Utilising Independent Event-Related Potentials to Determine if Learners Can Be Classified as Attention Deficit/ Hyperactivity Disorder Based on Their Auditory Difficulties

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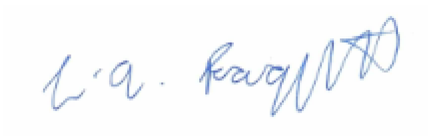
DECLARATION

I declare that the thesis hereby submitted by me for the MEd degree at the University of the Free State are my own independent work and have not previously been submitted by me at another university or faculty. I furthermore cede copyright of these articles in favour of the University of the Free State.



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GENERAL ORIENTATION

The research submitted for examination was completed in accordance with Regulation G7.5.4.1 of the discipline Psychology of Education, Faculty of Education, University of the Free State. This regulation stipulates that a thesis can also entail the submission of two related publishable articles (in article format) for examination. The candidate therefore submits two related articles to fulfil the requirements of the qualification Magister Educationis (MEd) in Psychology of Education.

As indicated on the title page the registered title of this thesis is as follows:

Utilising Independent Event-Related Potentials to Determine if Learners Can Be Classified as ADHD Based on Their Auditory Difficulties

The thesis consists of two related articles, namely one theoretical paper, entitled:

A Research Overview on Neuro-Electrical Findings in ADHD and APD in order to Draw Inter-Relational Conclusions

and one empirical article, entitled:

An ERP analysis of Auditory and Attentional processes with the aim of better clarification of the electrical process involved in ADHD

A summary of both articles is included, explaining the conclusions drawn by the researcher upon completion of the investigation.

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Annexures

Annexure A: Ethical clearance

Annexure B: Consent form to parents

Annexure C: Clarification of terms

Annexure D: Certification of proof reading

A Research Overview on Neuro-Electrical Findings in ADHD and APD in order to Draw Inter-Relational Conclusions

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Abstract

This is a theoretical article (Article 1of2) followed by an empirical article (Article 2 of 2). This paper gives a theoretical overview of research findings in Attention Deficit Hyperactivity Disorder (ADHD) and Auditory Processing Disorder (OPD). **Objective:** The objective of this article was to determine the role auditory difficulty plays in the ADHD process by using the Electro Encephalograph (EEG). **Results:** Research results mostly described ADHD in terms of executive functions and frontal lobe involvement, but auditory involvement and sensory input from the parietal lobe were found more and more to be integral parts of attention systems in ADHD during this literature overview. The literature findings clearly underlined the influence the one has on the other or the interplay between these two disorders. Auditory Event-Related Potential (ERP) patterns were further investigated by means of literature overview. Most of the research isolated the P1, P2, N2 and P3 ERP components as the significant electrical components during the ADHD process. **Conclusion:** ADHD and ERP components can be isolated, but they still have an intricate effect on one another which cannot be separated. These components that have been isolated will further be analysed during an empirical analysis in the follow-up article to further analyse the role auditory processing plays in ADHD children's difficulties. This process hopes to bring better understanding to parents, clinicians and therapists involved with ADHD children in South Africa in order to relieve the financial as well as emotional burden of this disorder.

Keywords: *Attention Deficit Hyperactivity Disorder, Auditory Processing, Event Related Potential, Electroencephalography, Diagnosis, Independent Component Analysis.*

1. Introduction

ADHD is characterized not only by developmentally inappropriate symptoms in attentional functioning but also social functioning due to inattention, impulsivity, and motor restlessness controlled mostly by the executive functioning system of the brain (Du Paul and Jimerson 2014:379; Willcutt, Doyle, Nigg, Faraone and Pennington 2005:1336). The prevalence of ADHD among children currently is estimated to be between 7 and 9 percent and the rate of diagnosis seems to be increasing (Ullebø, Posserud, Heiervang, Obel and Gillberg 2011:Abstract only; Van de Glind, Konstenius, Koeter, van Emmerik-van Oortmerssen, Carpentier, Kaye, Degenhardt, Skutle, Franck, Bu, Moggi, Dom, Verspreet, Demetrovics, Kapitány-Fövény, Fatséas, Auriacombe, Schillinger, Møller, Johnson, Faraone, Ramos-Quiroga, Casas, Allsop, Carruthers, Schoevers, Wallhed, Barta, Alleman, Levin and van den Brink 2014:158) (Visser, Bitsko, Danielson, Perou and Blumberg 2010:1439). In a recent study in South Africa a rate of 5.4% - 8.7% has been determined amongst school-going children which makes ADHD research as relevant to South Africa as to other countries (Bakare 2012:358). Despite the high prevalence, high heritability, and high costs of ADHD, biological markers have been difficult to obtain. Such biomarkers would be useful to help eliminate dependence on subjective methods of diagnosis by permitting diagnosis based on interviews. This could potentially allow for earlier diagnosis (Wallis 2010:438). The application of functional brain measurement methods has already brought unequalled insights into ADHD. EEG use points to altered neurobiological development, which affects higher-order cognition (Vaidya and Stollstorff 2008:261). Attention, distractibility, and impulsivity define ADHD and suggest selective weakness of regulatory or control processes (Vaidya and Stollstorff 2008:261). At an educational level, this clearly has an effect on the learner, as the learner's thinking process in class, as well as behavioural self-control are controlled by higher-order cognition processes. These processes are often labelled as ''executive'' processes in psychological theory (Bialystok 2015:117). Most of the neuroscientific research on ADHD focuses on processes of executive control such as response inhibition (Bush, Valera and Seidman 2005:1274). However, increasingly, studies are pointing towards other cognitive domains in lower-level ''non-executive'' functions and their underlying brain circuitry. As a result, a new trend among researchers supports a model of neuropathological heterogeneity produced by alterations in multiple neurocognitive circuits (Snyder, Yerkes and Pitts 2015:295; Vaidya and Stollstorff 2008:261). The relevance of this research in Education lies in the increased finding that the area of origin of ADHD is more diverse than initially believed. The educational implication here is that the treatment of ADHD may be more complex than merely determining and treating executive dopamine-related imbalances. This means that ADHD could be a more heterogeneous process than previously described. Underlying brain circuitry may involve sensory detection difficulties during a much earlier neurological process than the execution process. Utilising Event Related Potentials (ERP's) give the means to analyse at which moment in processing an atypical process occurs, based on normative comparison.

