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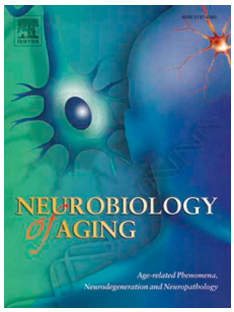

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Resting state EEG power and connectivity are associated with alpha peak frequency slowing in healthy aging

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slowing in healthy aging

Abstract

The individual alpha peak frequency (IAPF) of the human EEG typically experiences slowing with increasing age. Despite this hallmark change, studies that investigate modulations of conventional EEG alpha power and connectivity by aging and age-related neuropathology neglect to account for inter-group differences in IAPF. To investigate the relationship of age-related IAPF slowing with EEG power and connectivity, we recorded eyes-closed resting state EEG in 37 young adults and 32 older adults. We replicated the finding of a slowed IAPF in older adults. IAPF values were significantly correlated with the frequency of maximum global connectivity and the means of their distributions did not differ, suggesting that connectivity was highest at the IAPF. Older adults expressed reduced global EEG power and connectivity at the conventional upper alpha band (10-12 Hz) compared to young adults. In contrast, groups had equivalent power and connectivity at the IAPF. The results suggest that conventional spectral boundaries may be biased against older adults or any group with a slowed IAPF. We conclude that investigations of alpha activity in aging and age-related neuropathology should be adapted to the IAPF of the individual and that previous findings should be interpreted with caution. EEG in the dominant alpha range may be unsuitable for examining cortico-cortical connectivity due to its subcortical origins.

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Introduction

Aging is associated with a host of functional changes in the resting brain. Using the electroencephalography (EEG) neuroimaging method, some of the most commonly documented changes in older age are (i) reductions in oscillatory power, (ii) a weakening of functional connectivity between electrode time series data and (iii) a slowing of the dominant alpha EEG frequency. The relationship between these hallmark changes has rarely been systematically investigated. Of particular interest is how the use of conventional EEG frequency bands, which do not account for age-related frequency shifts, may influence age-group differences in EEG power and connectivity. These relationships may have important implications for the interpretation of previous findings and for progression in the analysis of resting state EEG in aging research.

The EEG frequency spectrum ranges from 0 to ~100 Hz. Most commonly, spectral properties of the EEG are analysed within conventional frequency bands: Delta (0-4 Hz), theta (4-8 Hz), alpha (8-12 Hz), beta (12-30 Hz) and gamma (>30 Hz) bands. Research into the cognitive modulation of EEG frequency power emphasises the inter-individual variation across the spectral boundaries of these conventional frequency bands, and also the boundaries of sub-bands within the alpha range (for a review, see Klimesch, 1999). A suggested marker for determining the individualised frequency boundaries is the individual alpha peak frequency (IAPF). The IAPF is the average frequency of highest power between 6-13 Hz across the electrodes of the EEG montage (Angelakis, Lubar, & Stathopoulou, 2004). The IAPF is a stable and highly heritable physiological

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characteristic (Grandy et al., 2013; Posthuma, Neale, Boomsma, & De Geus, 2001; Christine M Smit, Wright, Hansell, Geffen, & Martin, 2006) that typically increases during the first 20 years of development and commences slowing from age 40 (Aurlien et al., 2004; Bazanova, 2008; Chiang, Rennie, Robinson, van Albada, & Kerr, 2011). Reported averages range from 9.8-10.5 Hz in young adults (age 17-30), to 8.5-9.7 in older adults aged 60 and above (Dustman, Shearer, & Emmerson, 1993).

An abundance of research has demonstrated that there are clear age-related modulations of the IAPF. Despite this, very few studies have abandoned the use of conventional frequency bands when investigating oscillatory power and connectivity. Duffy, Albert, McAnulty, & Garvey (1984) observed a weak negative correlation between chronological age and alpha (8-11.75 Hz) amplitude in 30-80-year-old males (r = -0.27). Barry & De Blasio (2017) reported reduced delta (0.5-3.5 Hz), theta (4-7.5 Hz) and alpha (8-13 Hz) power, and increased beta (13.5-24 Hz) power in older compared to young adults; age-related alpha reductions were mainly evident in the posterior right hemisphere, with a weaker effect than observed in the other frequency bands. Gaál et al. (2010) observed reductions of delta and alpha power in older adults. Babiloni et al. (2006) also reported reduced power for older adults in the lower and upper alpha bands (8-10.5 Hz, 10.5-13 Hz). However, reduced alpha power may not be specific to the latest decades of development, as Aurlien et al. (2004) described a steady decline of IAPF amplitude from birth to age 30, where amplitude stabilised for the rest of the lifespan.

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Functional connectivity in EEG generally refers to the temporal correlations between time series data from two or more independent EEG channels or sources. Connectivity strength between regions of interest may be extracted from the data, or the entire dataset may be summarized in terms of its network properties (Rubinov & Sporns, 2010). Connectivity metrics, which attempt to characterize the strength of connectivity in the presence of noise, are plentiful. Many early investigations of EEG functional connectivity have relied on the EEG coupling metric known as spectral coherence. Coherence is an estimate of the linear correlation between a pair of signals in the time-frequency domain (Bowyer, 2016; French & Beaumont, 1984), and is usually computed within a frequency band of interest. Coherence between EEG channels is prone to overestimation due to volume conduction, whereby neighbouring electrodes may record the signal from the same underlying neural generator, resulting in inflated estimates of connectivity between them. Novel connectivity metrics such as the phase-lag index (Stam, Nolte, & Daffertshofer, 2007) and weighted phase-lag index (Vinck, Oostenveld, Van Wingerden, Battaglia, & Pennartz, 2011) aim to attenuate the effects of volume conduction by disregarding the zero-phase relationships between a pair of EEG signals. In many cases, EEG functional connectivity has been shown to reflect the underlying structural properties of the brain. For example, coherence between electrodes placed on each hemisphere is weakened in individuals with surgically sectioned or underdeveloped commissural white matter fibres (Koeda et al., 1995; Montplaisir et al., 1990; Nagase, Terasaki, Okubo, Matsuura, & Toru, 1994; Nielsen, Montplaisir, & Lassonde, 1993). Furthermore, studies have noted positive correlations between functional EEG coherence and white matter tract integrity in patients with

Alzheimer's disease pathology (Pogarell et al., 2005; Teipel et al., 2009; Vecchio et al., 2015).

While many studies have investigated EEG connectivity in age-related diseases, relatively few have characterised the connectivity changes that occur with typical aging. Duffy, Mcanulty, & Albert (1996) examined EEG coherence in a large sample (N = 350) of adults aged 20-79 and reported age-related reductions in theta, alpha and beta frequencies. However, they exclusively considered interhemispheric pairs of electrodes and could not differentiate between eyes-open and eyes-closed conditions in their factor-analytic approach, which are known to generate distinct functional connectivity networks (Miraglia, Vecchio, Bramanti, & Rossini, 2016). Kikuchi and colleagues (2000) also found reductions in delta, theta, upper alpha (11-12.5 Hz) and beta interhemispheric EEG coherence during eyes-closed recordings. In a large sample of 17,722 individuals, an age-related decrease of global theta and alpha (8-12.5 Hz) coherence, along with an increase in beta coherence was reported (Vysata et al., 2014). Few studies have employed connectivity measures that aim to reduce volume conduction. In a sample of 1500 individuals between age 5-71, alpha PLI (6-13 Hz) derived from minimum spanning tree graphs declined in late adulthood from about age 50 (Smit, de Geus, Boersma, Boomsma, & Stam, 2016). Vecchio, Miraglia, Bramanti, & Rossini (2014) described a reduction of lagged linear coherence in the upper alpha frequencies (10.5-13 Hz) in early (50-70) and later old aged (>70) adults, which were accompanied by age-related increases in delta and theta connectivity.

