# Brain oscillations in relation to attention deficit hyperactivity disorder: A review

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## Abstract

In this review, I will discuss individual brain oscillations in relation to attention deficit hyperactivity disorder (ADHD). The main thesis of this paper is as follows: “Can the individual brain oscillations of theta, beta and alpha relate to different behavioral markers of ADHD and what is the role that needs to be assigned to these individual brain oscillations?”. I will discuss the theta-beta ratio, the individual brain oscillations of theta, beta and alpha, and the spectral power of the EEG as a whole. As a conclusion, it can be said that the individual brain oscillations do have a different behavioral marker (especially the theta oscillations) but that there needs to be a focus on the whole picture of all the brain oscillations together and the individual differences and subgroups of ADHD need to be taken into account as well.

## Introduction

The amount of diagnoses of a behavioral disorder such as the attention deficit hyperactivity disorder (ADHD) has been growing the last couple of years among young children. A reason for this might simply be because there are more children with ADHD, that are more noticeable. It might be related to a growing concern in the welfare of the children and thus might mean that parents and teachers are more aware of the issues that are associated with ADHD. Thus there is more diagnosis of children with ADHD because it really is there more, and it is known more clearly what kind of behavioral issues need to be associated with it.

The behavioral issues of ADHD are associated with certain neurological markers, for example a lack of attentional control can be related to an elevated theta-beta ratio (Picken et al., 2019; Angelidis et al., 2016). The elevated theta-beta ratio has not been as widely acknowledged as a marker for ADHD in the last couple of years. The focus has also been on other and separate brain oscillations for example. The alpha peak frequencies for example have been related to ADHD as well (Lansbergen et al., 2011).  For this review, I have chosen to pick the topic of ADHD and I will focus on the different brain oscillations and their effect on the behavioral characteristics of ADHD. The reason for this choice is related to the difference in opinion or view on the theta-beta ratio in people with ADHD. There is no consensus in the field on the role this theta-beta ratio plays in the development or the diagnosis of ADHD. Moreover, there are a lot of individual differences and subgroups that can be distinguished within ADHD. This makes it difficult to be able to name one behavioral or neurological marker that can been seen in every child or adult with ADHD. The main thesis for this review is as follows: “Can the individual brain oscillations of theta, beta and alpha relate to different behavioral markers of ADHD and what is the role that needs to be assigned to these individual brain oscillations?”

This review consists of three different parts. In the first section, I will more closely discuss the theta-beta ratio in people with ADHD. It will contain different articles with different opinions on the role of the theta-beta ratio and it will contain the behavioral characteristic that can be associated with this ratio. I have chosen to focus on this ratio in the first section, because from this point on it can be further investigated what the individual roles of the brain oscillations are. In the second section, the individual brain oscillations of theta, beta and alpha are more closely discussed. It will mostly contain the or a behavioral marker(s) that can be associated with the oscillations. As a last part, I will discuss the evidence relating to the combination of all different brain oscillations and its effect on

ADHD. In this part, the spectral power of an EEG and the subgroups within ADHD are central.

## Theta-beta ratio

In the first section of the paper, I will discuss the evidence relating to the theta-beta ratio (TBR) in ADHD-patients. In multiple studies, it is suggested that there is some relation between behavioral characteristics and an elevated theta-beta ratio in people with ADHD (Picken et al., 2019; Liao et al., 2020; Zhang et al., 2017; Arns, Conners and Kraemer, 2012). However, the theta-beta ratio is still a point of discussion when it comes to its role in ADHD. It is not entirely understood if the theta-beta ratio is indeed a neurological marker for ADHD, as is suggested in some articles and disproven in some others. For example, an article by Loo and colleagues (2012) suggests that in adults with ADHD the theta-beta ratio is even lower than that of controls. This means that the elevated ratio might not be a neurological marker for ADHD in adults. Moreover, they suggest that different factors have a mediating effect on the theta-beta ratio in adults with ADHD. An article by Ogrim and colleagues (2012) also suggests that there is not an elevated theta-beta ratio to be noticed in people with ADHD. They did find an effect of theta and beta separately, but the two were not correlated thus suggesting there need not be an elevated theta-beta ratio for ADHD to exist. Other articles did find an elevated ratio of theta-beta in children with ADHD, for example in an article by Barry & Clark (2009) or in the meta-analysis by Arns, Conners and Kraemer (2012). In the article by Barry & Clark, they found that patients with ADHD showed a higher theta-beta ratio because there was increased activity in the slow wave and decreased activity in the fast wave brain oscillations. In the meta-analysis by Arns, Conners and Kraemer, they compared multiple studies that had found a correlation between an elevated theta-beta ratio and ADHD. They found that not in every subgroup of ADHD the theta-beta ratio is of relevance. However, because there are certain subgroups of which this elevated theta-beta ratio is a neurological marker, the theta-beta ratio should be kept in consideration. For this reason, it is useful to consider the possible behavioral characteristics that can be related to an elevated theta-beta ratio.