Many children with ADHD have severe challenges in focusing their attention, resulting in poor scholastic performances. The above may also be the consequence of other factors such as auditory processing difficulties/delays (APD). More recently, APD is increasingly being researched. APD is explained as the inability to understand auditory information.

The present study aims to determine the value of ERP research in education by pointing towards the likelihood that the area of origin and the treatment of ADHD may be more than executive dopamine-related imbalances. Underlying brain circuitry to execution involves sensory detection, occurring during a much earlier neurological process than execution. ADHD leads to difficulties throughout school and learning, supporting its neuro-scientific significance. APD is commonly explained as a problem in the ability of understanding information received through the ears. This disorder is being researched more and more in connection with ADHD to establish the relationship or possible influence of the one on the other. Developments in electro physiological measurements such as ERP are providing means of measuring auditory selective attention as a single modality (Giuliano, Karns, Neville and Hillyard 2014:1; Woldorff, Gallen, Hampson, Hillyard, Pantev, Sobel and Bloom 1993:8722). Differentiation of this diagnosis for professionals remains a challenge (Schochat, Scheuer and Andrade, 2002:742). Better understanding of the inter-relationship between ADHD and auditory difficulties may provide biological diagnostic markers that will make us less dependent on symptom-based approaches of diagnosis of these conditions by including objective scientific measures. These objective measures may help to improve diagnostic credibility for children with unidentified learning problems and may also contribute to the identification of specific additional aspects related to the auditory process that may be contributing to learning or attentional difficulties in children with ADHD. The persistent patterns of inattention and/or hyperactivity-impulsivity in ADHD cases are problematic for both teachers and learners. As many as half of the children visiting psychiatric clinics are diagnosed with ADHD, which points to the importance of an accurate characterization of ADHD (Cantwell 1996:978).

If research indicates that more circuits are involved during attentional processes than the frontal circuit, looking at an overview of the role sensory circuitry plays in attention could shed light on this broader involvement. Clear research findings linking the fronto-parietal activation during attentional processes points us to the fact that neither frontal nor parietal networks controls the attention process in isolation (Ptak 2012:502; Spreng, Sepulcre, Turner, Stevens and Schacter 2013:Abstract only). It is rather the flexible interaction between frontal and parietal networks as well as dorsal and ventral brain networks that enables the dynamic control of attention (Vossel, Geng and Fink 2014:150). Auditory pathways in the parietal brain regions such as the reticular formation involve structures related to wakefulness, awareness and attention which is linked to frontal regions (Paus, Zatorre, Hofle, Caramanos, Gotman, Petrides and Evans 1997:392). ADHD and APD also have many co-morbid symptoms and the discrimination between these two disorders is as complex as the discrimination of the brain network involvements. Research specializing in both the fields of ADHD and APD state that when children who are not hyperactive but have difficulties are assessed, psychologists diagnose ADHD while audiologists diagnose APD in the same children (Bailey 2010:521). The diagnosis determines the intervention process therapy and psychotropic-wise. Parallel research (Chermak 2002:733) finds that children diagnosed with ADHD often have histories of chronic otitis media, and that children with APD often have co-morbid diagnoses of one or more learning disabilities and/or specific language impairment. If ERP research can then contribute in the slightest to discrimination of the neural networks involved in auditory attention, this may lead to better insight of the processes involved in order to establish more accurate treatment goals for learners with ADHD.

2. Theoretical Framework

From an educational psychology perspective, this research will be informed by two main theoretical frameworks. First, the researcher will aim to investigate the prevalence, symptoms, causes and subsequent challenges of children with ADHD by drawing from (Frith, Morton and Leslie 1991:433) causal modeling framework. The three-stage model of Morton and Frith views construction of knowledge as a function of the interaction between three related factors, namely genetic, cognitive, and behavioural, and how these elements are affected by environmental factors, which include the learning environment and cognitive learning style (Frith et al. 1991:433).

The first of the three causal factors in ADHD and the focus of a large amount of research is the genetic cause. There have been about 2800 publications on the genetic cause of ADHD in 2012-2013 (Schachar 2014:41). A candidate gene, DAT1, has been identified in genetic ADHD studies (Sokolova, Hoogman, Groot, Claassen, Vasquez, Buitelaar, Franke and Heskes 2015:508). This gene is the dopamine transporter. Dopamine deficiency is the widest genetically proven factor to lead to ADHD (Crosbie and Schachar 2014:1; Hansen, Skjørringe, Yasmeen, Arends, Sahai, Erreger, Andreassen, Holy, Hamilton and Neergheen 2014:3107; Ruocco, Treno, Carnevale, Arra, Mattern, Huston, De Souza Silva, Nikolaus, Scorziello and Nieddu 2014:2105; Whalley 2015:188). Dopamine is linked to raised theta content but proving this lies beyond the aims of the present study.

Secondly, the causal model suggests cognitive grounds for ADHD. Sluggish and day-dreaming cognitive patterns are linked to poor concentration (Langberg, Becker and Dvorsky 2014:91; McBurnett, Pfiffner and Frick 2001:207). This slots in closely with the low level of arousal model in ADHD and the Inattentive subtype. Another well-researched cognitive cause of ADHD is poor language development. Children who seem not to execute tasks often do not understand (Cohen, Vallance, Barwick, Im, Menna, Horodezky and Isaacson 2000:353). This cause targets the essence of this theoretical paper. These learners seem to battle with processing of information rather than inattentive or hyperactive behaviours. This causes difficulty in understanding due to their slower processing speed. They do not understand what they read as the language aspect of the work becomes their main problem (August and Garfinkel:739). Results in ERP studies show that ADHD is associated with reduced amplitude of all ERP's and reflect widespread cognitive control impairments during task execution (Shephard, Jackson and Groom 2015a:1).

