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State-related electroencephalographic deviances in attention deficit hyperactivity disorder

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This study investigated the stability and state-related characteristics of electroencephalographic (EEG) deviances in attention-deficit/hyperactivity disorder (ADHD). Three minutes resting EEG with eyes closed and eyes open were compared between 21 children with ADHD and 29 typically developing children. Across resting conditions, children with ADHD exhibited divergent topographic distribution for theta, alpha and beta power compared to typically developing children. In addition, less alpha and theta suppression to eye opening was found in children with ADHD, but only in those without comorbid ODD/CD. Findings of the present study refer to a consistent divergence in topographic distribution in ADHD across resting state conditions, yet demonstrate that state-related factors and comorbidity may also contribute to resting EEG deviances in ADHD. The state-related findings are in accord with several theoretical accounts emphasizing the role of contextual and state factors defining deficits in ADHD.

1. Introduction

Attention-deficit/hyperactivity disorder (ADHD) is a neurodevelopmental disorder, affecting an estimated 5–7% of the worldwide population (Willcutt, 2012), and is characterized by varying age-inappropriate levels of inattention and/or hyperactivity/impulsivity, leading to impairment in multiple life domains (American Psychiatric Association, 2013). Although the mechanisms are not fully understood, it has often been claimed that ADHD is associated with a dysfunction in the central nervous system (CNS), which has frequently been investigated by means of electroencephalography (EEG).

Resting EEG studies with either eyes closed or open typically have reported increased theta power or an elevated proportion of slow to fast frequency power, theta/beta ratio (TBR), in children with ADHD compared to typically developing children (e.g., Barry, Clarke, & Johnstone, 2003; Dupuy, Clarke, Barry, McCarthy, & Selikowitz, 2011; González-Castro, Rodríguez, López, Cueli, & Álvarez, 2013; Lansbergen, Arns, van Dongen-Boomsma, Spronk, & Buitelaar, 2011; Loo et al., 2010; Shi et al., 2012; Snyder et al., 2008). However, lately the robustness of these EEG deviances characterizing the whole ADHD population has become the focus of a debate, as a number of studies, mainly addressing eyes open resting EEG, could not invariably distinguish children with ADHD from a typically developing group based on theta power or TBR (Coolidge, Starkey, & Cahill, 2007; Liechti et al., 2013; Loo et al., 2013; Nazari, Wallois, Aarabi, & Berquin, 2011; Ogrim, Kropotov, &

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Hestad, 2012; Swartwood, Swartwood, Lubar, & Timmermann, 2003). This also appears to find support by a meta-analysis, revealing less discrepancy in eyes open TBR between children with and without ADHD in recent compared to earlier studies (Arns, Conners, & Kraemer, 2013). In addition, in a recent study, eyes closed theta activity was observed to be enhanced in 60%, yet reduced in 40% of children with ADHD (Clarke et al., 2011). EEG findings regarding brain wave activity in the faster frequency bands appear to be even more mixed. That is, although some studies have documented decreased beta (Clarke, Barry, McCarthy, & Selikowitz, 1998, 2002a; Clarke et al., 2003; Dupuy et al., 2011; Shi et al., 2012), others have reported increased beta power in a subgroup of children with ADHD (Chabot & Serfontein, 1996; Clarke et al., 1998; Clarke, Barry, McCarthy, & Selikowitz, 2001a) or failed to find group differences in beta power (Liechti et al., 2013; Loo et al., 2010). Likewise, alpha power has often been reported to be reduced in children with ADHD (Barry, Clarke, Johnstone, McCarthy, & Selikowitz, 2009; Clarke et al., 1998, 2001a, 2003; Clarke, Barry, Bond, McCarthy, & Selikowitz, 2002), but has also been found to be enhanced (Chabot & Serfontein, 1996; Clarke et al., 2011), or equivalent to that of typically developing children (Loo et al., 2010; Shi et al., 2012). Various factors may have contributed to the apparent discrepant findings between studies, including sample characteristics and resting state condition in which EEG was recorded (i.e., eyes open or closed). ADHD presents a heterogeneous clinical expression with different subtypes, often comorbid with other conditions such as oppositional defiant disorder (ODD) or conduct disorder (CD). These sample characteristics may vary across studies and although not often taken into account, available research indicates that these may mediate EEG deviances in ADHD (e.g., Buyck & Wiersema, 2014; Clarke et al., 2002; Loo et al., 2013). Studies also differ in the resting state condition in which EEG was recorded. Crucially, in order to consider EEG deviances as a trait-like hallmark of ADHD, there should be stability in these abnormalities across different states. Although several studies have demonstrated intra-individual stability of EEG in typically developing children over time (e.g., Fein, Galin, Yingling, Johnstone, & Nelson, 1984; Gasser, Bacher, & Steinberg, 1985), brain oscillations have also been found to be affected by contextual and state factors, such as opening of the eyes (e.g., Barry, Clarke, Johnstone, Magee, & Rushby, 2007; Karhu, Könönen, Herrgard, & Partanen, 1996; Ristanovic, Martinovic, & Jovanovic, 1999; Samson-Dollfus & Goldberg, 1979). Opening of the eyes has been related to an increase in arousal (Barry et al., 2007; Hüfner et al., 2009). Interestingly, although some recent studies challenge this account (Barry et al., 2009; Clarke et al., 2013), one of the dominant theories interpreting the most consistent EEG deviances in ADHD (i.e., aberrant theta and TBR) has been that the abnormalities represent hypoarousal of the CNS (for reviews, see Barry et al., 2003; Barry & Clarke, 2009). This raises the question whether changes in arousal state with eye opening is an important factor that should be taken into account in characterizing EEG deviances in ADHD.