The elevated theta-beta ratio might be related to attentional or executive cognitive control (Picken et al., 2019; Angelidis et al., 2016). In an article by Putman, Maimari and Werff (2010) it was suggested that the slow wave/fast wave ratio, which might be interpreted as either theta-beta ratio or delta-alpha ratio, was negatively correlated with self-reported attentional control. This means that an elevated theta-beta ratio as found in children with ADHD is related to a lower self-reported attentional control. However, in an article by Picken and colleagues (2019) it is suggested that the theta-beta ratio might be related to cognitive processing instead of arousal. Cognitive processing is linked to the latency of the P300, as was already proven earlier by Clarke and colleagues (2019) in a study using healthy subjects. Picken and colleagues replicated this study in a group of people with ADHD and found that the theta-beta ratio is also related to cognitive processing as it is in healthy subjects. In a study by Angelidis and colleagues (2016), they replicated similar results. Angelidis and colleagues found a negative correlation between theta-beta ratio and self-reported attentional control. In another study on an elevated theta-beta ratio, it was found that a higher theta-beta level might be correlated to inhibition (Zhang et al., 2017). This inhibition might be strange to link directly to ADHD, since this behavioral disorder is not really known for its inhibition. However, the inhibition in the study by Zhang and colleagues links to attentional processes. Thereby, it is logical that this inhibition does indeed link to ADHD, the elevated theta-beta ratio ensures that there is less allocation of attention.

Thus, it might not be said that theta and beta do not have an influence on the creation of ADHD. However, there is not always a coupling of an increased theta activity and a decreased beta activity. This might suggest looking at the individual brain oscillations.

## Individual brain oscillations: theta, beta and alpha

In the second section, I will discuss these individual brain oscillations. In particular, I will be looking at theta, beta and alpha oscillations in relation to ADHD.

It has been established that there often is an increase in activity in theta oscillations, with or without an elevated theta-beta ratio, in people with ADHD (Picken et al., 2019; Liao et al., 2020; Zhang et al., 2017; Arns, Conners and Kraemer, 2012; Ogrim, Kropotov and Hestad, 2012; Lansbergen et al., 2011). In this section, I will focus on the individual activity of theta oscillations. In an article by Ogrim, Kropotov and Hestad (2012), they found increased theta activity in about a quarter of the people with ADHD as opposed to only one control subject. In individuals with ADHD, it can thus be said that there is a case of increased theta activity, which might correlate with inattention and executive problems. In an article by Lansbergen and colleagues (2011), it was found that the theta-beta ratio might in some cases be due to increased theta activity in the frontal lobe in certain subgroups in individuals with

ADHD. It cannot be said that in all cases an increased theta activity can be seen in individuals with ADHD.