The behavioural cause for ADHD is the third factor linked to ADHD by the causal model. Media plays a large role in what children perceive to be normal behaviour (Nikkelen, Vossen, Valkenburg, Velders, Windhorst, Jaddoe, Hofman, Verhulst and Tiemeier 2014:42). Cultural values and spiritual beliefs in children and traditional behaviours experienced by learners could lead to behavioural traits in certain cultures and among certain etiological family set-ups (Lawton, Gerdes, Haack and Schneider 2014:189). Latin and Anglo American studies in America on ADHD have shown for example that gender role and the influence of friends and tradition, influenced behaviour (Lawton, Gerdes, Haack and Schneider 2014:35).

In order to better explain ADHD, these models provide categorical placing of the information we gather in this theoretical paper. The EEG findings may not fit these categories all the time, but the model provides a framework of thought to move within. Causal model aims to identify causal relations between variables of interest in order to better explain social phenomena (Russo 2011:1). If the role between auditory and attentional variables is better explained, the behaviour of ADHD learners will be better understood and addressed in the classroom.

Alternatively, the researcher, from a neurosciences perspective, will investigate how the arousal model of brain activation briefly mentioned under cognitive control in the causal model discussion, can be used to explain activation systems in the brain underlying the electrical activation measured.

According to the arousal model, neurological problems can be explained by considering the mechanism of deregulation of the brain. As illustrated in Figure 1, an under-or over stimulated brain does not function as optimally as a correctly modulated brain. Under arousal as well as over arousal could lead to the brain having too much input or energy to function optimally. The image of overweight or underweight people can well describe this. Too little food leads to too little energy to apply to tasks and too much food leads to over input of energy with bad results towards output of work. Electro encephalographic studies support the idea that individuals who have deviances on a neuro-functional level and these deviances put strain on the attentional process. The brain needs higher levels of activation or amplitude in order to be roused enough to perform in attentional tasks. (Loo, Hale, Macion, Hanada, Mc Gough, Mc Cracken and Smalley 2009:2114).

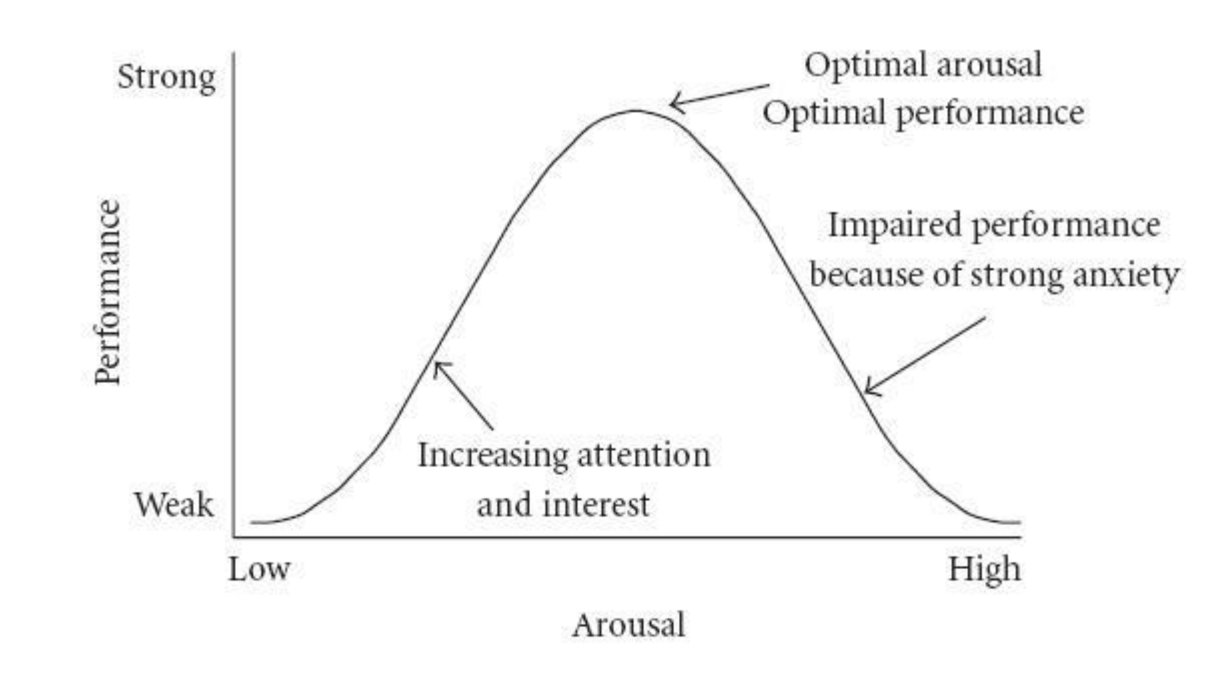

Figure 1: Arousal level model (Mitchell 2015:1)

3. Research Problem and Questions

Exact replicable test results for the diagnosis of ADHD based on the *Diagnostic and Statistical Manual of Mental Disorders* (*DSM-5*) or pen-and-paper type assessments are difficult to obtain (Forsyth, Mc Ewen, Gee, Bearden, Addington, Goodyear, Cadenhead, Mirzakhanian, Cornblatt, Olvet, Mathalon, McGlashan, Perkins, Belger, Seidman, Thermenos, Tsuang, van Erp, Walker, Hamann, Woods, Qiu and Cannon 2014:41; Huang-Pollock, Karalunas, Tam and Moore 2012:360; Thome, Ehlis, Fallgatter, Krauel, Lange, Riederer, Romanos, Taurines, Tucha, Uzbekov and Gerlach 2012:379). A diagnosis made on the basis of the DSM relies on the interpretation of the assessor as well as the report of the parents (Faraone, Biederman and Milberger 1995:1001). Biological data will aid in developing a more scientific and exact, replicable diagnostic tool to add to the diagnosis of ADHD. This article will attempt to clarify the role auditory difficulty plays in ADHD by identifying specific diagnostic markers of EEG slowing in the auditory or executive/ attentional areas. If auditory difficulties play a role in the functioning of ADHD learners, the analysis of the auditory-related brain markers will support the academic value of this paper toward the analysis of ADHD.

