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Neural changes related to motion processing in healthy aging

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ABSTRACT

Behavioral studies have found a striking decline in the processing of low-level motion in healthy aging whereas the processing of more relevant and familiar biological motion is relatively preserved. This functional magnetic resonance imaging (fMRI) study investigated the neural correlates of low-level radial motion processing and biological motion processing in 19 healthy older adults (age range 62–78 years) and in 19 younger adults (age range 20–30 years). Brain regions related to both types of motion stimuli were evaluated and the magnitude and time courses of activation in those regions of interest were calculated. Whole-brain comparisons showed increased temporal and frontal activation in the older group for low-level motion but no differences for biological motion. Time-course analyses in regions of interest known to be involved in both types of motion processing likewise did not reveal any age differences for biological motion. Our results show that low-level motion processing in healthy aging requires the recruitment of additional resources, whereas areas related to the processing of biological motion processing seem to be relatively preserved.

1. Introduction

Research in healthy aging has increasingly extended its scope from investigating higher cognitive functions to all areas of perception, and it has been shown that a variety of cognitive and perceptual abilities are affected by healthy aging (Grady, 2012; Greenwood, 2007; Hedden and Gabrieli, 2004). It has been proposed that an attenuation in neuromodulation and an increase in neural noise with increasing age are possible causes of the observable decline in abilities (Li et al., 2001).

Motion perception is an important and vital visual ability, which helps us to safely navigate through the environment. Previous studies have shown that low-level motion perception declines with healthy aging (Hutchinson et al., 2012). In an early study, Buckingham et al. (1987) found a deterioration of movement sensitivity with increasing age. In addition, motion detection and direction discrimination (Bennett et al., 2007) as well as speed perception (Atchley and Andersen, 1998; Norman et al., 2003, 2010) have been shown to be impaired. Older participants furthermore exhibit reduced spatiotemporal integration for apparent motion, requiring both shorter interstimulus intervals and smaller spatial displacements to reach accuracy comparable to younger adults (Roudaia et al., 2010). Moreover, motion direction discrimination thresholds have been found to continually increase with increasing age (Billino et al., 2008; Velarde et al., 2012). These age-related changes in low-level motion perception have been related to loss in sensitivity, increased spontaneous noise, and increased excitability of neurons in early visual areas, potentially related to a decrease in the inhibitory neurotransmitter gamma-aminobutyric acid (Leventhal et al., 2003; Schmolesky et al., 2000).

In addition to decreased low-level motion perception, more recent studies have also shown age-related changes in biological motion perception tasks. Biological motion perception is commonly investigated using point-light walkers (Johansson, 1973). Point-light walkers are stimuli that consist of local dots that represent the joints of a moving person. Each dot has a local motion trajectory that represents the movement of its corresponding joint over time. By integrating the local motion signals of all dots, the biological motion of the figure becomes apparent (for a review see Blake and Shiffrar, 2007). Previous research has suggested that biological motion is processed in 2 interacting neural pathways, the dorsal and the ventral pathway. The dorsal pathway is thought to process biological motion primarily based on the local motion information of the single dots, integrating information from local motion detectors in V1/V2 and middle temporal area hMT+ into optic flow detectors, further into optic flow pattern neurons in the superior

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temporal sulcus (STS). The ventral pathway is thought to process biological motion primarily based on the global form information, which is achieved by integrating the local dots into a global figure at any given point in time. Information from both pathways is thought to be integrated in motion pattern neurons in areas such as STS that allow for the decoding of the underlying movement (Giese and Poggio, 2003; Lappe, 2012).

In line with the previously mentioned model, STS activation has been shown to be specific to the perception of biological motion, while hMT+ has been shown to respond to visual motion more generally (Grossman et al., 2000; Morrone et al., 2000; Schultz and Pilz, 2009). Furthermore, areas previously related to static face processing—the occipital face area (OFA) and the fusiform face area (FFA)—have been found to show increased activation to point-light walkers (Grossman and Blake, 2002), but also to moving faces (Schultz and Pilz, 2009; Schultz et al., 2013). Michels et al. (2005) investigated brain structures responding preferentially to normal biological motion point-light walkers compared to point-light walkers devoid of local motion trajectories. Although STS showed a preferential response for the normal point-light walkers, it was still active during the presentation of the point-light walkers that contained primarily global form information. The same was true for FFA and OFA. These 3 areas consequently seem to be specifically attuned to the perception of biological motion as well as biological form information. Psychophysiological studies furthermore suggest that input from only the form pathway is sufficient to perceive biological motion, as participants still reached high discrimination accuracy for point-light walkers with no local motion information (Beintema and Lappe, 2002; Beintema et al., 2006). To summarize, biological motion can be processed using both the global motion and the form that is contained in the stimulus, and it has been suggested that both the ventral and the dorsal pathway are involved in the processing of biological motion. Information from both pathways is thought to be integrated in STS.

