stimulus sets. For example, as noted in Chapter 1, meta-analyses of facial emotion recognition by Ruffman et al. (2008) and Hayes et al. (2020) were consistent to a reasonably large degree, but also differed in several intriguing respects. For that reason, this thesis sought to assess whether some findings in relation to preservations as well as deficits in social cognition could potentially derive from lower-level perceptual properties.

In addition and as set out in Chapter 2, the accuracy and response time methodology used in many previous studies have drawbacks in terms of specifying more precisely the nature of deficits and preservations in healthy aging. In particular, there are reasons to suggest older adults may systematically exhibit response biases, including some evidence of a conservative response bias in many circumstances (i.e. an unwillingness to report the presence of a target feature without a high level of confidence in its presence - Ferris et al., 1980; Vakil et al., 2003) but, conversely, a liberal response bias in particular circumstances, relating to 'positivity bias' (Carstensen et al., 2012; Reed et al., 2014). By using signal detection methods, this thesis sought to further specify the nature of differences and separate, to the extent possible, response bias and sensitivity.

Body language – posture, kinematics, and emotion

Chapters 3 and 4 applied the approach of starting by measuring perceptual deficits and preservations, working towards a task requiring a judgment of a social nature through a paradigm involving point light displays. Compared with extensive previous studies on visual cues provided by faces, there has been surprisingly limited focus on extracting social information from body language cues, particularly in relation to affect. Findings to date have been inconclusive and have differed in the pattern observed in studies of identification of emotion in face stimuli. In particular, there is some evidence of an age-related deficit in accurately categorising bodily expressions of happiness, and preservation in relation to fear, neither of which reflects the larger body of evidence from studies involving facial expressions (Montepare et al., 1999; Ruffman et al., 2009; Spencer, 2016).

Chapter 3 hypothesised that older adults would exhibit a deficit in sensitivity to postural cues in point light displays, but relatively preserved sensitivity to kinematic cues. This hypothesis was based on behavioural evidence indicating a reduced 'global precedence' effect in older adults (Lux et al., 2008) as well as neurophysiological evidence of cortical thinning affecting peripheral visual field representations (Griffis et al., 2016) and white matter decline (Bennett et al., 2010). As hypothesised, Experiment 1 found a significant main effect of age group in the task involving detection of postural differences which was not reflected in the task involving kinematic differences (Experiment 2 – indeed, older adults in our sample exhibited closely equivalent sensitivity to their younger counterparts). It is noted that the tasks differed in difficulty, with both groups being less sensitive to the visual difference in Experiment 1 than Experiment 2. However, the experiments included by design two levels of difficulty (i.e. trials where the size of the postural or kinematic signal was smaller or larger) enabling confirmation that the effect was not driven by ceiling effects in the kinematic task.

Chapter 4 developed the findings of Chapter 3, hypothesising that older adults would exhibit impairments in detecting emotions believed to be conveyed primarily through postural cues but relative preservation in detecting those believe to be expressed primarily through kinematics. Experiment 3 found a significant interaction between age group and the emotional valence conveyed via the point light displays, with older adults significantly less sensitive in relation to happiness (considered to be conveyed primarily through posture), while showing no deficit in sensitivity to anger and being significantly more sensitive to sadness (both considered to be conveyed principally through kinematics). Noting that the hypothesis rested on assumptions about the type of cues that were most relevant to recognition of each of the emotions tested, but that point light displays depicting them differed in both posture and kinematics, cross-experiment comparisons were carried out. Partial correlations, controlling for age group, between performance in each of Experiments 1 and 2 and detection of the three separate affective states in Experiment 3 confirmed that sensitivity to posture (but not kinematics) was significantly related to sensitivity to the point light display depicting happiness, while sensitivity to kinematics (but not posture) was significantly related to sensitivity to the point light displays depicting sadness and anger.

The findings in relation to bias in Experiment 3 highlight some of the value in a signal detection approach compared with accuracy measures that have been commonly used. Both age groups were biased towards reporting the presence of happiness, while there was a trend towards older adults being consistently biased towards reporting the presence rather than absence of emotion across all conditions, which is consistent with the 'positivity bias' suggested in older adults depending on precisely how such an account is characterised. Whilst there was no interaction between age group and affect, the findings at least illustrate how biases could contribute to findings in relation to emotion recognition, such that age-related changes in accuracy may be indicative of changes in biases rather than sensitivity in some cases.