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A critical issue for the study of EEG power and connectivity in the conventional alpha frequency range is the role of inter-individual IAPF variability. In 1999, Klimesch argued that because the spectral boundaries of the alpha frequency band and sub-bands vary between individuals, the alpha frequency boundaries should be adapted to the IAPF of the individual under study (Klimesch, 1999). Older adults would therefore be at an artificial disadvantage when compared to young adults within conventional frequency bands, such as the upper alpha (10-12 Hz) frequencies, due to the age-related slowing of the IAPF. While this is certain for EEG power, the relationship between IAPF variability and connectivity is largely unknown. We are unaware of any studies that have investigated age-related changes of EEG connectivity while also considering age-related IAPF slowing. By considering IAPF, we can uncover real age-related modulations of EEG activity and connectivity to inform future studies of aging and age-related neuropathology.

The present study aimed to examine whether the IAPF is associated with EEG power and connectivity in the context of age-related physiological differences. We first replicated the finding of a slowed IAPF in older adults, to demonstrate that our data is coherent with previous findings. We then determined whether global connectivity was modulated by the IAPF, that is, whether the frequency at which connectivity was strongest was correlated with, and different to the IAPF across and within participant groups. We then compared younger and older adults on global power and connectivity at both the IAPF and the conventional upper alpha frequency band. We hypothesised that age differences would be observed in the conventional upper alpha band, as reported in previous studies (Gaál et al., 2010; Kikuchi et al., 2000; Vecchio et al., 2014),

while age differences may be absent at the IAPF, outlining the redundancy of conventional frequency boundaries where IAPF is slowed in one group.

Materials and methods

Participants

Data from 32 older adults (11 male, 21 female, mean age = 69.75, SD = 4.91) and 37 young adults (13 male, 24 female, mean age = 20.3, SD = 2.06) were analysed in this study. Older adults were recruited from the community and young adults were recruited from the undergraduate psychology programme of the School of Psychology, University of Leeds, UK. All participants were self-reportedly right-handed. No participant reported a history of neurological disease or head trauma. Older adults were screened for dementia-related cognitive impairment with the Memory Alteration Test (Ozer et al., 2016; Rami, Molinuevo, Sanchez-Valle, Bosch, & Villar, 2007), and for depression using the depression subscale of the Hospital Anxiety and Depressions Scale (Zigmond & Snaith, 1983). No participant breached the guideline cut-off criteria for memory impairment or depression. Informed consent was obtained from all participants.

EEG recording and pre-processing

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Continuous EEG recordings were made on a Neuroscan SynAmps2 system using a 64 channel headcap. Five minutes of eyes-closed resting state EEG was recorded at a sampling rate of 1000 Hz. The ground electrode at the time of recording was at AFZ, with the reference electrode located on the vertex between CZ and CPZ. Data pre-processing was performed offline. The data were filtered between 1-40 Hz and downsampled to 200 Hz. Noisy channels were omitted from the dataset by way of visual inspection (2.78 channels on average were removed, SD = 1.92). The continuous data were segmented into epochs of 2 seconds with 0% overlap. An iterative amplitude thresholding process was applied to the epochs to eliminate noisy trials from the dataset. The threshold was set at ±100 μV, and reduced by ±1 μV with each iteration. Epochs containing data that breached the adaptive threshold were removed until 80 epochs remained. The remaining epochs were visually inspected for artefacts such as eye-blinks that happened to evade the thresholding process. At least 75 epochs per participant were selected for further analysis. The data were re-referenced to the common average reference.

Dominant alpha frequency estimation

The power spectral density of each EEG channel was estimated using the *spectopo* function from the EEGLAB software (Delorme & Makeig, 2004). The *findpeaks* function in Matlab (version 2015a) was used to locate the frequency of maximum absolute logarithmic power between 6 Hz and 14 Hz. The peak frequency from each channel was averaged to determine the IAPF (see **Figure 1**).

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- *Insert figure 1 here*

Power and connectivity analysis

Time-frequency information was extracted from the EEG signals using the Fieldtrip toolbox (Oostenveld, Fries, Maris, & Schoffelen, 2011) within Matlab. Sliding Hanning windows with a fixed length of 2 seconds (offering a 0.5 Hz frequency resolution) were used to extract the power-spectral density for every EEG channel, and cross-spectral density between every pair of EEG channels, from 6 to 12 Hz in steps of 0.5 Hz. Absolute spectral power at the IAPF and the upper alpha frequency band (10-12 Hz) was extracted and averaged across channels and trials. The array of power values at each frequency were log transformed to normalise their distribution. Power at the IAPF and upper alpha frequencies (10-12 Hz) were recorded for each individual.

The phase lag index (PLI; Stam et al., 2007) and weighted phase-lag index (WPLI; Vinck et al., 2011) were used to measure connectivity between all pairs of electrodes. Both measures stem from a longstanding development of connectivity metrics that attempt to account for the spurious connectivity estimates caused by the volume conduction phenomenon. Nolte et al. (2004) initially proposed that the imaginary part of spectral coherence between two signals was less sensitive to volume conduction than the real part of coherence. However, imaginary coherence was influenced both by the signal amplitude and the magnitude of the phase delay between the signals (Stam et al., 2007), and was prone to Type II errors; real connectivity was sometimes dismissed as volume

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conduction. This was improved upon with the introduction of the phase-lag index (PLI), which measures connectivity based on the imbalance in the distribution of phase angle differences between a pair of oscillations (Stam et al., 2007). To control for volume conduction, zero-phase relationships are disqualified by the PLI (Stam et al., 2007; Vinck et al., 2011) under the rationale that instantaneous phasic relationships are not representative of inter-regional neural connectivity, which must incorporate some time delay, characteristic of axonal transmission. The PLI is defined by the absolute value of the average sign of the imaginary part of the cross spectrum. The PLI was calculated from the imaginary part of the cross-spectral density using the formula:

$$PLI_{xy} = \left|\langle sign\left(imag\left(S_{xy}\right)\right)\rangle\right|$$

whereby $imag(S_{xy})$ denotes the imaginary component of the cross-spectrum between channels x and y, and $sign(imag(S_{xy}))$ refers to the sign (-/0/+) of this property. According to Vinck et al. (2011), the signal-to-noise ratio of the PLI is limited, as volume conducted noise components in the data could alter the sign of the imaginary component, leading to spuriously inflated connectivity estimates. The WPLI was developed in response, which weighted the phase leads and lags by the magnitude of the imaginary component of the cross-frequency spectrum (Vinck et al., 2011), thus further removing the contribution of zero-lag phase differences and improving the signal-to-noise ratio. Here, the WPLI was calculated as follows:

$$WPLI_{xy} = \frac{\left|\langle imag\left(S_{xy}\right)\rangle\right| * \langle sign(imag\left(S_{xy}\right))\rangle}{\langle\left|imag\left(S_{xy}\right)\right|\rangle}$$

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Global PLI and WPLI connectivity were calculated by taking the average of connectivity values between every possible pair of channels.