The following questions will guide this research:

1. How does ERP apply to the fields of ADHD and APD and what is the nature of the information we receive from this method?
2. Are ADHD and APD ERP components alike or different and how do they differ?
3. How can ERP use support current methods of ADHD and APD diagnosis?

Answering these questions may shed light on the causes of ADHD and APD as well as on the genetic, cognitive, and behavioural factors contributing to better explain these disorders within the theoretical framework of Morton and Frith. As brain activation stands central to ADHD, the role arousal of the frontal lobe areas play will be described in terms of the activation it needs from more posterior brain areas.

Furthermore, answering these questions will give guidance towards the challenges ADHD and APD learners may have in the classroom. The forgetfulness, under achievement, time management challenges, motivation difficulties, impulsivity, constant seeking of novelty, distractibility and scattered-mindedness are characteristics of these learners (Cherkasova 2014:172) that need to be better understood (Parker, Hoffman, Sawilowsky and Rolands 2013:215). Understanding themselves better may benefit ADHD and APD diagnosed learners to feel better about themselves as ADHD also tends to affect self-image negatively to a large extent. The development of more productive beliefs, experiencing of more positive feelings and engagement in more self-regulated behaviours have proven to be outcomes of better understanding of the diagnosis of the above learners.

4. Aims

The aim of this paper is to establish what ERP findings bring to the table in terms of ADHD and APD learners. Furthermore, it aims to establish if ERP markers differ in the two disorders or are mutually inclusive. The lack of auditory processing and the influence it has on attention or on auditory processing will be discussed in terms of brain response. The aim of the paper is to establish if classroom behaviour in learners can be defined in terms of auditory or ADHD markers according to ERP's. The value of these aims will lie in better understanding of learners in a classroom. Being able to understand behaviour on the knowledge that a learner battles with making sense processing auditory information, rather than battles to concentrate, will guide the teacher towards better understanding. If this could be applied in order to raise self-esteem, it could add value to the classroom situation. (Parker et al. 2013:215).

5. Causes of ADHD

Classroom numbers are large in departmental schools in South Africa with up to 50 learners per class(Engelbrecht, Oswald and Forlin 2006:122). The average learners per class in departmental schools in Europe is 21 learners (EU 2014:1) and 26 learners in the US (Statistics 2011:1).Within the larger South African context where private schooling is not affordable for parents, the management and understanding of difficulties is an important factor. A teacher who may understand the need of re-teaching to a certain group to support slower perception due to longer latency processes of auditory processes, or the need of more emphasis on certain areas of her teaching in order to aid brain activation, may have better results and more engaged learners. Learners have diverse difficulties and needs.

ADHD is linked to deficiencies of dopamine and nor-epinephrine levels in the brain and these deficiencies, if not treated, lead to other conditions such as bipolar disorder and depression in adulthood. For this reason, further investigation of underlying causes of ADHD is very important (Adler, Newcorn and Faraone 2007:1). This cause points to the biological or genetic factor of the causal model or theoretical framework of ADHD research. Cognitive neuroscience studies of ADHD suggest that there are more functional structures in the brain involved in cognition than was examined until the present (Evans and Frankish 2009 ; MacDonald, Cohen, Stenger and Carter 2000:1835). Difficulties during cognition occur earlier in the cognitive process than have been the findings until now. More areas are also involved and ADHD may involve not only the frontal lobes. Also shown by this research investigation is that neurological function seen as non-executive may be involved as much as executive functions are. On a chemical level this implies more neuro-transmitting hormonal involvement than earlier research suggested (Del Campo, Chamberlain, Sahakian and Robbins 2011:e145). Major insights gained from functional brain imagery studies in ADHD (Vaidya and Stollstorff 2008:261) discuss working hypotheses regarding their neuro chemical underpinnings. EEG and ERP studies can bring new ways to the table to project functional information in order to quantify the diagnostic road of investigation. Both the ADHD and language related learning difficulty fields can benefit from these procedures. Looking at information processing across brain areas can be explained as a cognitive cause within the theoretical framework of the causal model. Language processing is needed on a cognitive level in order for execution to happen during task conditions in which ADHD learners battle to perform (Arbel and Donchin 2014:83).

The Bellis Ferre model, trying to explain APD causes, points to related underlying neurophysiologic areas connected to APD which may lead to specific higher level language disorders, but APD mostly co-exists with other learning disorders. This suggests possible overlay brain function properties with other disorders (Sahli 2009:105). This research further notes that APD can have underlying structural difficulties like in the case of chronic otitis media but that 43% of learners diagnosed with ADHD are expected to have APD (Sahli 2009:105).

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6. Characteristics of Learners with ADHD and APD

In the classroom, ADHD is commonly perceived as a difficulty in receiving instructions on a given task, understanding it, and then focusing to execute it. These learners struggle to remember to bring school materials to school or home for homework, to remain seated for work, and to convey messages about homework or responsibilities, resulting in compromised academic achievement (Carbone 2001:72). The underachievement rate of ADHD learners relative to non ADHD learners is rather significant (Frazier, Youngstrom, Glutting and Watkins 2007:49). These symptoms have been found to have a root in executive function problems such as inhibition, regulation of self and behaviour and working memory difficulties (Langberg, Becker, Epstein, Vaughn and Girio-Herrera 2013:1000). According to the causal model or theoretical framework, the prevalence, symptoms, causes and subsequent challenges of children with ADHD are caused by genetic, cognitive, and behavioural factors.