Beta activity is usually reduced in people with ADHD, as is also shown in articles suggesting an elevated theta-beta ratio. However, there are some effects of beta activity which differ in patients with ADHD as opposed to healthy subjects. Moreover, beta activity might even have a positive effect on ADHD when it is practiced. In an article by Ogrim, Kropotov and Hestad (2012) they spoke of the effects of beta activity in children with ADHD. There is a difference between the effect beta activity has within cognition on children with and without ADHD. In children without ADHD, beta activity correlated with attention. In children with ADHD, however, it correlated with ADHD symptoms. In another article by Liao and colleagues (2020), it was found that beta activity in a subgroup of ADHD patients was low and therefore the attention performance in the tests was poor. The subgroup of ADHD patients was termed the slow group, based on previous similar tests and reaction times. This slow group had less beta activity and therefore might have a different attention process. Liao and colleagues suggest that frontal beta activity might be used to train this attention process in the group with slower reaction times.

Less is known about the role of alpha oscillations in ADHD. However, in multiple articles there is a difference of alpha oscillations in healthy subjects and people with ADHD. In the article by Lansbergen and colleagues (2011), the elevated theta-beta ratio in people with ADHD might not be due to an increased theta activity and decreased beta activity at the same time. When Lansbergen and her colleagues would measure the theta-beta ratio with fixed frequency bands there was an elevated theta-beta ratio. However, when they were using individualized frequency bands, this effect of an elevated theta-beta ratio was not found. They suggest that an elevated theta-beta ratio might in fact be due to a slow alpha-peak, instead of increased theta and decreased beta activity. A similar article by Picken and colleagues (2019) discusses the relation of the theta-beta ratio to either arousal or cognitive processing. They found that the theta-beta ratio is related to cognitive processing in both healthy subject and in subjects with ADHD. However, there is a difference between healthy subjects and ADHD-subjects when considering the arousal linkage. The article states that the linkage between arousal and alpha oscillations is anomalous in people with ADHD.

## Combination of brain oscillations

As a last part of this paper, I wanted to discuss the overall image of EEG within ADHD. I have now discussed the theta-beta ratio and the individual brain oscillations, but mainly we can speak of multiple combinations that have an influence on ADHD. In an article by Clarke and colleagues (2011) they found four clusters within EEG concerning ADHD. An elevated beta activity, an elevated theta activity with deficiencies of alpha and beta, an elevated slow wave with less fast wave activity and an elevated alpha activity. These different clusters of activity within EEG might suggest the different subgroups that can be obtained from the entire group of ADHD people. An article by Kiiski and colleagues (2019) overthrew the theta-beta ratio as a predictor for ADHD, but instead named a few other predictors for ADHD. An increased power of delta activity, increased theta activity and a low power of alpha over parietal regions. As for the beta activity, there has been found a low power of beta in the frontal regions and in the parietal regions mid power of beta activity.

## Discussion

In this review, I have attempted to answer the main thesis “Can the individual brain oscillations of theta, beta and alpha relate to different behavioral markers of ADHD and what is the role that needs to be assigned to these individual brain oscillations?”. I have started this review with an overview of the evidence relating to the theta-beta ratio and found that there is not a consensus on the role that needs to be placed on this ratio. This ratio can be related to attentional control, but as can be shown in the different parts of the review is this ratio not entirely due to the increased or decreased activity in theta and beta oscillations respectively. It might in fact be due to a slow alpha peak frequency, in which it can be said that this peak relates to less or dysfunctional arousal. Not in all subgroups of ADHD is an increased theta oscillation seen. However, the theta oscillations can be related to inattention and executive problems. As for the beta oscillations, it is mostly known that there is less activity in the beta oscillations. Not much else is known, except that beta oscillations in people with ADHD might relate to symptoms associated with this disorder as opposed to controls in which this relates to good attention. In the last section, the power of the entire EEG of brain oscillations was discussed. It was found out that in fact different clusters can be distinguished which can be related to different subgroups within ADHD.

In the future, it might be useful to focus more on the whole picture and keep in mind that individual differences are not uncommon in this behavioral disorder. As was also said in the review above, a training in beta activity might also be useful for patients with ADHD.

The answer to the main thesis might not be as simple or as clear as I would have hoped. However, the individual brain oscillations do in fact relate to different behavioral markers of ADHD especially the theta oscillations. The role that can be assigned to the brain oscillations needs to be further investigated, and I think might not need to be the main focus since the summed-up brain oscillations as a whole need to be further investigated in order to be able to say something about the diagnosis of ADHD.

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