Statistical analysis

IAPF values were compared between younger and older adults using t-tests for independent samples, with Welch's correction for unmatched sample variances. Pearson product-moment correlations were used to measure the relationships between the IAPF and the peak PLI and WPLI frequencies in young adults, older adults, and the entire sample. To investigate whether or not the peak connectivity frequencies differed from the IAPF, we conducted a one-sample t-test on the signed differences between the IAPF and peak connectivity frequency values, to determine if the mean of the difference distribution did not statistically differ from zero. Power and connectivity estimates were analysed using a Group (young/older) x Frequency (IAPF/upper alpha) ANOVA, to determine whether between-group differences varied according to the choice of frequency implemented in the analysis. As we are interested in age differences, we specify a priori *t*-tests between young and older adults at each level of frequency. The false discovery rate was implemented to control for multiple comparisons in the planned contrasts. For t-tests, effect sizes in the form of Cohen's *D* are reported. For the fixed ANOVA effects, generalized eta squared (*ges*) effect sizes are reported (Bakeman, 2005; Olejnik & Algina, 2003).

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Results

Age differences in IAPF

IAPF values were compared between young and older adults. Young adults had a mean IAPF of 10.04 Hz (SD = 0.83), while older adults had a mean IAPF of 8.78 Hz (SD = 1.19). On average, older adults had significantly slower IAPFs compared to younger adults, $t(53.92) = 4.96$, $p < .001$, *Cohen's D* = 1.23, consistent with a slowing of EEG frequencies in older age (Aurlien et al., 2004) (**Figure 2**).

- *Insert figure 2 here*

IAPF and peak connectivity frequencies

IAPF was positively correlated with peak PLI frequency across the entire group ($r = 0.82$, $p < .001$), and within the younger ($r = 0.74$, $p < .001$) and older subgroups ($r = 0.77$, $p < .001$; **Figure 3**). A one-sample t-test demonstrated that the mean of the difference distribution between the IAPF and peak PLI frequency values was not significantly different from 0, $t(68) = 1.16$, $p = .248$, *Cohen's D* = 0.14.

- *Insert figure 3 here*

For WPLI, high positive correlations were observed between IAPF and peak WPLI frequency across the entire sample ($r = 0.85$, $p < .001$), in the young adult group ($r = 0.72$, $p < .001$) and in the older adult group ($r = 0.84$, $p < .001$; **Figure 4**). A one sample t-

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test showed that the mean difference between the IAPF and WPLI peak connectivity values was not significantly different from 0, $t(68) = 0.37$, $p = .711$, *Cohen's D* = 0.04.

- *Insert figure 4 here*

EEG power

A Shapiro-Wilks test for normality demonstrated that the log transformed EEG power values were normally distributed ($W = 0.99$, $p = 0.433$). The Group (young/older) x Frequency (upper alpha/IAPF) ANOVA yielded a significant Group x Frequency interaction on EEG power estimates, $F(1,67) = 17.2$, $p < .001$, *ges* = 0.02. Between-group t-tests suggested that young adults had significantly higher upper alpha power than younger adults, $t(66.93) = 3.87$, *adjusted p* < .001, *Cohen's D* = 0.93 (**Figure 5**). The difference in IAPF power between young and older adults was not significant, $t(66.98) = 1.48$, *adjusted p* = .141, *Cohen's D* = 0.36.

- *Insert figure 5 here*

EEG connectivity

The PLI values were positively skewed and not normally distributed ($W = 0.89$, $p < .001$) and were log transformed to assume a normal distribution ($W = 0.99$, $p = .887$). There was a significant Group x Frequency interaction, $F(1,67) = 9.04$, $p = .003$, *ges* = 0.04. Between-group t-tests showed that older adults had significantly weaker global PLI

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connectivity than young adults in the upper alpha frequency band, $t(63.76) = 3.81$, *adjusted* $p = .001$, *Cohen's D* = 0.93, whereas the group difference for PLI in the IAPF frequencies was negligible, $t(59.19) = 0.32$, *adjusted* $p = .75$, *Cohen's D* = 0.08 (**Figure 6**).

- *Insert figure 6 here*

The raw WPLI values were positively skewed ($W = 0.93$, $p < .001$) and were log transformed to satisfy the normality assumptions of ANOVA ($W = 0.98$, $p = .414$). There was a significant Group x Frequency interaction on WPLI, $F(1,67) = 8.17$, $p = .006$, *ges* = 0.04. Older adults had weaker WPLI connectivity than young adults in the upper alpha band, $t(61.83) = 4.58$, *adjusted* $p < .001$, *Cohen's D* = 1.12. At the IAPF frequencies, WPLI was equivalent across groups, $t(52.53) = 0.89$, $p = .374$, *Cohen's D* = 0.22 (**Figure 7**).

-*Insert figure 7 here*

Discussion

In the present study we sought to evaluate the effect of age-related dominant EEG frequency slowing on EEG power and connectivity differences between young and older adults. We replicated the well-documented finding of a slower IAPF in older adults, detecting an average slowing of 1.26 Hz. Across all participants, there was a strong positive correlation between the IAPF and the peak PLI and WPLI frequencies

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suggesting that global connectivity strength was generally highest at or around the IAPF. For each connectivity metric, there was no statistical difference between the mean IAPF and peak connectivity frequencies. This and the replication of slowed IAPF in older adults highlights the key disparity between young and older adults in the context of conventional frequency bands. For example, the majority of the strongest connectivity frequencies for young adults were in the 10-12 Hz (conventional upper alpha) range, whereas age-related IAPF slowing allocated the strongest connectivity frequencies for older adults to the 8-10 Hz (conventional lower alpha) range. Testing for group differences in the conventional upper alpha band therefore leads to ambiguous age effects that may lead to spurious interpretations concerning the underlying brain properties of older adults.

As expected, upper alpha frequency power was significantly reduced in older adults compared to young adults. In contrast, IAPF power was preserved, suggesting that alpha power differences in aging are due to IAPF slowing with advancing age. Consistent with this finding, we demonstrated that older adults had significantly weakened global PLI and WPLI connectivity in the conventional upper alpha band, as has been demonstrated in previous studies (Gaál et al., 2010; Kikuchi et al., 2000; Vecchio et al., 2014). There was no modulation of connectivity by age in the IAPF frequencies, demonstrating that age-related IAPF slowing not only impacts spectral power, but also estimates of brain connectivity. Aging studies should therefore consider individualizing frequency bands to avoid misinterpretations of power and connectivity differences that might be due to age-related changes in the frequency spectrum. Furthermore, there was considerable

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intra-group variability of IAPF, suggesting that individualized frequency analysis should be implemented regardless of the age group of interest.

Our analysis of global connectivity at the IAPF revealed no effects of age. It is therefore unlikely that these IAPF parameters reflect the underlying microstructural relationships of the older brain, which encompasses degeneration of both gray and white matter (Allen, Bruss, Brown, & Damasio, 2005; Lebel, Caverhill-Godkewitsch, & Beaulieu, 2010; Westlye et al., 2010; Yeatman, Wandell, & Mezer, 2014), and compromised functional connectivity within the default mode network (Ferreira & Busatto, 2013). However, it is yet unknown if local IAPF connectivity is affected by age, rather than global connectivity as studied here. Eyes-closed IAPF oscillations, which dominate the EEG frequency spectrum, are heavily localized to occipital areas (Bazanova & Vernon, 2014; Michel, Lehmann, Henggeler, & Brandeis, 1992) and therefore may not be appropriate for the examination of whole-brain functional connectivity. Indeed, functional magnetic resonance imaging (fMRI) studies have shown that IAPF power is associated with reduced blood-oxygen-level dependent (BOLD) signal power in the visual cortex and other cortical areas, and increased BOLD activity in subcortical regions such as the thalamus (Goldman, Stern, Engel, & Cohen, 2002; Laufs et al., 2003; Liu et al., 2012; Scheeringa, Petersson, Kleinschmidt, Jensen, & Bastiaansen, 2012; Tagliazucchi, von Wegner, Morzelewski, Brodbeck, & Laufs, 2012). Additionally, periods of increased alpha oscillatory power have been linked to lapses in attention and sensory suppression (Craddock, Poliakoff, El-deredy, Klepousniotou, & Lloyd, 2017; Jensen & Mazaheri, 2010; Klimesch, Sauseng, & Hanslmayr, 2007), suggesting that alpha activity at rest has a highly inhibitory function. For these reasons, task-related EEG and eyes-open resting

state recordings may be more useful when attempting to make inferences about underlying brain connectivity that relates to oscillations in the IAPF domain, instead of focusing on electrophysiological signals that are generated by subcortical structures. Alternatively, eyes-closed resting state EEG during periods of attenuated IAPF power may be more informative of cortical activity (Kanda, Oliveira, & Fraga, 2017).