Faces – configural and featural processing differences

The motivation for the experiments reported in Chapters 3 and 4 derived from previous findings suggesting possible differential deficits in older adults in integrating across space.

Detection of postural cues in Experiments 1 and 3 required comparison of relative positions across space while detection of kinematics in Experiments 2 and 3 was possible without such integration. For that reason, it was speculated that the findings reported in Chapters 3 and 4 may reflect a wider configural processing deficit in older adults, alongside relative preservation in relation to local features. However, this was based on an assumption as to the strategy used to extract postural and kinematic information rather than constituting direct evidence of a wider pattern.

Chapter 5 sought to test the hypothesis that there was a wider deficit in relation to configural processing that extended to face processing tasks. Experiments 4 and 5 in Chapter 5 were based on the composite face illusion, which has been considered to arise from a novel perception of facial configuration emerging when the top and bottom halves of a face are aligned, altering perception of the target half of the compared with a presentation where halves are misaligned (Hancock & Burton, 1996). On that basis it was hypothesised that, to the extent they had a configural processing deficit, older adults would be less susceptible to the composite face illusion (i.e. less susceptible than younger adults to being hindered by alignment where incongruent face halves are aligned and to being assisted by alignment when congruent faces are aligned). Experiment 4 found a trend in the predicted direction, which appeared to be influenced particularly by those aged 70 or over in the older age group. However, an online replication (Experiment 5) with three groups (aged under 35, between 60 and 69, and over 70) did produced neither significant results nor an appreciable trend.

Chapter 5 noted reasons why Experiments 4 and 5 may have at least been underpowered in terms of finding significant results, including the suggestion that alignment of composite faces may additionally or instead affect featural processing (Farah & Wilson, 1998). Additionally, it was noted that composite faces were all made up of the same actor displaying different emotions. Given there is mixed evidence on the relative importance of configural and featural processing in emotion recognition, to the extent featural information is particularly important to emotion recognition, it may be that the results were unexpectedly driven by featural processing which, if it was indeed related to processing of kinematics in Experiment 2, was relatively unimpaired in older adults.

Given the limitations of Experiments 4 and 5, and the trend in Experiment 4, Chapter 6 sought to test the same hypothesis with a paradigm involving more controlled, direct manipulation of features and configurations of faces (and of non-face objects). This Chapter used stimuli developed by Yovel & Kanwisher (2004) which digitally manipulated images of a face and house to alter configuration (distance between eyes and mouth or windows and door respectively) or which swapped them for other features. Experiment 6, and the online replication in Experiment 7, found a significant interaction between age group and task type (i.e. configural or featural) in relation to sensitivity such that, in line with the hypothesis, older adults exhibited impaired configural processing but relatively preserved featural processing. This effect was apparent across stimulus types, indicating a general deficit in relation to integration of visual information across space.

Reaction time data collected in Experiments 6 and 7 also allowed for a hierarchical drift diffusion model to be fitted, to further specify the nature of the deficit in older adults. This concluded that the effects seen were driven by reduced evidence accumulation by older adults (i.e. lower drift rate), rather than by a willingness to reach a conclusion based on a lower level of perceptual evidence (i.e. reduced response threshold).

Sense of agency – integrating across modalities

The pattern of deficit and relative preservation evident in the experiments noted above, and in particular the age-related impairment in configural processing, could be explained specifically by changes in the visual system which may be expected to make reliably integrating across space more challenging for older adults (Brewer & Barton, 2014; Griffis et al., 2016). However, one possibility is that the findings are indicative of a wider difficulty regarding integration of information associated with declining white matter integrity. Such a deficit may be expected to impact particularly negatively on older adults' performance in more complex tasks involving distributed neural networks (Filley & Fields, 2016; Peer et al., 2017) such as sense of agency (Seghezzi et al., 2021).