It therefore makes sense to investigate the link between understanding what we hear (auditory processing) and difficulties in the execution of tasks (associated with ADHD). Previous research supports the notion that there is significant overlap between APD and ADHD, and that this association should be further investigated (Schochat, Scheuer and Andrade 2002:742). Broadly defined, APD is problematic processing of information specific to the auditory modality (Jerger and Musiek 2000:467). By analysing APD, we aim to better understand some of the neuro-scientific aspects of ADHD. The causal model will be used to better explain the extent to which the one explains the other. A preliminary literature search found no previous published research in South Africa on the link between ADHD and APD using ERP technology.

Different from what was believed in the past ADHD persists into adulthood in most cases and influences behaviour significantly. It is not a symptom cluster alone (Katragadda and Schubiner 2007:317). Inattentiveness, impulsivity, and motor restlessness are classified as the basic symptoms of ADHD. The pervasiveness of ADHD, starting in most cases before the age of seven (Erb 2014 ; Retz-Junginger, Retz, Blocher, Weijers, Trott, Wender and Rössler 2002:830) and continuing for an unpredictable period, makes it a highly relevant characteristic for study in learners of 8-18 years.

7. Cognitive functioning and learning in ADHD and APD

If the most recent cognitive research finds that ADHD is not centred only in the fronto-striatal loop and that the parietal areas involved in auditory and sensory processing are involved too, (Gyldenkærne, Dillon, Sharma and Purdy 2014:676; Tomlin, Dillon, Sharma and Rance 2015:527) then linking APD to ADHD makes sense. These findings are clear in functional magnetic resonance imaging (fMRI) studies as well as neuro-functional analyses such as electro encephalogical analyses of brain function during different stages of information processing (Ahmed, Khaled, Mohammad, Mansour and Ezz-Eldine 2014:22; Pluta, Wolak, Czajka, Lewandowska, Cieśla, Rusiniak, Grudzień and Skarżyński 2014:33). Functional magnetic resonance image (fMRI) studies of ADHD individuals concludes that the structural findings of these individuals do not show similar pathways of processing as norms.

ADHD researchers (Adler et al. 2007:1) noted that frontal lobe activation during information processing and the cognitive processes in a normative group, was lacking during the same cognitive processing in the ADHD group. They further described executive function difficulties such as sustained attention or vigilance, planning and organization, response inhibition, set shifting and categorization, selective attention and visual scanning, verbal and visual learning, and memory to be the main deficits in the ADHD group during their research conclusions (Adler et al. 2007:1). This will influence a student's ability to succeed in all areas in classroom learning – perseverance, maths, spelling and reading. The impaired learner needs to receive support in accordance with the source of the neuro-functional difficulty.

Dopaminergic and nor-epinephrine circuits affect different areas neuro-biologically. Whether the learner has a fronto-striatal or a parietal dysfunction, the ADHD symptoms present are very similar, if not analysed electro and neuro-physiologically. (Pliszka, Mc Cracken and Maas 1996:264). The cognitive processes of ADHD learners are situated in the frontal lobes and possibly the central and parietal lobes. Underlying to these processes lays hormonal processes, involving the chemical dopamine as well as the chemical nor-epinephrine and others. This research explains that defective nor-epinephrine and dopamine processes will lead to insufficient activation of the parietal lobes, lacking therefore in arousal level to process sensory stimuli in the parietal lobes.
Research aimed more towards the field of APD, shows that in children with a language disorder the functionality of the executive control system is deficient and performance on tasks utilising executive control was impaired (Arbel and Donchin 2014:83). Arbel and Donchin further point out that a controversy exists about the extent to which language difficulty is truly specific to the a) language domain versus b) a general deficit in processing or c) a general information processing difficulty. Their work studies the role of self-monitoring of performance based in the frontal lobes where attention and executive function are controlled. The role self-monitoring plays in language processing of APD learners points to the interplay of ADHD and APD. This specific research places a) language processing and the b) deficit in processing auditory stimuli in the auditory field, while c) general information processing is placed in the concentration field.

In order to study the processes involved in APD it is important to understand that sound or auditory stimuli picked up by the ear is a sound vibration, absorbed by the ear drum, processed by the hammer and anvil and then transformed to electricity by hair cells. This is where sound becomes brain electricity. It is a progressive migration of the sound vibrations from the outer, to middle to inner ear and then to the brain (Musiek, Baran, Shinn, Guenette, Zaidan and Weihing 2007:433). Sound is an auditory stimulus carried via the auditory nerve to a branch of the eighth cranial nerve, then via the ascending auditory pathways, then to termini in the auditory cortex and the cerebellum or small brain (Bailey 2010:521). From the cerebellum, the electrical signal is transmitted to the auditory cortex on the temporal lobes. Other pathways run through the thalamo-cortical portion of the brain to the auditory cortex through different pathways (Hall and Lomber 2015:1). The thalamus (Pastor, Vidaurre, Fernández-Seara, Villanueva and Friston 2008:1699) is the area of the brain involved in attention to auditory stimuli as well as in how the response on auditory information is integrated or processed (Pastor et al., 2008). The basal ganglia is involved in further processing this auditory signal and plays a role in speech in the pathway of hear-to-talk (Kotz, Schwartze and Schmidt-Kassow 2009:982), particularly timing. Auditory processing processes therefore involve sound travelling through ear and brain structures in order to become electricity processed in several areas of the brain for us to understand what we hear.