In our study, older and younger adults had equivalent global power at the IAPF, leading to the conclusion that despite the slowing of IAPF oscillations, the output of the dominant alpha generator was uncompromised. Age-related structural changes to the thalamus have been noted using magnetic resonance imaging (Cherubini, Péran, Caltagirone, Sabatini, & Spalletta, 2009), and may therefore be expressed in the EEG by dominant frequency slowing, rather than by attenuation of activity. Further multimodal imaging work is necessary to tease apart these relationships.

In the present study, we demonstrated that power and connectivity differences between younger and older adults in the alpha range are biased against older adults when adopting fixed spectral boundaries for frequency analysis. Our study was well powered to account for inter-individual variability of IAPF values in both the younger and older adult group. Unlike the majority of previous studies on resting state EEG, we utilised a connectivity metric that is insensitive to the effects of volume conduction, which traditional measures such as coherence are vulnerable to (Stam, Nolte, & Daffertshofer, 2007; Vinck et al., 2011). We supported the finding of slowed IAPF in older adults, in line with previous literature (Aurlien et al., 2004; Bazanova, 2008; Chiang et al., 2011; Dustman et al., 1993). We went on to show that the global EEG power and connectivity

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of young and older adults dissociate at the conventional upper alpha band, but not when the frequency of interest was adapted to the IAPF.

Our findings have important implications for the interpretation of resting state EEG studies on aging and age-associated neuropathology such as the dementias. Countless spectral analyses of individuals with Alzheimer's disease and its prodromal stages have described neuropathological changes to alpha band connectivity and power (Babiloni et al., 2006; Jelic et al., 2000; Jeong, 2004; Kwak, 2006; Locatelli, Cursi, Liberati, Franceschi, & Comi, 1998) without considering the slowing of the IAPF, which has been shown to slow even further in neuropathological states (Jelic et al., 2000; Jeong, 2004; Kwak, 2006; Penttilä, Partanen, Soininen, & Riekkinen, 1985). Adapting resting state analysis to the IAPF should compensate for the bias accrued by using conventional frequency bands across groups that may vary in terms of the IAPF. Future analysis of resting state EEG parameters should consider the presence of the IAPF and its underlying neurophysiology (i.e. subcortical generation) when making inferences about cortico-cortical connectivity. Correct classification and interpretation of the electrophysiological features expressed by healthy older adults are critical when making inferences about age-related disease and neuropathology, to determine how sensitive and specific the effects are to the disease of interest.

Figure Captions

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slowing in healthy aging

Figure 1. Power spectral density of EEG from electrode OZ plotted as a function of frequency (1-30 Hz) for one young adult and one older adult participant. The IAPF values are the frequencies of maximum power between 7-14 Hz. The shaded area outlines the conventional upper alpha frequency limits (see e.g. Fink, Grabner, Neuper, & Neubauer, 2005; Klimesch, Schack, & Sauseng, 2005; Krause, Pörn, Lang, & Laine, 1997).

Figure 2. Violin plots illustrating the distributions of IAPF values in young (dark gray region) and older adults (light gray region). White dots represent participant data points. Older adults show a significant slowing of IAPF values compared to younger adults. *** $p < .001$.

Figure 3. Positive correlations are shown between IAPF and peak PLI frequencies in both younger (dark gray dots/line) and older adults (light gray triangles/line).

Figure 4. Positive correlations are shown between IAPF and peak WPLI frequencies in both younger (dark gray dots/line) and older adults (light gray triangles/line).

Figure 5. Distribution of EEG spectral power in young (dark grey) and older (light grey) adults at the IAPF (right) and upper alpha (left) frequency range. White dots represent participant data points. Young adults had significantly higher upper alpha power than older adults. *** $p < .001$, n.s. not significant.

Figure 6. Distribution of global PLI values (log normalised) in young and older adults at the IAPF and at the upper alpha frequency range. White dots represent participant data points. Older adults had significantly weaker global PLI connectivity in upper alpha

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frequencies (but not IAPF) when compared to younger adults. *** $p < .001$, n.s. not significant.

Figure 7. Distribution of global WPLI values (log normalised) in young and older adults at the IAPF and at the upper alpha frequency range. White dots represent participant data points. Global WPLI connectivity in the upper alpha range was weaker for older adults than younger adults, whereas there was no effect of age on WPLI at the IAPF. *** $p < .001$, n.s. not significant.

References

Allen, J. S., Bruss, J., Brown, C. K., & Damasio, H. (2005). Normal neuroanatomical variation due to age: The major lobes and a parcellation of the temporal region. *Neurobiology of Aging*, *26*(9), 1245–1260. http://doi.org/10.1016/j.neurobiolaging.2005.05.023

Angelakis, E., Lubar, J. F., & Stathopoulou, S. (2004). Electroencephalographic peak alpha frequency correlates of cognitive traits. *Neuroscience Letters*, *371*(1), 60–63. http://doi.org/10.1016/j.neulet.2004.08.041

Aurlien, H., Gjerde, I. O., Aarseth, J. H., Eldøen, G., Karlsen, B., Skeidsvoll, H., & Gilhus, N. E. (2004). EEG background activity described by a large computerized database.

Clinical Neurophysiology, *115*(3), 665–673. http://doi.org/10.1016/j.clinph.2003.10.019

Babiloni, C., Binetti, G., Cassarino, A., Dal Forno, G., Del Percio, C., Ferreri, F., … Rossini, P. M. (2006). Sources of cortical rhythms in adults during physiological aging: A multicentric EEG study. *Human Brain Mapping*, *27*(2), 162–172. http://doi.org/10.1002/hbm.20175

Bakeman, R. (2005). Recommended effect size statistics for repeated measures designs. *Behavior Research Methods*, *37*(3), 379–384. http://doi.org/10.3758/BF03192707

Barry, R. J., & De Blasio, F. M. (2017). EEG differences between eyes-closed and eyes-open resting remain in healthy ageing. *Biological Psychology*, *129*, 293–304. http://doi.org/10.1016/j.biopsycho.2017.09.010

Bazanova, O. M. (2008). Age Related Alpha Activity Change Differs for Males and Females and for Low and High Al- pha Frequency EEG Pattern. *Revista Espanola de Neurop- Sicologia*, *10*(1), 82–83.