Experiment 8 involved two tasks, one of which involved performing a simple hand movement and judging congruency with a dot shown moving on a monitor (i.e. integrating information of both the participant's own motor movement and visual information) and the other passive observation of an avatar hand performing the same task with the dot movement beside it. It was hypothesised that older adults would exhibit a deficit in relation to sensitivity in the first of these tasks, and a relative preservation in the latter. A significant interaction was found between task and age-group in the hypothesised direction. Interestingly, there was also a correlation between sensitivity in the first task and Rotter's Locus of Control scores, controlling for age and sensitivity in the second task.

The results in relation to sense of agency are particularly interesting in the context of the pattern of changes in measures of wellbeing across lifespan. As noted in Chapter 1, studies measuring wellbeing have tended to indicate increased wellbeing in healthy aging (Blanchflower & Oswald, 2008; Van Landeghem, 2012) but with some evidence of a decline in later old age (Wettstein et al., 2015) and more generally in the self-reported sense of control as a facet of wellbeing (Lachman, 2006; Mirowsky, 1995). Combined with findings in relation to other aspects of social cognition including sensitivity to affect and identity, reduced sensitivity to own agency may contribute to a cascade of difficulties in later old age (Happé et al., 1998; Luo et al., 2012).

8.2 Implications and future directions

Interpretation of earlier findings in visual perception of social stimuli

The experiments reported in this thesis cast new light on the interpretation of previous findings in relation to the pattern of deficits and relative preservations observed in older adults in tasks intended to assess social cognition, which have often been attributed to structures associated with a postulated 'social brain' (Fischer et al., 2010; Ziaei et al., 2019) and that have tended to downplay perceptual contributions as either readily correctable or likely to give rise to across-the-board reductions in task performance rather than accounting for a more nuanced pattern.

In one sense, the findings in this thesis may help to reconcile some intriguing inconsistencies in previous research, where the pattern of impairments differs depending on stimuli used. For example, findings reported in Chapters 3 and 4 may provide a lower level, perceptual explanation for studies indicating that older adults' detection of happiness in body language appears impaired when the same does not apply, in most previous studies, to perception of the same emotion in faces (Montepare et al., 1999; Ruffman et al., 2009; Spencer, 2016).

However, in resolving that inconsistency, the findings in this thesis highlight a wider issue that the results of earlier studies relating to social cognition in healthy aging may themselves be explained, or at least contributed to, by patterns of perceptual deficits and preservations. In particular, degraded visual perception will not necessarily reduce performance across all tasks involving similar visual stimuli, and may either account for or contribute to distinctive patterns of findings that might otherwise be attributed to higher level cognitive mechanisms.

Noting that many studies involve presentations of facial stimuli, and that findings in Chapters 3 and 4 could potentially be explained by a relatively narrow deficit in visual perception of body posture, experiments reported in Chapter 6 provided evidence of a wider age-related deficit regarding integration of visual information across space, alongside relative preservation in relation to local detail. Further work would be needed to establish whether a perceptual account based on deficits in configural processing, alongside relative preservation in sensitivity to local features, may account for some of the patterns observed in studies involving social cognition based on face processing, including some differences observed when different stimulus sets are used, as well as areas where there is a degree of consistency in previous work (Hayes et al., 2020; Ruffman et al., 2008).

Further work would be needed on the elements of social cognition that may be affected by configural processing deficits in healthy aging. Traditionally, theories of identity recognition have emphasised the role of configural processing (Diamond & Carey, 1999; Richler et al., 2011) and therefore difficulties with rapid and automatic recognition of individuals in healthy aging may relate to aberrant processing of configurations. Whilst recognition of identity does not directly involve a judgment of another person's state of mind, it is likely to be of relevance to the quality of social interactions and to provide relevant prior information based on experience of the individual involved. Additionally, it is possible that configural processing is helpful in judging the emotional content of facial expressions, particularly those like anger and sadness where individual features are less informative in isolation (Bombari et al., 2013; Smith et al., 2005) albeit that it should be noted that Experiments 4 and 5, reported in Chapter 5, used emotionally valenced stimuli and one explanation for the absence of significant effects in those studies would be that featural information is of more value in emotion processing (Calvo et al., 2010). Therefore, the difficulties processing configural information from faces may have a range of implications for the social understanding and interactions of older adults.

