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Age-related changes in EEG coherence

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ABSTRACT

Background and purpose: Coherence changes can reflect the pathophysiological processes involved in human ageing. We conducted a retrospective population study that sought to analyze the age-related changes in EEG coherence in a group of 17,722 healthy professional drivers.

Materials and methods: The EEGs were obtained using a standard 10–20 electrode configuration on the scalp. The recordings from 19 scalp electrodes were taken while the participants' eyes were closed. The linear correlations between the age and coherence were estimated by linear regression analysis.

Results: Our results showed a significant decrease in coherence with age in the theta and alpha bands, and there was an increasing coherence with the beta bands. The most prominent changes occurred in the alpha bands. The delta bands contained movement artefacts, which most likely do not change with age.

Conclusions: The age-related EEG desynchrony can be partly explained by the age-related reduction of cortical connectivity. Higher frequencies of oscillations require less cortical area of high coherence. These findings explain why the lowest average coherence values were observed in the beta and sigma bands, as well as why the beta bands show borderline statistical significance and the sigma bands show non-significance. The age-dependent decrease in coherence may influence the estimation of age-related changes in EEG energy due to phase cancellation.

1. Introduction

Ageing can be defined as 'a progressive and generalized impairment of function, resulting in an increased vulnerability to environmental challenges and a growing risk of diseases and death'. Ageing is likely a multifactorial process that is caused by accumulated damage to a variety of cellular components. Ageing is a major risk factor for neurodegenerative diseases such as Alzheimer disease. Two processes that have been implicated in the ageing process are free radical-induced oxidative damage and mitochondrial dysfunction.

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Advancing age in mammals is correlated with increased levels of mitochondrial DNA mutations and deteriorating respiratory chain function. Respiratory chain-deficient cells are prone to apoptosis; therefore, this increased cell loss is likely an important consequence of age-associated mitochondrial dysfunction [1,2]. Furthermore, apoptosis in the human brain decreases the vast amount of large neurons and leads to an increased number of relatively smaller neurons and glia [3]. As the brain atrophies, there are fewer neurons left to produce electrical potentials and form neural connections. A common approach for interpreting and spatially analysing these apoptotic brain changes is to assume that the cerebral cortex is composed of a mosaic of quasi-autonomous areas. Each area transmits a signal to one or more areas in a network, and its signal may appear in the scalp electroencephalogram (EEG), where it overlaps with other signals both spatially and temporally by volume conduction. The spatial statistics of scalp EEG are usually presented as coherence estimates in individual frequency bands. In EEG, one source of signal dependency is from the propagation of signal alongside the neural pathways. The second source of dependence is the volume conduction of electrical potential and the potential summation from distant sources. The third source is the activity of the reference electrode, which is never silent. The scalp EEG is spatially low-pass filtered by the poorly conducting skull, introducing an artificial correlation between the electrodes [4]. Coherence indicates similarity between two signals on certain frequencies.

The distributed brain activation patterns of young and old adults can differ in their responses to similar task demands. Compared to younger adults, the HAROLD (Hemispheric Asymmetry Reduction in Older Adults) model shows that older adults have a reduction in asymmetrical activation of the frontal cortex during verbal recall [5]. Coherence between two EEG signals, which is the squared cross-correlation in the frequency domain between two EEG time series measured simultaneously at different scalp locations [6], has been interpreted as a measure of the degree of synchronization between the brain signals of certain brain regions. Research suggests that patterns of high coherence between EEG signals recorded at different scalp sites have functional significance and can be correlated with different kinds of cognitive information processing, such as memory, language, concept retrieval and music processing [7,8]. In relation to memory processes, studies in healthy humans have generally reported increases in synchronization between coordinating brain regions that are responsible for performing their respective functions [9,10]. In normal adults, the interhemispheric coherence at rest decreases with advancing age [11,12].

The aim of this work is to test the null hypothesis that the coherence in the delta, theta, alpha and beta bands does not change during ageing.