Bazanova, O. M., & Vernon, D. (2014). Interpreting EEG alpha activity. *Neuroscience and Biobehavioral Reviews*, *44*, 94–110. http://doi.org/10.1016/j.neubiorev.2013.05.007

Bowyer, S. M. (2016). Coherence a measure of the brain networks: past and present. *Neuropsychiatric Electrophysiology*, *2*(1), 1. http://doi.org/10.1186/s40810-015-0015-7

ACCEPTED MANUSCRIPT

Cherubini, A., Péran, P., Caltagirone, C., Sabatini, U., & Spalletta, G. (2009). Aging of subcortical nuclei: Microstructural, mineralization and atrophy modifications measured in vivo using MRI. *NeuroImage*, *48*(1), 29–36. http://doi.org/10.1016/j.neuroimage.2009.06.035

Chiang, A. K. I., Rennie, C. J., Robinson, P. A., van Albada, S. J., & Kerr, C. C. (2011). Age trends and sex differences of alpha rhythms including split alpha peaks. *Clinical Neurophysiology*, *122*(8), 1505–1517. http://doi.org/10.1016/j.clinph.2011.01.040

Craddock, M., Poliakoff, E., El-deredy, W., Klepousniotou, E., & Lloyd, D. M. (2017). Pre-stimulus alpha oscillations over somatosensory cortex predict tactile misperceptions. *Neuropsychologia*, *96*, 9–18. http://doi.org/10.1016/j.neuropsychologia.2016.12.030

Delorme, A., & Makeig, S. (2004). EEGLAB: An open source toolbox for analysis of single-trial EEG dynamics including independent component analysis. *Journal of Neuroscience Methods*, *134*(1), 9–21. http://doi.org/10.1016/j.jneumeth.2003.10.009

Duffy, F. H., Albert, M. S., McAnulty, G., & Garvey, A. J. (1984). Age-related differences in brain electrical activity of healthy subjects. *Annals of Neurology*, *16*(4), 430–438. http://doi.org/10.1002/ana.410160403

Duffy, F. H., Mcanulty, G. B., & Albert, M. S. (1996). Effects of age upon interhemispheric EEG coherence in normal adults. *Neurobiology of Aging*, *17*(4), 587–599. http://doi.org/10.1016/S0197-4580(96)00007-3

Dustman, R. E., Shearer, D. E., & Emmerson, R. Y. (1993). EEG and event-related potentials in normal aging. *Progress in Neurobiology*. http://doi.org/10.1016/0301-0082(93)90005-D

Ferreira, L. K., & Busatto, G. F. (2013). Resting-state functional connectivity in normal brain aging. *Neuroscience and Biobehavioral Reviews*, *37*(3), 384–400. http://doi.org/10.1016/j.neubiorev.2013.01.017

Fink, A., Grabner, R. H., Neuper, C., & Neubauer, A. C. (2005). EEG alpha band dissociation with increasing task demands. *Cognitive Brain Research*, *24*(2), 252–259. http://doi.org/10.1016/j.cogbrainres.2005.02.002

French, C. C., & Beaumont, J. G. (1984). A critical review of EEG coherence studies of hemisphere function. *International Journal of Psychophysiology*, *1*(3), 241–254. http://doi.org/10.1016/0167-8760(84)90044-8

Gaál, Z. A., Boha, R., Stam, C. J., & Molnár, M. (2010). Age-dependent features of EEG-reactivity-Spectral, complexity, and network characteristics. *Neuroscience Letters*, *479*(1), 79–84. http://doi.org/10.1016/j.neulet.2010.05.037

Goldman, R. I., Stern, J. M., Engel, J., & Cohen, M. S. (2002). Simultaneous EEG and fMRI of the alpha rhythm. *NeuroReport*, *13*(18), 2487–2492. http://doi.org/10.1097/00001756-200212200-00022

Grandy, T. H., Werkle-Bergner, M., Chicherio, C., Schmiedek, F., Lövdén, M., & Lindenberger, U. (2013). Peak individual alpha frequency qualifies as a stable

ACCEPTED MANUSCRIPT

neurophysiological trait marker in healthy younger and older adults. *Psychophysiology*, *50*(6), 570–582. http://doi.org/10.1111/psyp.12043

Jelic, V., Johansson, S. E., Almkvist, O., Shigeta, M., Julin, P., Nordberg, A., … Wahlund, L. O. (2000). Quantitative electroencephalography in mild cognitive impairment: Longitudinal changes and possible prediction of Alzheimer's disease. *Neurobiology of Aging*, *21*(4), 533–540. http://doi.org/10.1016/S0197-4580(00)00153-6

Jensen, O., & Mazaheri, A. (2010). Shaping Functional Architecture by Oscillatory Alpha Activity: Gating by Inhibition. *Frontiers in Human Neuroscience*, *4*. http://doi.org/10.3389/fnhum.2010.00186

Jeong, J. (2004). EEG dynamics in patients with Alzheimer's disease. *Clinical Neurophysiology*. http://doi.org/10.1016/j.clinph.2004.01.001

Kanda, P. A. M., Oliveira, E. F., & Fraga, F. J. (2017). EEG epochs with less alpha rhythm improve discrimination of mild Alzheimer's. *Computer Methods and Programs in Biomedicine*, *138*, 13–22. http://doi.org/10.1016/j.cmpb.2016.09.023

Kikuchi, M., Wada, Y., Koshino, Y., Nanbu, Y., & Hashimoto, T. (2000). Effect of Normal Aging upon Interhemispheric EEG Coherence: Analysis during Rest and Photic Stimulation. *Clinical EEG and Neuroscience*, *31*(4), 170–174. http://doi.org/10.1177/155005940003100404

Klimesch, W. (1999). EEG alpha and theta oscillations reflect cognitive and memory performance: A review and analysis. *Brain Research Reviews*.

ACCEPTED MANUSCRIPT

http://doi.org/10.1016/S0165-0173(98)00056-3

Klimesch, W., Sauseng, P., & Hanslmayr, S. (2007). EEG alpha oscillations: The inhibition-timing hypothesis. *Brain Research Reviews*. http://doi.org/10.1016/j.brainresrev.2006.06.003

Klimesch, W., Schack, B., & Sauseng, P. (2005). The functional significance of theta and upper alpha oscillations. *Experimental Psychology*, *52*(2), 99–108. http://doi.org/10.1027/1618-3169.52.2.99

Koeda, T., Knyazeva, M., Njiokiktjien, C., Jonkman, E. J., De Sonneville, L., & Vildavsky, V. (1995). The EEG in acallosal children. Coherence values in the resting state: left hemisphere compensatory mechanism? *Electroencephalography and Clinical Neurophysiology*, *95*(6), 397–407. http://doi.org/10.1016/0013-4694(95)00171-9

Krause, C. M., Pörn, B., Lang, A. H., & Laine, M. (1997). Relative alpha desynchronization and synchronization during speech perception. *Cognitive Brain Research*, *5*(4), 295–299. http://doi.org/10.1016/S0926-6410(97)00009-8

Kwak, Y. T. (2006). Quantitative EEG findings in different stages of Alzheimer's disease. *Journal of Clinical Neurophysiology*, *23*(5), 457–462. http://doi.org/10.1097/01.wnp.0000223453.47663.63

Laufs, H., Kleinschmidt, A., Beyerle, A., Eger, E., Salek-Haddadi, A., Preibisch, C., & Krakow, K. (2003). EEG-correlated fMRI of human alpha activity. *NeuroImage*, *19*(4), 1463–1476. http://doi.org/10.1016/S1053-8119(03)00286-6

ACCEPTED MANUSCRIPT

Lebel, C., Caverhill-Godkewitsch, S., & Beaulieu, C. (2010). Age-related regional variations of the corpus callosum identified by diffusion tensor tractography. *NeuroImage*, *52*(1), 20–31. http://doi.org/10.1016/j.neuroimage.2010.03.072

Liu, Z., de Zwart, J. A., Yao, B., van Gelderen, P., Kuo, L. W., & Duyn, J. H. (2012). Finding thalamic BOLD correlates to posterior alpha EEG. *NeuroImage*, *63*(3), 1060–1069. http://doi.org/10.1016/j.neuroimage.2012.08.025