Methodological approaches

Chapter 2 set out the signal detection methodologies applied in this thesis, and reasons why these may provide particular benefits in terms of understanding the nature of age-related differences in tasks involving social cognition.

Whilst the key findings reported in this thesis relate to sensitivity (d'), there are a number of areas where the importance of distinguishing this from bias (c) in order better to understand patterns should be highlighted. For example, the results of Experiment 3 indicated a trend towards older adults having a greater bias than their younger counterparts to reporting presence rather than absence of emotion in point light walkers (i.e., a high rate of false alarms), albeit with substantial variability between individuals. There is some risk in experimental design that difficulties in accurate perception of cues of a social nature may be overlooked to the extent older adults may have a liberal response bias in certain tasks, potentially consistent with 'positivity bias' accounts, depending on how precisely these are specified (Mather & Carstensen, 2005).

The use of drift diffusion modelling in experiments reported in Chapter 6 helped further to describe the nature of sensitivity deficits. The reduced sensitivity to configural differences in older adults could, in theory, be indicative either of reduced evidence accumulation (i.e., drift rate) or a tendency to make a judgment based on less evidence (i.e., threshold). Confirming that a deficit likely relates to evidence accumulation, as in this case, is relevant in terms of identifying candidate mechanisms that may underlie that result.

Visual system and beyond

There are several neurophysiological changes in healthy aging that may account for the findings of Chapters 3 and 6, and these differ in the extent to which they might be expected to be limited to tasks based on visual perception, or to generalise more widely. At a relatively low level, there is evidence of degraded peripheral vision that could in theory account for some difficulties integrating across visual space (Brewer & Barton, 2014; Griffis et al., 2016). Whilst stimuli used in these chapters were equivalent in size, and as such similarly susceptible to degraded peripheral vision, postural and configural tasks necessarily required judgments as to relative position of points across visual space, whereas kinematic and featural tasks could be carried out by attending to local detail. However, concluding the findings are purely related to peripheral vision requires assumptions as to strategies used in these tasks.

There is also evidence that neural areas implicated in featural and configural processing differ, with featural processing more reliant on left prefrontal areas and configural processing particularly recruiting the right fusiform gyrus and right frontal cortex (Maurer et al., 2007). However, although there is evidence of atrophy in such areas in healthy aging, there is limited evidence that this differentially impacts areas implicated in configural relative to featural processing (Hogstrom et al., 2013; Salat, 2004).

However, there is also evidence that configural differences are less salient that featural differences, and that their processing is more reliant on cortical feedback (Mercure et al., 2008), including connectivity with the dorsal stream (Zachariou et al., 2016). As such, the pattern of relative decline and preservation evidenced in Chapters 3 to 6 may be indicative of a wider decline in connectivity, mediated by deterioration in white matter integrity (Bennett & Madden, 2014; Branzoli et al., 2016) and evidence of an associated age-related changes both in processing speeds and in variability of processing speed (Nilsson et al., 2014). This would be consistent with the neural noise hypothesis whereby increased low frequency 1/f noise disrupts long range communication between neural regions (Dave et al., 2018; Voytek et al., 2015).

If so, even more substantial effects may be expected in more complex tasks involving integration not just across visual space but across modalities, particularly where tasks require rapid and consistent processing speeds. Chapter 7 found evidence for this in reduced sensitivity to own agency in a motor-visual task compared with a matched task requiring visual-visual mapping. Whilst provisional, given that experiments reported in this thesis primarily relate to visual processing tasks, the findings in Chapter 7 provide a basis for possible further work on the nature of mechanisms underlying the pattern of deficits in earlier chapters and whether they arise from broader deterioration in neural connectivity in healthy aging.

The evidence of an association between questionnaire measures is of interest, albeit noting that it is based on a relatively small sample size. There has been a relatively substantial number of studies on sense of control as a facet of wellbeing in healthy aging where declines are observed in healthy aging that run counter to many findings on preserved or even improved wellbeing in older adults (Lachman, 2006; Mirowsky, 1995). However, there has been relatively little consideration of the extent to which findings, which raise inter-disciplinary questions regarding older people's position in society, may also be impacted to some degree by older adults exhibiting a reduced sensitivity towards their own relative to conspecifics' agency. Whilst tentative, the findings indicate an area with potential for further research.

