Int. J. Devl Neuroscience 29 (2011) 163–170

Contents lists available at ScienceDirect

International Journal of Developmental Neuroscience

journal homepage: www.elsevier.com/locate/ijdevneu

Individual analysis of EEG background-activity within school age: impact of age and sex within a longitudinal data set

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ARTICLE INFO

Article history:
Received 16 August 2010
Received in revised form
12 November 2010
Accepted 29 November 2010

Keywords:
EEG
Longitudinal development
Peak frequency
Individualized band power
Sex

ABSTRACT

Objectives: Quantitative EEG can monitor changes in brain function during development and may help to understand developmental disorders. However, current EEG-databases are primarily based on standardized frequency bands which disregard age-related changes in alpha peak frequency (PF) and therefore complicate the interpretation of spectral estimates in the theta and alpha range.
Methods: We used a two point longitudinal design in order to analyze intraindividual changes in 40 healthy children and adolescents with age (T_1: 6–18 years; interval approximately 4 years). Using a 64-channel eyes closed resting EEG we calculated absolute/relative power in individualized frequency bands (IFB: delta, theta, $alpha_{1/2}$ and beta) based on PF.
Results: PF increased with age, with changes being larger for children than adolescents. Controlling for changes in PF, changes in absolute/relative $alpha_{1/2}$ power and in absolute beta power were minor. Relative beta power, however, increased while absolute/relative delta and theta power decreased massively.

Sex-differences in PF did not reach significance. However, boys exhibited larger changes during adolescence than girls for all absolute power measures except alpha.
Conclusion: Normal EEG development during school-age is mainly based on an absolute decrease of slow frequency activity and increases of PF which may be interpreted in terms of a reorganization of the EEG towards a higher frequency oscillatory scale rather than a maturation of the theta–$alpha_{1/2}$ band power sequence. Age-related changes differed between boys and girls suggesting a different developmental timing for the sexes. In future studies a combined analysis of PF and IFB may help to specify deviations in developmental disorders.

1. Introduction

Development in childhood and adolescence is marked by dramatic changes in both brain structure and function (Whitford et al., 2007; Feinberg and Campbell, 2010). Electroencephalography (EEG) as a direct and non-invasive measure of brain function is particularly well suited for the repeated examination of children and adolescents. An exact description of the normal development of brain function is of utmost importance as it may provide basic information for the understanding, diagnosis and therapy of different disorders like schizophrenia, autism and ADHD, which are associated with developmental problems (Coburn et al., 2006).

The resting EEG recorded from the scalp is a complex summation of multiple waves of different frequencies. For the purpose of quantification spectral analysis can be used to estimate amplitude or power measures in the frequency-bands delta, theta, alpha and beta providing reliable information about the excitability of neural networks and their change with age (Nunez and Srinivasan, 2006).

1.1. Age-related changes in the EEG power spectrum

Considering both older qualitative (Smith, 1938; Lindsley, 1939) and recent quantitative studies (Dustman et al., 1999; Clarke et al., 2001; Whitford et al., 2007) in EEG developmental literature, one consistent finding is a reduction of the proportion of slow waves in the delta and theta range accompanied by a relative increase of faster alpha and beta activity during childhood and adolescence (Segalowitz et al., 2010). Generally these relative changes have been shown to be based on a strong decrease in absolute delta and theta power (Matoušek and Petersén, 1973; Somsen et al., 1997).

Abbreviations: IFB, individualized frequency bands; SFB, standardized frequency bands; PF, peak frequency.

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doi:10.1016/j.ijdevneu.2010.11.005