Locatelli, T., Cursi, M., Liberati, D., Franceschi, M., & Comi, G. (1998). EEG coherence in Alzheimer's disease. *Electroencephalography and Clinical Neurophysiology*, *106*(3), 229–237. http://doi.org/10.1016/S0013-4694(97)00129-6

Michel, C. M., Lehmann, D., Henggeler, B., & Brandeis, D. (1992). Localization of the sources of EEG delta, theta, alpha and beta frequency bands using the FFT dipole approximation. *Electroencephalography and Clinical Neurophysiology*, *82*(1), 38–44. http://doi.org/10.1016/0013-4694(92)90180-P

Miraglia, F., Vecchio, F., Bramanti, P., & Rossini, P. M. (2016). EEG characteristics in "eyes-open" versus "eyes-closed" conditions: Small-world network architecture in healthy aging and age-related brain degeneration. *Clinical Neurophysiology*, *127*(2), 1261–1268. http://doi.org/10.1016/j.clinph.2015.07.040

Montplaisir, J., Nielsen, T., Côté, J., Boivin, D., Rouleau, I., & Lapierre, G. (1990). Interhemispheric EEG Coherence before and after Partial Callosotomy. *Clinical EEG and Neuroscience*, *21*(1), 42–47. http://doi.org/10.1177/155005949002100114

ACCEPTED MANUSCRIPT

Nagase, Y., Terasaki, O., Okubo, Y., Matsuura, M., & Toru, M. (1994). Lower Interhemispheric Coherence in a Case of Agenesis of the Corpus Callosum. *Clinical EEG and Neuroscience*, *25*(1), 36–39. http://doi.org/10.1177/155005949402500110

Nielsen, T., Montplaisir, J., & Lassonde, M. (1993). Decreased interhemispheric EEG coherence during sleep in agenesis of the corpus callosum. *European Neurology*, *33*(2), 173–176. http://doi.org/10.1159/000116928

Nolte, G., Bai, O., Wheaton, L., Mari, Z., Vorbach, S., & Hallett, M. (2004). Identifying true brain interaction from EEG data using the imaginary part of coherency. *Clinical Neurophysiology*, *115*(10), 2292–2307. http://doi.org/10.1016/j.clinph.2004.04.029

Olejnik, S., & Algina, J. (2003). Generalized Eta and Omega Squared Statistics: Measures of Effect Size for Some Common Research Designs. *Psychological Methods*, *8*(4), 434–447. http://doi.org/10.1037/1082-989X.8.4.434

Oostenveld, R., Fries, P., Maris, E., & Schoffelen, J. M. (2011). FieldTrip: Open source software for advanced analysis of MEG, EEG, and invasive electrophysiological data. *Computational Intelligence and Neuroscience*, *2011*. http://doi.org/10.1155/2011/156869

Ozer, S., Noonan, K., Burke, M., Young, J., Barber, S., Forster, A., & Jones, R. (2016). The validity of the Memory Alteration Test and the Test Your Memory test for community-based identification of amnestic mild cognitive impairment. *Alzheimer's*

and Dementia, *12*(9), 987–995. http://doi.org/10.1016/j.jalz.2016.03.014

Penttilä, M., Partanen, J. V., Soininen, H., & Riekkinen, P. J. (1985). Quantitative analysis of occipital EEG in different stages of Alzheimer's disease. *Electroencephalography and Clinical Neurophysiology*, *60*(1), 1–6. http://doi.org/10.1016/0013-4694(85)90942-3

Pogarell, O., Teipel, S. J., Juckel, G., Gootjes, L., Moller, T., Burger, K., … Hampel, H. (2005). EEG coherence reflects regional corpus callosum area in Alzheimer's disease. *Journal of Neurology, Neurosurgery, and Psychiatry*, *76*(1), 109–111. http://doi.org/10.1136/jnnp.2004.036566

Posthuma, D., Neale, M. C., Boomsma, D. I., & De Geus, E. J. C. (2001). Are smarter brains running faster? Heritability of alpha peak frequency, IQ, and their interrelation. *Behavior Genetics*, *31*(6), 567–579. http://doi.org/10.1023/A:1013345411774

Rami, L., Molinuevo, J. L., Sanchez-Valle, R., Bosch, B., & Villar, A. (2007). Screening for amnestic mild cognitive impairment and early Alzheimer's disease with M?? (Memory Alteration Test) in the primary care population. *International Journal of Geriatric Psychiatry*, *22*(4), 294–304. http://doi.org/10.1002/gps.1672

Rubinov, M., & Sporns, O. (2010). Complex network measures of brain connectivity: Uses and interpretations. *NeuroImage*, *52*(3), 1059–1069. http://doi.org/10.1016/j.neuroimage.2009.10.003

Scheeringa, R., Petersson, K. M., Kleinschmidt, A., Jensen, O., & Bastiaansen, M. C. M.

ACCEPTED MANUSCRIPT

(2012). EEG Alpha Power Modulation of fMRI Resting-State Connectivity. *Brain Connectivity*, *2*(5), 254–264. http://doi.org/10.1089/brain.2012.0088

Smit, C. M., Wright, M. J., Hansell, N. K., Geffen, G. M., & Martin, N. G. (2006). Genetic variation of individual alpha frequency (IAF) and alpha power in a large adolescent twin sample. *International Journal of Psychophysiology*, *61*(2), 235–243. http://doi.org/10.1016/j.ijpsycho.2005.10.004

Smit, D. J. A., de Geus, E. J. C., Boersma, M., Boomsma, D. I., & Stam, C. J. (2016). Life-Span Development of Brain Network Integration Assessed with Phase Lag Index Connectivity and Minimum Spanning Tree Graphs. *Brain Connectivity*, *6*(4), 312–325. http://doi.org/10.1089/brain.2015.0359

Stam, C. J., Nolte, G., & Daffertshofer, A. (2007). Phase lag index: Assessment of functional connectivity from multi channel EEG and MEG with diminished bias from common sources. *Human Brain Mapping*, *28*(11), 1178–1193. http://doi.org/10.1002/hbm.20346

Tagliazucchi, E., von Wegner, F., Morzelewski, A., Brodbeck, V., & Laufs, H. (2012). Dynamic BOLD functional connectivity in humans and its electrophysiological correlates. *Frontiers in Human Neuroscience*, *6*. http://doi.org/10.3389/fnhum.2012.00339

Teipel, S. J., Pogarell, O., Meindl, T., Dietrich, O., Sydykova, D., Hunklinger, U., … Hampel, H. (2009). Regional networks underlying interhemispheric connectivity: An EEG and DTI study in healthy ageing and amnestic mild cognitive impairment. *Human*

Brain Mapping, *30*(7), 2098–2119. http://doi.org/10.1002/hbm.20652

Vecchio, F., Miraglia, F., Bramanti, P., & Rossini, P. M. (2014). Human brain networks in physiological aging: A graph theoretical analysis of cortical connectivity from EEG data. *Journal of Alzheimer's Disease*, *41*(4), 1239–1249. http://doi.org/10.3233/JAD-140090

Vecchio, F., Miraglia, F., Curcio, G., Altavilla, R., Scrascia, F., Giambattistelli, F., … Rossini, P. M. (2015). Cortical brain connectivity evaluated by graph theory in dementia: a correlation study between functional and structural data. *J Alzheimers Dis*, *45*(3), 745–756. http://doi.org/10.3233/jad-142484

Vinck, M., Oostenveld, R., Van Wingerden, M., Battaglia, F., & Pennartz, C. M. A. (2011). An improved index of phase-synchronization for electrophysiological data in the presence of volume-conduction, noise and sample-size bias. *NeuroImage*, *55*(4), 1548–1565. http://doi.org/10.1016/j.neuroimage.2011.01.055