The American Speech and Hearing Association (Bailey 2010:521) identified some of the central auditory processing mechanisms namely; localizing a sound, discrimination of a sound (breaking it up), pattern recognition in sounds and time related aspects of sound. If physical damage to the structures of the ear is not present, a lack of tracking of sounds and an inability to comprehend sound and respond correctly is linked to ADHD or APD (Kotz et al. 2009:982). This links up with the arousal model or theoretical framework where we assume the brain needs to be awake or aroused enough to make use of input or to pay attention which may be linked to the causal model as a cognitive ground for ADHD.

The difference between auditory perception first and then attention, or first attention to a stimulus and then the processing of it, needs to be examined in order to determine to which extent APD and ADHD influence one another. Attention difficulty could be poor executive functioning or it could be due to poor processing of auditory input. Early work (Chermak, Somers and Seikel 1998:78) in ERP has already shown a two way influence of these modalities on one another. This study has found a mutual influence of auditory attention and comprehension in learners. Dysfunction in learners was linked to both attention and listening. This study sets listening and attention as separate but closely related which is core to the hypothesis of the current study. The fact that auditory processing and attentional processes are separate, but can also not be separated, is key to the question if separate biomarkers for these disorders exist. (Bailey 2010:521). The fact that auditory and attentional dysfunctions are separate but have closely related behavioural manifestations stands central to this research paper.

In more work done on the differential diagnosis and management of APD and ADHD, researchers looked at the commonly assumed behavioural overlap between the two disorders (Bellis, Billiet and Ross 2011:501; Chermak, Hall and Musiek 1999:289). The above researchers describe APD as a selective auditory attention deficit with problems in language processing and accompanying academic problems while ADHD is described as more a motor regulation problem with impulsivity (Chermak, Silva, Nye, Hasbrouck and Musiek 2007:428). ADHD relates more to inattentive and distractibility difficulties, according to this research while learners with APD tend to ask for things to be repeated, tend to have poor listening skills, have problems following oral instructions and have difficulty discriminating between back-and foreground noise. From a neuropsychological evaluation perspective, this research group found the APD group to show poor sustained auditory attention, poor auditory memory, and difficulty discriminating speech. None of these behaviours was shown by the ADHD inattentive type checklist (Bailey 2010:521).

8. How biomarkers can aid Education in more precise description

In the classroom, a learner needs to be able to self-regulate in order to improve and have good academic performance. This is not only a critical factor in child development but also in the learning process (Harris, Friedlander, Saddler, Frizzelle and Graham 2005:145). A precise-as-possible-tool to access this self regulatory function of cognitive function is then very important. The National Institute of Mental Health (NIMH) in America announced that it will not fund further cognitive research unless bio-markers are included. This institution is a leader in the medical research field. The director of the NIMH, concluded that research should not only use the DSM to categorize mental illnesses. The DSM, published by the American Psychiatric Association, had been used for psychiatric and other diagnosis for 6 decades, and should still be applied, but not in isolation (NIMH 2015:1). In its approval of research projects, the NIMH prefers to apply more and more biomarker technology according to their Research Domain Criteria (RDoC). This system relies on brain anatomy, chemistry and genetic research rather than mainly patient symptom analysis. Recent international discussion followed the announcement of the director of the NIMH, questioning the validity of psychiatric diagnoses. He questioned the weight of life experience or clinical self-report against brain pathology technology in the handling of mental illness (Koven 2015:1). South Africa, like all developed countries, may benefit from incorporating EGG bio-markers in ADHD related research. Event related potential analysis gives insight into functioning of impulse control areas in the brain. ADHD medications are aimed at impulse control-related dopamine targets. In studies where electrophysiological techniques have been utilized to analyse brain waves in impulsive conditions and disorders, results pointed to elucidated brain functioning associated with these conditions (Kamarajan and Porjesz 2012:21).

A learner who is not able to self regulate academic and cognitive functioning, could have temporary electrical instability on a neurological level (possibly indicating epilepsy in different forms) (Major and Benga 2010:313) This will also lead to restlessness and mimic ADHD (Taylor, Sergeant, Doepfner, Gunning, Overmeyer, Möbius and Eisert 1998:184). Alternatively excessively slow activities in certain areas may lead to poor cognitive functioning (executive difficulties) (Barry, Clarke, Johnstone, Mc Carthy and Selikowitz 2009:398). In the case of ADHD, the slowing will be in the executive areas; in the case of APD it will be in the parietal lobes T5 and T6. Slow sensory processing will lead to slower information processing (sensory component in ADHD) (Deonna, Zesiger, Davidoff, Maeder, Mayor and Roulet 2000:595). Bio-markers point out all of these variants of unregulated academic and cognitive difficulties discussed above by Harris et.al.

If genetic studies of ADHD according to the causal model widely point to dopamine deficiency on a neurological level, then dopamine markers may be of use in ADHD research. Dopaminergic neurons of the ventral tegmental area (mid-brain) in EEG studies have been found to be linked to theta oscillations (Blaha, Yang, Floresco, Barr and Phillips 1997:902;

Christie and Tata 2009:415; Rutishauser, Ross, Mamelak and Schuman 2010:903). When ERPs are drawn, mathematical transformation of brain electricity data is transferred from the time frame into a frequency framework. (Sadock and Sadock 2011). Predominantly excessive slow activity in the 4-7Hz electrical frequencies of the brain, slower than the expected 12-15Hz dominance in activity for the eyes-open condition, will make it difficult for the learner to focus, as slower electrical frequencies are not associated with the wakeful state the learner needs to maintain during class time (Wangler, Gevensleben, Albrecht, Studer, Rothenberger, Moll and Heinrich 2011:942). Table 1 illustrates the states of arousal associated with its corresponding frequency of brain electricity measured. Brain frequencies are similar to radio frequencies. As we tune into a different station, the brain tunes into a different state.

