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Enhancing anger perception in older adults by stimulating inferior frontal cortex with high frequency transcranial random noise stimulation

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ABSTRACT

Extensive behavioural evidence has shown that older people have declined ability in facial emotion perception. Recent work has begun to examine the neural mechanism that contribute to this, and potential tools to support emotion perception during aging. The aim of this study was to investigate whether high frequency tRNS applied to the inferior frontal cortex would enhance facial expression perception in older adults. Healthy aged adults (60+ years) were randomly assigned to receive active high-frequency or sham tRNS targeted at bilateral inferior frontal cortices. Each group completed tests of facial identity perception, facial happiness perception and facial anger perception. These tasks were completed before and after stimulation. The results showed that, compared to the sham group, the active tRNS group showed greater gains in performance after stimulation in anger perception (relative to performance before stimulation). The same tRNS stimulation did not significantly change performance on the two other face perception tasks assessing facial identity and facial happiness perception. Examination of how inter-individual variability related to changes in anger perception following tRNS indicated that the degree of performance change in anger perception following active tRNS to inferior frontal cortex was predicted by baseline ability and gender of older adult participants. The findings suggest that high frequency tRNS may be a potential tool to aid anger perception in typical aging, but flag that performance variability and gender may interact with stimulation leading to different outcomes.

1. Introduction

Emotional facial expression perception plays an important role in interpersonal communication. Difficulties with emotion perception are associated with specific types of social impairment, including poor interpersonal interaction, reduced social competence, loneliness, and inappropriate social behaviours (e.g., Spell and Frank, 2000; Kanai et al., 2012). Numerous studies have focused on establishing how emotion perception is affected as a function of normal adult aging, as well as the extent and implications of any observed difficulties (e.g. Sullivan and Ruffman, 2004; Isaacowitz et al., 2007; Ebner et al., 2013; Ebner and Fischer, 2014). The overall pattern of results regarding age group differences in facial expression perception is quite consistent: a recent meta-analysis reviewed papers examining age differences in emotion perception and concluded that older adults (60+) have increased difficulty in perceiving at least some basic emotions (particularly anger, sadness, and fear) from faces, but that others remain spared (e.g. disgust perception; Ruffman et al., 2008).

Although many studies have investigated the cognitive and neural basis of decline in emotion perception during typical aging, little attention has been directed towards improving face emotion processing in these individuals. In other areas of research one tool that has proved to be useful in aiding social perception is transcranial electrical stimulation (tES). TES is a safe and noninvasive technique for brain stimulation that can be used to increase or decrease brain activity under a targeted brain region. It refers to a range of techniques, including transcranial direct current stimulation (tDCS), transcranial random noise stimulation (tRNS), and transcranial alternating current stimulation (tACS), which involve passing a weak current between electrodes placed on the scalp (Miniussi et al., 2013). For instance, in high-frequency tRNS, an alternating current ranging randomly between 100 and 640 Hz is passed between electrodes leading to bilateral increases in cortical excitability under two stimulating electrodes (Terney et al., 2008).

Prior work has shown that tES can be effective in improving performance on several tasks in young adults, including memory, perception, social cognition, social perception, learning and motor abilities (e.g. Cohen Kadosh et al., 2010; Snowball et al., 2013; Fertonani et al., 2011; Sellaro et al., 2016; Romanska et al., 2015). While tES has been employed to study young adults, it has been used less frequently to

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study older adult participants (see Tatti et al., 2016 for review). This is surprising given a) the psychosocial consequences of reduced emotion perception ability (Spell and Frank, 2000), b) the consistent pattern of age-related declines in emotion perception ability (e.g. Ruffman et al., 2008), and c) prior work showing that social processing (including emotion perception) can be improved following tES in young adult participants (e.g. Santiesteban et al., 2012, 2015; Hogeveen et al., 2014, 2016; Janik et al., 2015; Romanska et al., 2015; Barbieri et al., 2016; Liepelt et al., 2016; Sellaro et al., 2016). Indeed, in other domains (e.g. memory, motor performance) non-invasive brain stimulation techniques have been shown to offer promise in enhancing performance of healthy older adults. For instance, Hsu et al. (2015) investigated the effect of non-invasive brain stimulation on healthy older adults by conducting a meta-analysis of fourteen studies with a total of 331 healthy older adults. The meta-analysis revealed that applying a single session of non-invasive brain stimulation typically positively influenced older adults' performance. With this in mind, assessing the effect of using non-invasive brain stimulation as a tool to improve older adults emotion perception seems an important avenue of investigation.

One form of tES that might be particularly useful in the context of aging is the use of high-frequency tRNS, which can induce bilateral changes in cortical excitability. This is important because age-related neural functions are often associated with shifts from unilateral functional brain activation to bilateral activation. For instance, the compensation-related utilisation of neural circuits hypothesis (CRUNCH) suggests that older people shift from unilateral functional brain activation to bilateral activation to achieve similar performance output as younger people who might only use unilateral neural activation (Reuter-Lorenz and Cappell, 2008). Similarly, aging has been linked with hemispheric asymmetry reductions and the recruitment of compensatory mechanisms (e.g. the hemispheric asymmetry reduction in older adults model [HAROLD], Cabeza, 2002). In this context high frequency tRNS may be useful to increase compensatory potential by inducing greater bilateral functional brain activation.