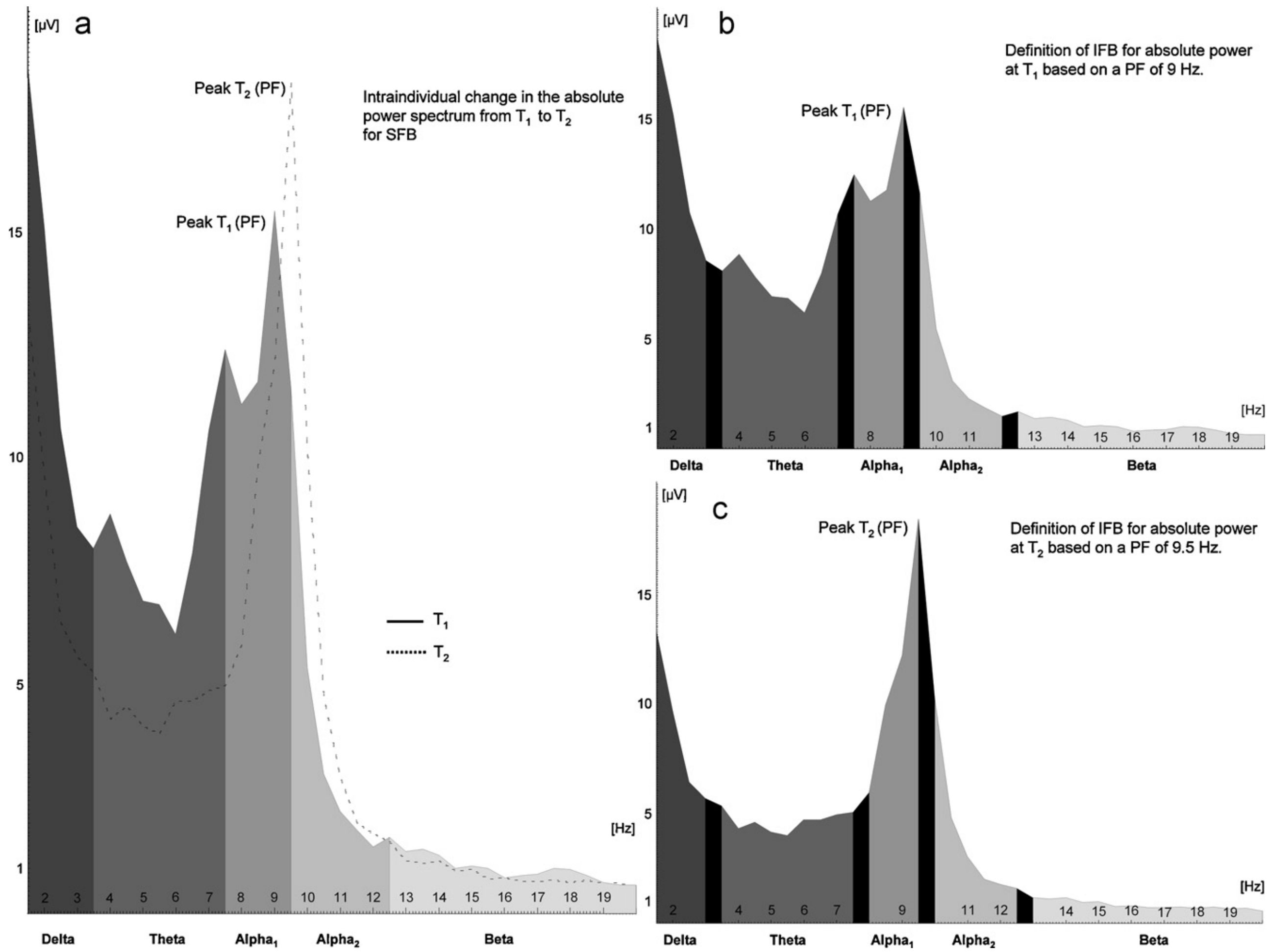

Fig. 1. Comparison of standardized and individualized frequency bands. Subject: Boy, 12 years old at T_1. Power is averaged over all electrodes. (a) SFB are defined according to Gasser et al. (1988a,b). (b and c) In contrast to SFB, IFB are defined without overlap. Additional information is given in Section 2.3.

Nevertheless a few questions remain unanswered. Concerning the alpha-band some results speak in favour of a general increase of relative alpha activity (John et al., 1980; Matthis et al., 1981; Clarke et al., 2001) whereas other studies found a more differentiated picture with relative alpha$_1$ decreasing and alpha$_2$ increasing with age (Gasser et al., 1988b). Unfortunately an integration of these inconsistent results is complicated by different definitions of the alpha band. Inconsistent results in EEG developmental literature are also evident with regard to sex differences. Though some authors have not been able to identify sex differences (Gasser et al., 1988b), the majority of studies found more relative theta and less relative alpha in girls (Matthis et al., 1980; Benninger et al., 1984; Clarke et al., 2001; Nanova et al., 2008). These results have often been taken as an evidence for a maturational lag of girls compared with boys, which is in contrast to common developmental knowledge. However some studies have also found increased beta activity in girls (Matoušek and Petersén, 1973; Friedl and Vogel, 1979).

Finally a more basic drawback of most quantitative studies is their cross-sectional design. Considering the substantial interindividual variability of EEG parameters this approach may mask age dependent effects. Based on one of the rare longitudinal datasets using spectral analysis, Benninger et al. (1984) showed that interindividual variability was larger than intraindividual change with age. In another longitudinal study dealing with dyslexia, 2/3 of the participants showed minor to severe reading difficulties, complicating statements about normal development (Harmony et al., 1995).

1.2. *Impact of peak frequency (PF)*

Besides cross-sectional data, all studies cited above used standardized frequency bands (SFB) to describe age-related changes in children and adolescents. However SFB were defined for (healthy) adults and it is a matter of debate if they can be applied to children (Bell and Wolfe, 2008). Peak frequency (PF) in normal adults is defined as the highest spectral estimate in the power spectrum. Despite large interindividual variability, PF in adults is marked by intraindividual stability and roughly corresponds to the alpha rhythm (Klimesch, 1999).

Although children and adolescents already exhibit a PF within the alpha-range (Niedermeyer, 1997), PF slowly increases and reaches an adult level not until the end of adolescence or early adulthood (Marcuse et al., 2008). Consequently, in developmental studies both age-related changes in power and increases in PF account for changes in SFB. A possible influence of PF on bandpower in SFB is exemplified in Fig. 1 for a single male subject. In accordance with a PF in the alpha range, Fig. 1 suggests that changes in PF mainly affect the alpha-band. However a possible influence on absolute theta power cannot be excluded.

One possibility to isolate the confounded development in PF and power measures is an application of individualized frequency bands (IFB). Using the PF as an anchor point for alpha, IFB correspond more closely to the actual alpha rhythm and control for intraindividual changes in PF. Thus IFB indicate changes in amplitude, independent of changes in PF. If comparisons between