Table 1: Brain frequency bandwidths and the functionality of these bandwidths (Sky 2014:1)

Bandwidth name	**Frequency range (Hz)**	**Associated features**
Delta	1-3	Sleep, fatigue, severe slowing of mental processes
Theta	4-7	Meditation, attention lapses, slow processing, memory consolidation, shallow sleep stages
Alpha	8-12	Relaxation, readiness, inactive cognitive process
Low Beta/SMR	12-15	Relaxation, calm focus
Beta 2	15-20	Intense focus, cognitive skills
Beta 3/High Beta	20-30	Anxiety, distractibility

In a double blind study conducted on ADHD and APD diagnosed individuals; methylphenidate was given to all subjects. During auditory and attention tasks, results pointed to no significant improvement on central auditory processing measures, although performance on attention tasks improved significantly (Schochat et al. 2002:742). This supports the importance of correct diagnosis. Commonly, both conditions are diagnosed as ADHD. APD presents as ADHD in the classroom, but a learner's inability to write down an answer could be due to a processing difficulty on a sensory level that occurs within the first 100 milliseconds after a stimulus is presented – the stimulus being a teacher giving a command in the classroom. If the difficulty occurs not within the first 100 milliseconds, but only at 300 milliseconds after the teacher gives a command, (Pinkerton, Watson and Mc Clelland 1989:569) then ADHD is playing a larger role than sensory processing. Later P3 components have been researched in ERP studies to play a role in ADHD (Banaschewski, Rothermel and Poustka 2014:1961). Previous research has shown sensory processing in ADHD to show slower executive function difficulties related to dopamine levels (Karch, Thalmeier, Lutz, Cerovecki, Opgen-Rhein, Hock, Leicht, Hennig-Fast, Meindl, Riedel, Mulert and Pogarell 2010:427; La Hoste, Swanson, Wigal, Glabe, Wigal, King and Kennedy 1996:121). Newer studies have shown contradictory findings where P100 (sensory detection ERPs within the first 100 milliseconds after stimulus presentation) findings were late as well as altered in ADHD learners compared to norms (Kim, Banaschewski and Tannock 2015:116; Kröger, Hof, Krick, Siniatchkin, Jarczok, Freitag and Bender 2014:1; Steger, Imhof, Steinhausen and Brandeis 2000:1141). A biological reading as researched in this paper can provide clearer direction towards the most appropriate treatment. The present study aims to link sensory detection and processing difficulty to APD and execution difficulty to ADHD. The role the one plays in the other is difficult to pin point, but this paper will aim to illustrate the importance of ERP findings in the diagnosis of ADHD and APD learners, pointing to the fact that ERP's can discriminate better than application of past measures.

9. How ERP Research Applies to the Analysis of Auditory Difficulties in ADHD

Neuroimaging in cognitive research provides a tool or measurement more effective than the current tools being used in education to address student difficulties (Dos Santos Siqueira, Biazoli Junior, Comfort, Rohde and Sato 2014:1; Karalunas, Geurts, Konrad, Bender and Nigg 2014:685; Poldrack and Gorgolewski 2014:1510). Psychology relies on an assessment tool called psychometrics, but in spite of a built-in lie scale in most test materials and split half statistical designs, they are still represented by behavioural data gained from self report or other reports. Neurometrics relies on measuring underlying characteristics of electrical human brain activity (Kropotov 2010:45). The term neurometrics is explanatory of the concept of ERP as the finder of the term, E. Roy John describes it. The statistical process of analyzing electrical brain data entails a quantitative procedure during which precise and reproducible scores are obtained. These statistics are compared to a normative group from which a deviation score is calculated numerically. This makes it possible to measure the extent of abnormality or deviation as statisticians calls it. The neurometrics procedure allows for brain quantification of brain statistics but with the advantage of being the same every time we measure and giving a degree of severity. Further biomarkers allow for groups of markers to be put together and to form subgroups in order to identify different disorders (John 1990:251). If ADHD is related to abnormal electrical activity derived by means of ERP, then setting up a group of ERP measurement to form a diagnostic criteria or biological marker, is a large contribution. Structural as well as functional research on the nature of ADHD deviations in electrical functioning is an important step towards more effective diagnosis and understanding of ADHD. ADHD research is aimed at early detection and more effective treatment and these could be aided by applying ERP testing and resting state functional analysis of the brain (Dos Santos Siqueira, Biazoli Junior, Comfort, Rohde and Sato 2014:10).

Studies in clinical electrophysiology literature suggest that children with ADHD (American Psychiatric Association, 1987) show differences from controls in their auditory ERP's recorded during attention-demanding tasks (Johnstone, Barry and Anderson 2001:73). Most studies have reliably found reduced amplitude in ERP measurements in their brain activity (Janssen, Heslenfeld, van Mourik, Geladé, Maras and Oosterlaan 2015:1087054715580847; Shephard, Jackson and Groom 2015b:1; Yang, Hsu, Yeh, Lee, Liang, Fu and Lee 2015). Less amplitude in auditory ERPs would lead to difficulty for the brain to pay attention to the oddball or the auditory target stimulus. The lack of amplitude leads to difficulty in identifying a sound as the auditory target sound by comparing it to auditory memory (Stevens, Pearlson and Kiehl 2007b:1737). Further ERP findings in the fields of ADHD and APD point to a longer latency or slower processing speed of auditory stimuli. The P3 component also shows less amplitude than norm groups (Jafari, Malayeri and Rostami 2015:325; Tristão, F., Pratesi, Gandolfi, Nobrega and Caixeta 2014:217; Yang et al. 2015). A slower processing speed or latency was found in the N2 component in the parietal lobes when ADHD learners were compared to norm groups. Confirmation of a delayed latency was confirmed in further literature reviews. Lower P3 amplitudes in the parietal lobes were also confirmed. (Fallgatter, Ehlis, Seifert, Strik, Scheuerpflug, Zillessen, Herrmann and Warnke 2004:973).