A further issue of general relevance findings reported in this thesis highlight is that, while studies of healthy aging unfortunately tend to involve identification of deficits consistent with a general pattern of neurophysiological decline, there are also areas of relative, or perhaps absolute, preservation. Outside the controlled context of a lab experiment, perceptual signals often have multiple dimensions both within and across domains allowing for the same conclusion to be reached (i.e. they include 'redundant' elements). Jasmin et al. (2020) provide an example in the auditory domain of how such redundancy may support robust understanding by allowing for individual differences in perceptual abilities and strategies, consistent with 'scaffolding' accounts (Cabeza et al., 2018). Such accounts provide a more optimistic view of the potential to slow declines in cognitive performance through adjustments in strategy. It should be noted, however, that a difficulty in healthy aging is that older adults may have developed models and strategies for sociocognitive tasks based on experience over a long period when perceptual abilities were different, and these may be slow to adapt to a degraded percept.

Parallels with patterns observed outside healthy aging

Difficulties in social cognition tasks in autism, particularly in relation to emotion recognition, has classically been assumed to stem from empathy difficulties (Baron-Cohen, 2009). However, more recent work has noted the potential role of perceptual atypicalities (Biotti et al., 2017; Brewer et al., 2016); see also Cracco et al., 2015; Hayes et al., 2018. The age-related impairments in visual perception reported in this thesis bear some similarities with those proposed as an explanation for face-processing difficulties in autism (Behrmann et al., 2006; Wallace et al., 2008 – although see also Joseph & Tanaka, 2002). Parallel visual processing and social cognition deficits have also been observed in some cases of developmental prosopagnosia (Avidan et al., 2011; Gerlach et al., 2017).

Some studies have indicated communication and social isolation problems in older populations that are analogous to those in autism and developmental prosopagnosia (Szanto et al., 2012). Such issues in older adults are, of course, likely related to a complex combination of situational factors tending to reduce social interaction (e.g. retirement, death of a partner, lower mobility; Vink et al., 2008), but the present study highlights an important contributor relating to cognitive decline.

Future directions

The experiments reported in this thesis, and methodology adopted, suggest several areas for further work in future. Firstly, the signal detection methodology, including drift diffusion modelling, used in this thesis provides a useful lens through which to examine the specific contribution of lower level perceptual sensitivity to patterns of deficit and preservation in areas where past findings have been attributed to higher level cognitive processes. In social cognition in particular, accuracy measures carry the risk of being affected by response bias, and differences in reaction times may reflect differences in response thresholds or in accumulation of evidence. Whilst this thesis has focussed primarily on visual perception, touching on proprioception in relation to sense of agency in Chapter 7, similar approaches could be applied, for example, in relation to auditory stimuli and in areas other than healthy aging where cognitive and perceptual impairments co-occur.

Secondly, future work could make use of complementary measures to further assess the nature of the pattern of deficits in older adults. For example, eye-tracking could be used to assess how far configural processing deficits relate to changes in the pattern of fixations (Wong et al., 2005), while neuroimaging would be needed to further assess the tentative suggestion in this thesis that reported deficits relate to declining white matter tract integrity.

Thirdly, it would be possible to assess interventions to slow cognitive decline. As noted in Chapter 1, healthy aging is associated with preserved or even improved wellbeing in many cases, but this is vulnerable to a cascade of difficulties in social cognition in later life the onset of which varies substantially between individuals (Luo et al., 2012; Shankar et al., 2011)(Luo et al., 2012; Shankar et al., 2011)(Luo et al., 2012; Shankar et al., 2011). Such interventions could focus on training of those perceiving social cues, but may alternatively involve those conveying them.

Finally, whilst Chapter 7 includes initial findings on reduced sensitivity to own agency and relatively preserved sensitivity to conspecifics' agency in older adults, further work would be needed to further assess mechanisms underlying this result, given the suggestion it is indicative of white matter deterioration is somewhat tentative. Again, such work could make use of complementary methodologies such as neuroimaging.