Vysata, O., Kukal, J., Prochazka, A., Pazdera, L., Simko, J., & Valis, M. (2014). Age-related changes in EEG coherence. *Neurologia i Neurochirurgia Polska*, *48*(1), 35–38. http://doi.org/10.1016/j.pjnns.2013.09.001

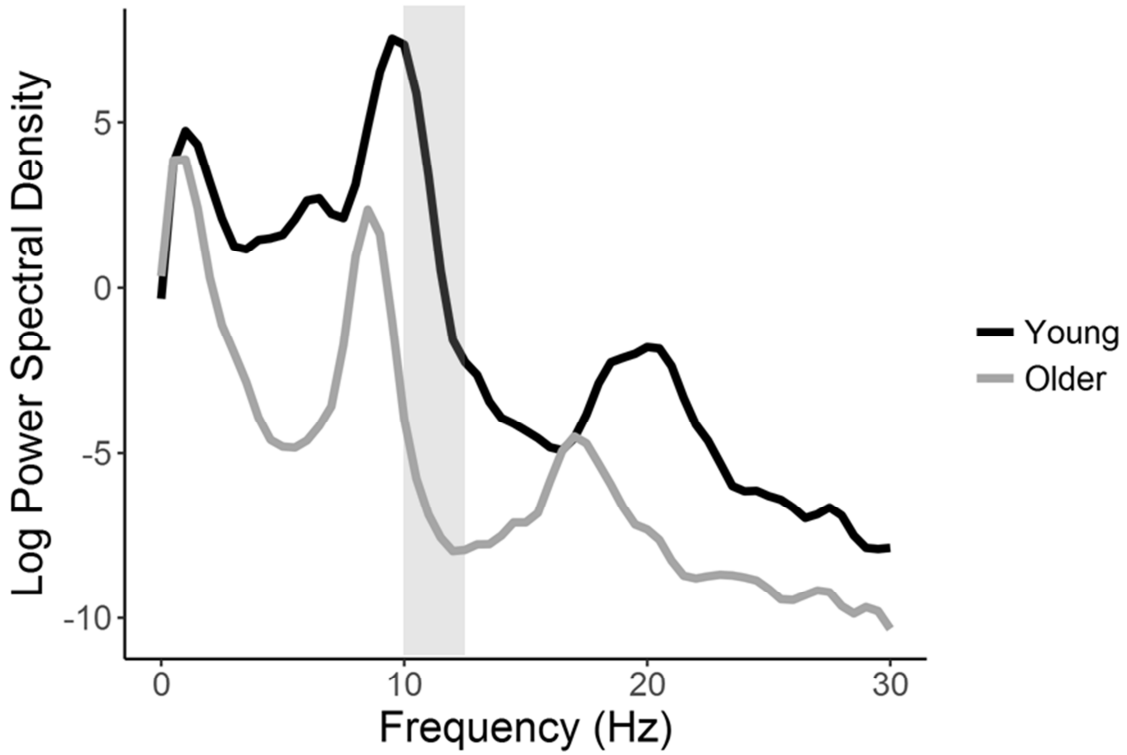
Westlye, L. T., Walhovd, K. B., Dale, A. M., Bjørnerud, A., Due-Tønnessen, P., Engvig, A., … Fjell, A. M. (2010). Life-span changes of the human brain white matter: Diffusion tensor imaging (DTI) and volumetry. *Cerebral Cortex*, *20*(9), 2055–2068. http://doi.org/10.1093/cercor/bhp280

ACCEPTED MANUSCRIPT

Yeatman, J. D., Wandell, B. A., & Mezer, A. A. (2014). Lifespan maturation and degeneration of human brain white matter. *Nature Communications*, *5*, 4932. http://doi.org/10.1038/ncomms5932

Zigmond, A. S., & Snaith, R. P. (1983). The Hospital Anxiety and Depression Scale. *Acta Psychiatrica Scandinavica*, *67*(6), 361–370. http://doi.org/10.1111/j.1600-0447.1983.tb09716.x

ACCEPTED MANUSCRIPT



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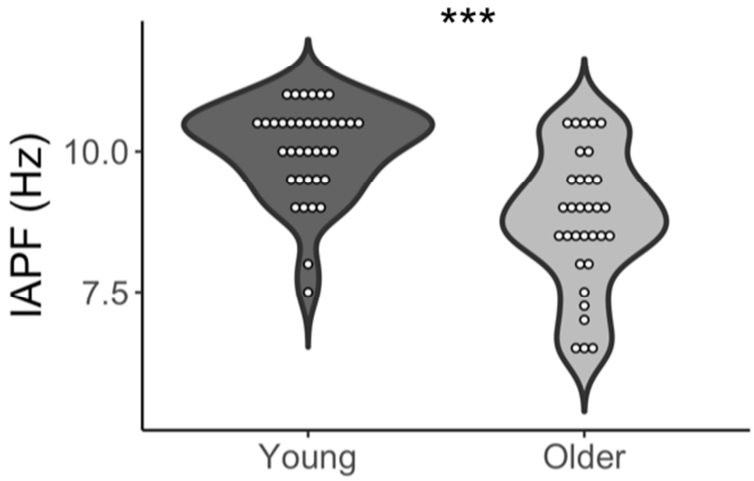

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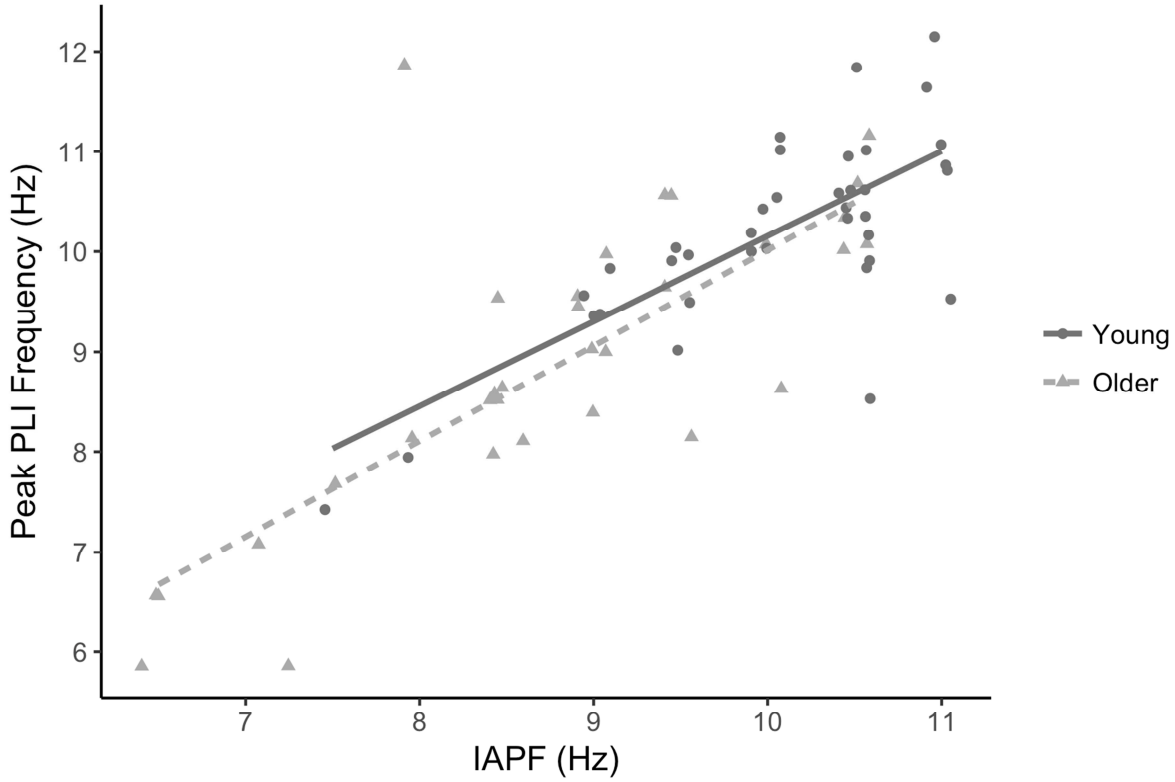