As for the biological motion perception, previous studies have also shown decreased biological motion perception for point-light walkers masked in a cloud of noise dots for older compared to younger adults (Billino et al., 2008; Pilz et al., 2010). However, it seems that older adults' performance for biological motion tasks improves with increased stimulus duration (Norman et al., 2004; Pilz et al., 2010; Spencer et al., 2016), suggesting that changes in biological motion perception might in part be related to increased processing times. In addition, older adults seem to use different strategies when processing biological motion, as performance for less familiar stimuli such as inverted point-light walkers improves for stimuli that primarily contain form information compared to those that contain both local motion and global form information: Pilz et al. (2010) asked older and younger participants to discriminate the walking direction of point-light walkers that contained primarily local motion, primarily global form, or both local motion and global form information. For upright walkers, older adults performed similarly to younger adults, especially at longer stimulus durations. When the walkers were inverted, older adults' performance for walkers containing both local motion and global form information was worse than performance of younger adults even for stimulus durations extending 3 seconds. However, older adults performed as well as younger adults for inverted walkers that primarily contained the global form information. These results suggest that brain areas primarily involved in motion processing are more affected by aging than areas primarily involved in form processing.

Age-related decline in visual processing has been hypothesized to be caused by neural changes leading to increased neural noise within the visual system (Betts et al., 2007). This is supported by animal studies finding decreased selectivity of V1 cells in senescent monkeys, which is possibly caused by reduced intracortical inhibition (Leventhal et al., 2003; Schmolesky et al., 2000). However, so far, the neural mechanisms underlying age-related changes in visual motion processing are relatively unknown. Therefore, this study investigated age-related changes in the neural activation of areas related to the perception of both low-level and biological motion. Changes in brain areas commonly related to low-level motion processing (hMT+) were investigated by showing participants a circular display of dots with alternating radial outwards and inwards motion, and a circular display of static dots. Neural activation related to biological motion processing (brain areas STS, FFA, OFA) was investigated by showing participants displays of normal (Johansson, 1973), random position (Beintema and Lappe, 2002; Beintema et al., 2006), and scrambled point-light walkers (Pilz et al., 2010; Vaina et al., 2001) performing different actions (Vanrie and Verfaillie, 2004).

Based on the previous neuroimaging and behavioral results regarding low-level and biological motion perception, we expected to find less efficient neural activation especially in the dorsal area hMT+ for both low-level and biological motion for older compared to younger participants. The processing of low-level motion stimuli heavily relies on processing in this area, whereas the processing of biological motion stimuli is thought to involve both dorsal area hMT+ and ventral areas FFA and OFA related to motion and form information, respectively, as well as STS (Giese and Poggio, 2003). Given the previously mentioned age-related behavioral changes in low-level motion perception, and altered processing of biological motion stimuli containing local motion information, it is likely that dorsal area hMT+ is especially prone to age-related decline.

2. Methods

2.1. Participants

All participants attended a screening appointment to assess their near and far vision, and obtain handedness data (Oldfield, 1971) as well as sociodemographic information, visual health, and relevant medical history. Only right-handed participants with near and far vision above 16/20, no history of cataract, glaucoma, or maculopathy, and an eye exam within the last 3 years were included in the study. To ensure that none of the older participants were suffering from mild cognitive impairment, the older group additionally completed the Montréal Cognitive Assessment (Nasreddine et al., 2005). As depression in old age was previously linked to executive (and visuospatial) impairment (Butters et al., 2004), older participants were screened for depressive symptomatology using the short version of the Geriatric Depression Scale (Sheikh and Yesavage, 1986). The cutoff scores were $\geq$26 for the MoCa and $\leq$10 for the Geriatric Depression Scale, as recommended by the respective authors.

A total of 21 younger participants (15 women, age range 20–30 years) and 20 older participants (12 women, age range 62–78 years) took part in the functional magnetic resonance imaging (fMRI) experiment. From this sample, 1 older participant had to be excluded because his structural scan showed an arachnoid cyst in the lower occipital cortex, and 2 younger participants had to be excluded because substantial movement after the initial slice alignment placed the lower portion of the occipital lobes outside the field of view and a technical error prevented the recording of responses to the attention task, respectively. The final sample thus consisted of 19 older (mean age 68.8 years, SD 4.5) and 19 younger (mean age 23.3 years, SD 3.0) participants. Ethical approval was obtained through the School of Psychology Ethics Committee of the University of Aberdeen, and the study was registered with the National Health Service Grampian Research and Development Office (NHS Grampian R & D; Project Number, 2014PC006); all procedures involved were in accordance with the Declaration of