2. Methods

2.1. Subjects

In this retrospective population study, EEG data were obtained during the examinations of 31,009 healthy truck drivers from the 32 Alien EEG machines. Each of the subjects underwent a neurological and neuropsychological examination. Subjects with potential brain damage ($n = 897$), mainly due to alcoholism, drug abuse, abnormal neurological function or abnormal neuropsychological function, were excluded. Another 12,390 EEG recordings were excluded because their EEG data contained high noise levels, which could not be filtered or corrected. The remaining 17,722 subjects who were included consisted of 17,540 males and 182 females with a mean age of 43.2 years (standard deviation [SD] = 11.2).

2.2. EEG measurement

All of the EEG recordings were performed according to the same standards and in similar conditions. The total recording time was approximately 20 min. The subjects were asked to lie on the bed in a comfortable manner with their eyes closed. Electrodes were placed according to the 10–20 system of electrode placement; the recording was conducted on a 21-channel digital EEG machine (Alien), with an analog-to-digital (AD) conversion of 22 bits and a sampling frequency of 128 Hz. The filter settings were 0.5–60 Hz. The results of the analyses demonstrate that linked ears and common references provide valid and systematic relations between the magnitude of coherence and the signal-to-noise ratio. Thus, linked ears montages were used in all the subjects for this study.

2.3. EEG pre-processing

The stored digitalized data (128 Hz) were zero-phase digitally filtered by a bandpass FIR filter (100 coefficients, Hamming window) at 0.5–60 Hz and a bandstop filter at 49–51 Hz. The analysis was started by automatically recognizing and removing artefacts. The automatic artefact recognizers removed approximately 91% of the artefacts based on the regularized Linear Discriminant (LD) classifier. Lastly, an off-line expert manually removed the remaining artefacts in the preprocessed data.

2.4. Coherence

EEG coherence is a large-scale measure, which reflects the dynamic functional interactions between electrode signals. The high coherence between EEG signals recorded at different electrodes indicates an increased functional interplay between the underlying neuronal networks. The magnitude squared coherence is used to measure brain synchrony [13]. This measure quantifies linear correlations as a function of frequency. The magnitude squared coherence was calculated as follows:

$$\mathrm{Co}(f,k) = \frac{P_{X_1,X_2}(f,k)^2}{P_{X_1,X_1}(f,k)P_{X_2,X_2}(f,k)}$$

The magnitude squared coherence was estimated in two-second (256 samples) EEG segments (more than 100 segments in a typical low-artefact three-minute interval for each patient). All the electrode pairs (171) were evaluated in delta (0.5–3.5 Hz), theta (4–7.5 Hz), alpha (8–12.5 Hz), beta (13–29.5 Hz) and sigma (30–60 Hz) bands.

2.5. Statistics

We investigated the relationship between age and coherence by linear regression analysis. The F statistic and its p-value were calculated. Estimates of the error variance are represented by 95% confidence intervals. The MATLAB environment was used for the coherence and statistical analysis.

3. Results

In the theta and alpha bands, we could find a clear tendency towards age-related decline in coherence magnitude (Table 1 and Figs. 1 and 2). In the beta bands, there is a coherence increase during ageing. The age-related reduction of inter-hemispheric coherence can be partly explained by the age-related EEG desynchrony that results from an age-related reduction of cortical connectivity. This decline is the steepest for the theta and alpha bands. Delta bands contain movement artefacts, which result in unchanging coherence with age. Higher frequencies of oscillations correspond to fewer cortical areas of high coherence. Thus, beta and sigma bands possess the lowest average coherence values. The beta bands show borderline significance and sigma bands show non-significance.

Table 1 – Significance of age-related coherence changes in all of the bands.

Band	Y-intercept	Slope	p-Value
Delta	0.41	−0.00015	0.09
Theta	0.36	−0.00023	0.000037
Alpha	0.37	−0.00023	0.0000023
Beta	0.30	0.000095	0.002
Sigma	0.30	−0.000055	0.16