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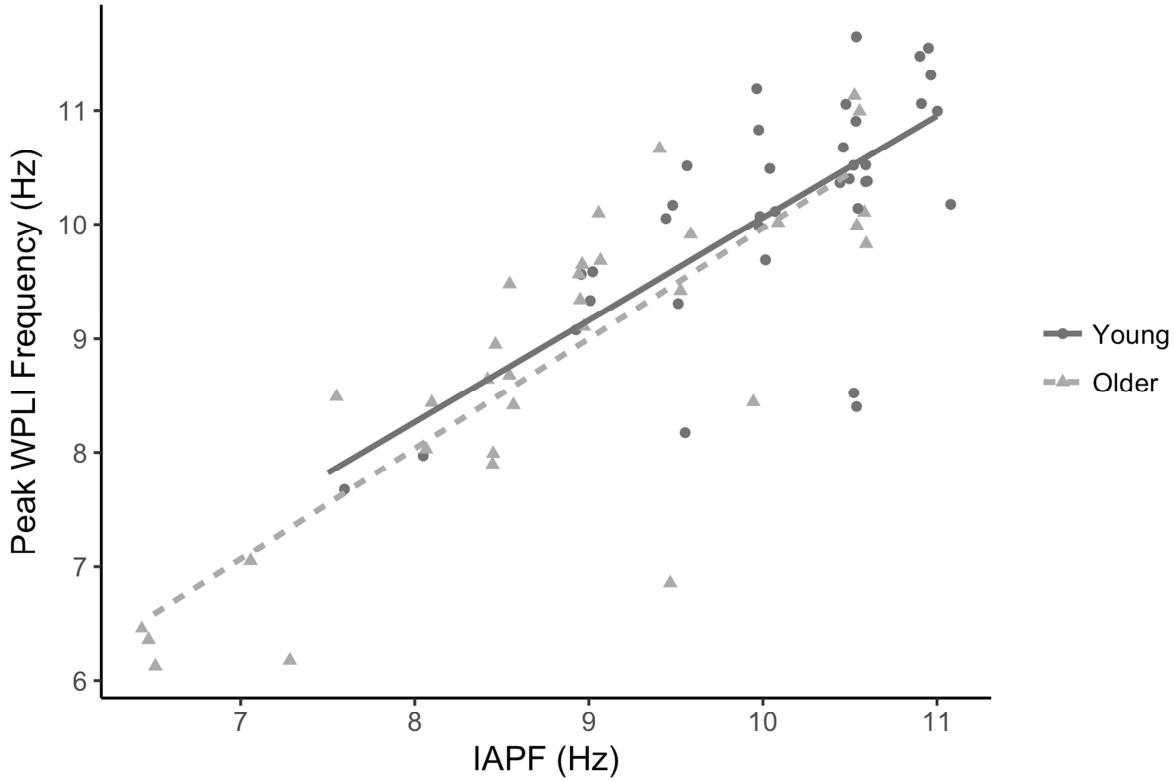

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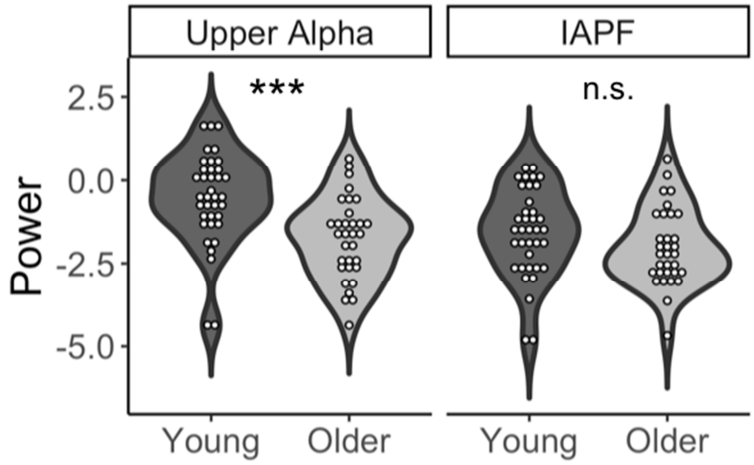

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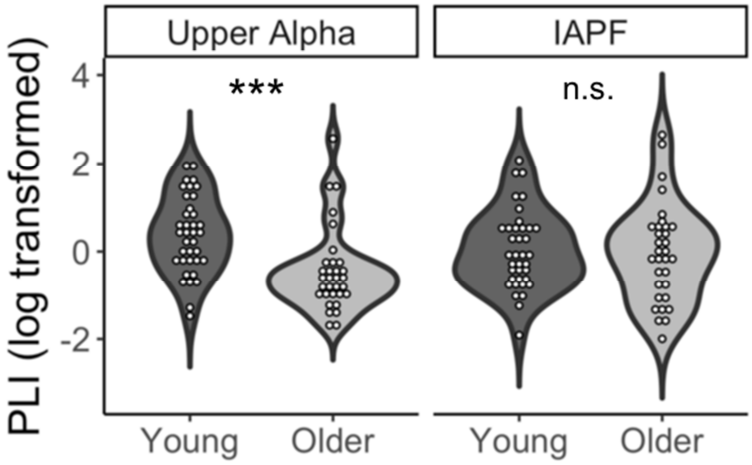

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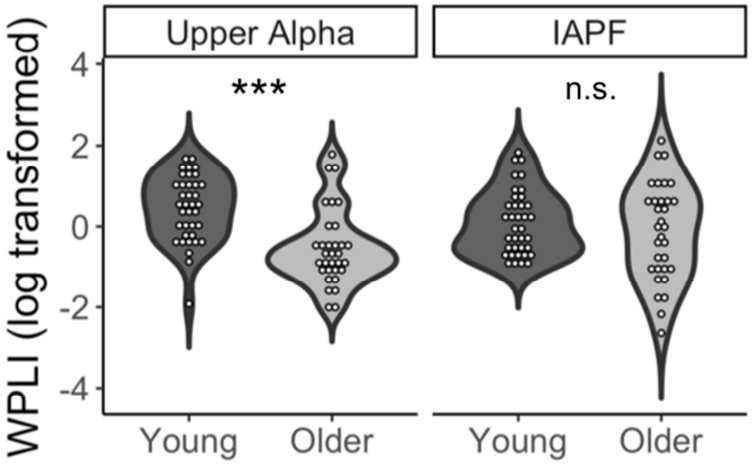

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- Older adults have slower individual alpha peak frequencies (IAPF) than younger adults
- Global connectivity is strongest at the IAPF
- Power and connectivity in the conventional upper-alpha (10-12 Hz) frequency band is reduced in older adults
- Power and connectivity at the IAPF are not affected by age
- Studies of alpha EEG power and connectivity that use fixed, conventional frequency bands are biased against older adults.

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This manuscript has not been published and is not under consideration for publication elsewhere, nor will it be submitted elsewhere while under the consideration of *Neurobiology of Aging.*

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