8.3 Limitations

This thesis has speculated that declines in white matter tract integrity in healthy aging represent a possible mechanism underlying a range of deficits in healthy aging, based on deficits in performance in tasks involving integrating either across visual space or between modalities, where the role of reliable and timely connectivity is thought to be particularly valuable. However, it is important to note that behavioural experiments such as those reported cannot of course provide direct evidence for that explanation. There is also a wider difficulty in studying cognitive change in healthy aging, as noted in Chapter 1, that the declines take place across a range of physiological, neurophysiological and psychological measures, providing multiple candidates for observed deficits. Although this thesis has sought to address these difficulties by designing experiments providing conditions where there is reason to anticipate relative preservation, the question of whether patterns identified are linked via a common aspect of neurophysiological decline would require application of complementary methodologies.

One area which would merit further investigation is how far age-related changes in strategy had a bearing on reported results. In relation to face processing in particular, it is plausible that preserved processing of local features could derive from a tendency apparent in eye-tracking studies for older adults to fixate more on the mouth area (Wong et al., 2005)(Wong et al., 2005)(Wong et al., 2005) which may reduce accumulation of configural information. To the extent this reflects an increased reliance on lip-reading, it may be a result of deterioration in the auditory rather than visual system.

Stimuli used were based on middle aged or younger models, including the point light walkers in Experiments 1 to 3 (albeit this may have been difficult to ascertain absent contextual information), faces in Experiments 4 to 7, and avatar hand in Experiment 8. As noted in Chapter 1, there is some evidence in relation to faces that older and younger adults spend more time attending to similarly aged stimuli (Ebner et al., 2011)(Ebner et al., 2011)(Ebner et al., 2011). Experiments 1 to 7 were designed to detect relative preservations as well as deficits using equivalent stimuli and, for that reason, it does not appear plausible that the pattern of results could have derived from attentional differences relating to own-age affects. Experiment 8 used the younger avatar hand in only one condition, but that was the condition in which older adults' sensitivity was preserved, contrary to what an own-age attentional bias would predict. However, there would have been merits in using stimuli derived from models in both age groups covered.

Two reported experiments (Experiments 5 and 7) were online replications of in-person studies. Such studies have advantages in terms of recruitment, particularly for older adults given the much younger profile of most individuals registered at universities to participate in psychological experiments. Indeed, it is possible that online participation opens involvement to a wider range of older adults as physical health may be an impediment to attending a lab to participate. However, they offer less control over the environment in which tasks are undertaken. Overall performance was lower across age groups, particularly in Experiment 5, albeit there were also methodological changes from Experiment 4 (whereas Experiments 6 and 7 did not differ materially in procedure.).

In Experiment 8, the physical challenge presented by producing repeated hand movements was underestimated when the experiment was designed, and this may have impacted upon results. Older adults in particular reported discomfort and ultimately a decision was made to stop testing just short of the pre-planned sample size. It appears plausible that differences in sensitivity in the Own Agency and Avatar Tasks related to difference in physical comfort experienced by older and younger adults. The results would still be of interest as an alternative explanation of lower sensitivity to own agency, but would not rely on white matter deterioration.

8.4 Conclusion

Healthy aging in later life involves a wide range of physiological, neurophysiological and psychological changes, which can take the form of increasing cognitive deficits, although also include areas of relative preservation. In relation to social cognition in particular, lower level perceptual difficulties have often been seen as having the potential to account for a general decline in performance in social cognitive tasks, but as less likely to explain more nuanced patterns of preservation as well as deficit.

This thesis has focused primarily on visual perception, with a series of experiments assessing whether older adults exhibit difficulties processing global configurations, alongside relative preservation in relation to processing local features. Signal detection methods have been used to further specify the nature of any deficits. It has indicated ways in which such visual perceptual difficulties may contribute to distinctive patterns of age-related changes in social cognition in a way that casts new light on earlier findings.

A range of changes in healthy aging could plausibly account for the patterns of deficit and preservation in visual perception. One of these implicates declining reliability in neural connectivity arising from reduced white matter tract integrity in older adults, and some tentative evidence from Chapter 7 suggests a broader age-related deficit in a task involving integrating between modalities, as well as visually across space, which would merit further investigation.

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