So far, most EEG studies on ADHD have focused on evaluating EEG in either an eyes closed or an eyes opened resting condition, with only a few addressing both resting conditions (Fonseca, Tedrus, Bianchini, & Silva, 2013; Lansbergen et al., 2011; Liechti et al., 2013; Loo et al., 2009, 2010, 2013; van Dongen-Boomsma et al., 2010; Woltering, Jung, Liu, & Tannock, 2012). Interestingly, some of these latter studies reported that deviances in TBR in children (Lansbergen et al., 2011) or adults (Loo et al., 2013) with ADHD were detected in the eyes closed but not in the eyes open condition. Hence, these findings suggest that, whether or not the EEG profile in ADHD is aberrant, it may depend on arousal state. The notion that state factors may play a role when investigating resting EEG in ADHD is further supported by findings of group differences in EEG reactivity to opening or closing the eyes. That is, studies have demonstrated reduced frontal and/or posterior alpha suppression to opening the eyes in children as well as adults with ADHD (Fonseca et al., 2013; Loo et al., 2010; Woltering et al., 2012, but see Loo et al., 2009; van Dongen-Boomsma et al., 2010). Also, a greater theta power increase to closing the eyes has been observed in children with ADHD (Liechti et al., 2013). Although studies that investigated resting EEG in ADHD during different arousal states are scarce, the findings seem to highlight a state-related factor in EEG deviances in ADHD. Interestingly, these results are in line with several theoretical frameworks that emphasize the role of contextual and state factors instead of fixed factors in defining deficits in ADHD, such as the state regulation deficit model (Sergeant, 2005; van der Meere, 2005) and the delay aversion model (Sonuga-Barke, Taylor, Sembi, & Smith, 1992), which emphasize respectively dynamic underlying failures of energetic state or motivational factors in ADHD (Sonuga-Barke, Wiersema, van der Meere, & Roeyers, 2010).

To gain further insight into the role of state-related factors (i.e., arousal) in determining EEG deviances in ADHD, in the current study, EEG activity in an eyes closed and eyes open resting condition will be compared between children with ADHD and typically developing children. Although most studies on ADHD address sagittal topographical differences in EEG reactivity following eye opening, to our knowledge EEG differences between groups on the lateral plane (i.e., left hemisphere, midline and right hemisphere) have hardly been investigated. Yet, this may be important, since a few studies documented hemispherical divergence in EEG activity in ADHD (Hale et al., 2009; Hale, Smalley, Dang, et al., 2010; Hale, Smalley, Walshaw, et al., 2010; Keune et al., 2011). Therefore, in the present study, sagittal as well as lateral scalp regions were included, enabling a thorough investigation of possible topographical differences between groups and conditions. Furthermore, as only a few studies on EEG reactivity in ADHD have systematically addressed a wide range of EEG frequencies and TBR, brain wave activity from theta to beta frequency bands and TBR related to eye opening will be evaluated.

If elevated theta power and TBR are trait-like markers of ADHD, then increased theta power and TBR are expected in both resting state conditions. An interaction effect between group and resting state condition would indicate that state factors are associated with EEG abnormalities in ADHD. In line with literature findings, the largest group differences are expected in the eyes closed condition. In addition, based on previous reactivity studies, children with ADHD are hypothesized to show less alpha suppression when opening the eyes.