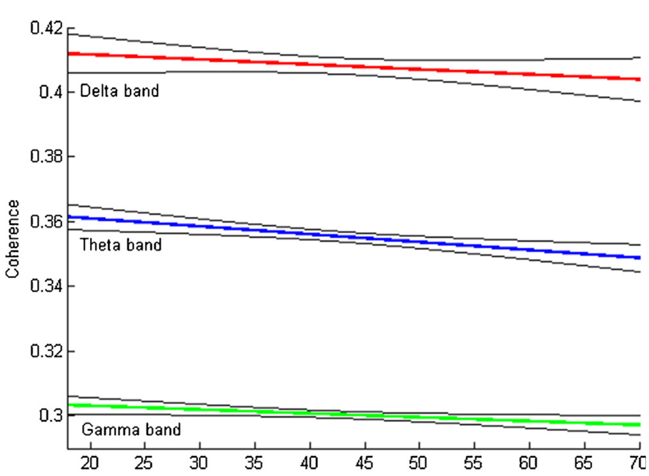

Fig. 1 – Age-related changes of coherence in delta, theta and gamma bands.

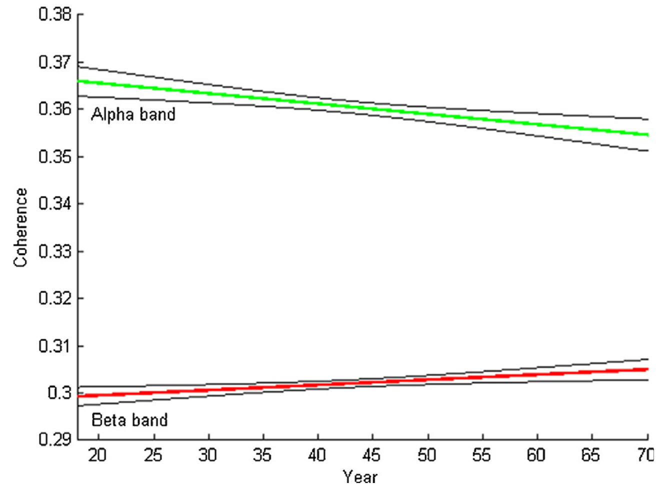

Fig. 2 – Age-related changes of coherence in alpha and beta bands.

4. Discussion

The higher beta bands' coherence in older drivers may arise from the dopamine depletion [14]. The age-related EEG desynchrony in theta and alpha bands can be explained with age-dependent deterioration of neuronal structures and the maturation and specialization of the cerebral functional systems. Delta activity is not a part of the physiological EEG activity, so no statistically significant changes were found in this band. Higher frequencies of oscillations require less cortical area of high coherence. This finding explains why the lowest average coherence values were observed in the beta and sigma bands and why the beta bands show borderline statistical significance and the gamma bands show non-significance. Despite the careful selection of low artefact segments, high frequency beta and sigma activity may be affected by muscle activity.

The absolute values of inter-electrode coherence were influenced by the effects of the reference electrode and volume conduction (erroneous high coherence). The inter-electrode coherence decreases the statistical significance of the results. The solution may involve high-pass filtering of genuine cortical signals by Laplacian or cortical imaging algorithms, but these algorithms may lead to erroneously low coherence. The average reference and Laplacian references also fail to systematically vary as a function of the signal-to-noise ratio. The reasons for the failure of the average and Laplacian references are that both methods involve mixing signals from each channel into all of the other channels; a common reference and linked ears do not add signals to other channels. The best solution would be to evaluate the electrocorticogram, but this solution is not practical in healthy people. An inherent limitation of this study is the low percentage of women in the group of truck drivers. Age-related changes may be gender-specific [15].

The age-dependent decrease in coherence may influence the estimation of age-related changes in EEG energy due to phase cancellation. The seasonal rhythm of EEG activity, which may be associated with the seasonal rhythm of melatonin excretion [16], was not taken into account.

5. Conclusions

1. The age-related EEG desynchrony can be partly explained by the age-related reduction of cortical connectivity. Higher frequencies of oscillations require less cortical area of high coherence. These findings explain why the lowest average coherence values were observed in the beta and sigma bands, as well as why the beta bands show borderline statistical significance and the sigma bands show non-significance.
2. The age-dependent decrease in coherence may influence the estimation of age-related changes in EEG energy due to phase cancellation.

Conflict of interest

None declared.

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Ethics

The work described in this article has been carried out in accordance with The Code of Ethics of the World Medical Association (Declaration of Helsinki) for experiments involving humans; Uniform Requirements for manuscripts submitted to Biomedical journals.

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