Prior work also suggests that age-related declines in emotion perception are related to changes in perceptual strategies employed by old relative to young adults; for example, older adults tend to use perceptual information from upper parts of the face (e.g. eye region) less often and less efficiently (i.e. they are worse at detecting changes in this region) than young adult participants (Circelli et al., 2013; Murphy and Isaacowitz, 2010; Sullivan et al., 2007; Slessor et al., 2013; Chaby et al., 2011; Wong et al., 2005). This perceptual strategy of privileging information from lower parts of the face appears to predict patterns of change in older adult emotion perception (Wong et al., 2005; Mather, 2016). In this regard, it has been argued that older adults have weaker perceptual representations of emotions that typically rely more heavily on information from the top half of the face (e.g. fear, sadness, and anger; Mather, 2016). One way in which high frequency tRNS is thought to aid performance is via mechanisms of stochastic resonance, with random noise amplifying weak neural signals (e.g. Moss et al., 2004). With this in mind, tRNS may offer a useful intervention to amplify weak signals in brain regions associated with emotion processing in older adults.

One brain region commonly linked with emotion perception is the inferior frontal cortex. For instance, a number of meta-analyses point to the involvement of inferior frontal cortex during expressive face perception (e.g. Sabatinelli et al., 2011; Fusar-Poli et al., 2009). Of particular interest in the context of aging is that activation within inferior frontal cortex has commonly been linked with the perception of facial emotions that older adults show impairments in perceiving (e.g. fear, sadness, and anger; Fusar-Poli et al., 2009; Fischer et al., 2010). Indeed in the meta-analysis by Fusar-Poli et al. (2009) it was found that bilateral inferior frontal cortex activity was most prominently associated with processing anger perception (an emotion that is typically linked with impaired perception in older adulthood). With this in mind, the inferior frontal cortex is a particularly interesting target region to assess whether high frequency tRNS could improve the emotion perception.

When investigating the utility of non-invasive brain stimulation for improvement, it is also important to consider individual variation within the target cohort and how this might interact with stimulation effects. One key feature that can interact with the effects of brain stimulation is baseline performance (e.g. Feurra et al., 2013; Hsu et al., 2014; Hsu et al., 2015; Hsu et al., 2017; Tseng et al., 2012). This is particularly important in aging research, since a number of studies point to differences in the functional brain networks recruited between high and low performing older adults (Cabeza et al., 2002; Reuter-Lorenz and Cappell, 2008). For example, in the context of face processing it has been shown that high performing older adults show activation in compensatory brain networks (i.e. different brain networks) when compared to young adults and when compared to low-performing older adults (Lee et al., 2011). These findings are often interpreted with the suggestion that low-performing older adults recruit similar brain networks as young adults but in an inefficient manner, whereas high-performing older adults show greater plastic reorganization of neurocognitive networks (and therefore compensate for deficiencies associated with typical aging; Cabeza et al., 2002, Reuter-Lorenz and Cappell, 2008). This highlights an important consideration for non-invasive brain stimulation studies since identifying a target brain region based on young adult or low-performing older adult brain networks may lead to differential patterns of behavioural change in low-performing versus high-performing older adults (i.e. low performing older adults may benefit from stimulating brain regions that younger adults use, but high performing older adults may benefit from stimulating a compensatory brain network).

To our knowledge no studies to date have examined a) if high-frequency tRNS can modulate emotion perception or b) if any effect can differ across older adults depending on baseline performance (i.e. high versus low performing older adults). With this in mind, this study sought to examine whether high-frequency tRNS targeted at the inferior frontal cortex could modulate older adults' abilities to perceive facial emotion (anger and happiness perception) and facial identity. We also assessed the extent to which any changes in performance following stimulation would be influenced by pre-stimulation (i.e. baseline) perceptual abilities. Based on prior work highlighting the involvement of bilateral inferior frontal cortex activity in anger perception (Fusar-Poli et al., 2009) and work suggesting that low-performing older adults tend to recruit similar brain networks as young adult participants (but high performing older adults tend to recruit compensatory brain networks) we predicted a specific improvement in low-performing older adults in anger perception.

2. Methods

2.1. Participants

Thirty-two healthy older adult volunteers (mean age = 70.1 years, SE = 2.8 years; fourteen males) participated in this study. Participants were randomly assigned to the active high frequency tRNS (n = 16, mean age = 69.2 years, SE = 1.5 years; eight males) or sham stimulation (n = 16, mean age = 70.9 years, SE = 2.28 years; six males) groups.

Participants were recruited from the community using fliers in, for example, retirement communities or senior citizen centers. All participants were native-English Caucasians, with normal or corrected-to-normal vision, with no known history of neurological problems, dyslexia or other language-related problems. Information on handedness, education level, and National Adult Reading Test (NART) score (Nelson and Willison, 1991) were obtained and recorded from each subject. All participants were asked to complete mini-mental state examination (MMSE) (Folstein et al., 1975) to evaluate mental states, and none of them scored lower than 24. Informed consent from all participants were obtained prior to beginning the experiment who were fully informed