Brain function needs to be analysed in order to monitor the auditory and attentional output of an academic learner. Electrical measurement provides an effective evaluation for neuronal function, as the flow of information from one neuron to the next via an axon and dendrite occurs at an electrical level (Merolla, Arthur, Alvarez-Icaza, Cassidy, Sawada, Akopyan, Jackson, Imam, Guo and Nakamura 2014:668). During the thought process, electrical currents are generated in the cortical areas of the brain. The cortex consists of the most exterior parts of the soft brain under the skull in which the electrical potentials occur. Brain electricity flows exactly like power flows from a switch to a light bulb and can be measured by an electrician using a multi meter. The professional recording data, measures the flow of electricity from one neuron to the next with an electrode. Between neurons, synapses carry the messages, similar to electric cables carrying voltage. Research findings on EEG as a biomarker sets aside groups of electric potentials that look different in ADHD groups from normative groups and these form possible markers based on their mutual deviation in electrical behaviour over many ADHD groups compared to normal groups (Anderson and Filley:1; Duffy, Hughes, Miranda, Bernad and Cook 1994:vi; Wallace, Wagner, Wagner and McDeavitt 2001:165).

In the mid-1950’s it was discovered that it was possible via averaging to extract a time series of changes in electrical brain activity recorded at the human scalp before, during, and after an event of interest and it was demonstrated that measurable parameters of these evoked potentials – their amplitudes, latencies, and scalp topographies – systematically varied with stimulus or response features for example the pitch or colour or intensity (Kutas and Federmeier 2011:621).

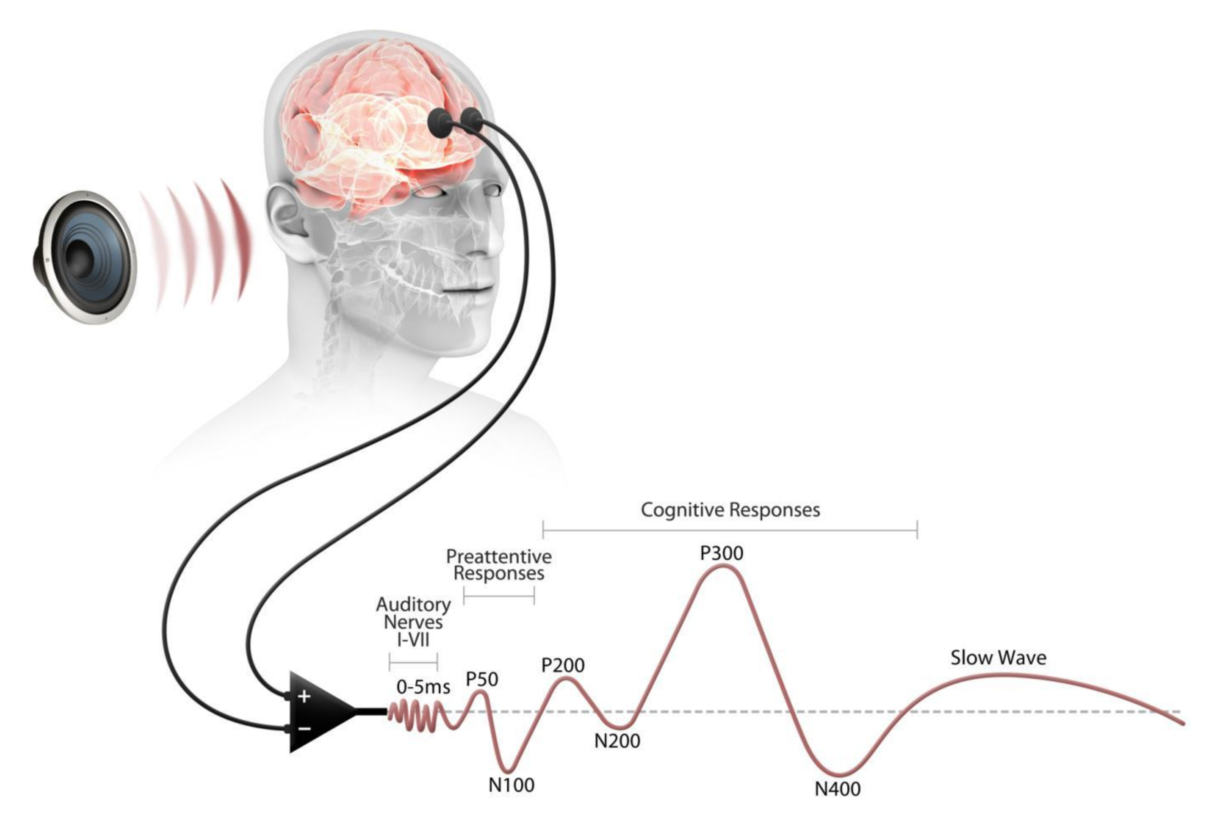


Figure 2: The recording of auditory ERPs. (Shai 2014)

During the EEG signal analysis process of auditory ERP measurement, auditory stimuli are given to the learner as in Figure 2. At the exact moment that the stimulus occurs, the related electrical potential (electrical brain-generated wave related to the stimulus) is analysed. An event-related potential is an averaged EEG occurrence. This means an event which occurs continually during processing of stimuli, is recorded and then averaged for that specific stimulus. At least 100 trials in every auditory stimulus type, for example a long sound or a short sound, are given and averaged. The ERP recorded during the active listening to a long tone or standard tone as discussed in the procedure, is related to auditory processing. To process an ERP, the WINEEG software retrieves the data from just before until just after an auditory event. This means that during the time of the long tone, EEG is drawn for all long tones and added together to divide by the 100 trials and find an average response over the 100 trials of the electrical behaviour during the long tone. This method has been used for a long time but is not yet general procedure in ADHD diagnosis procedures (Knowland, Mercure, Karmiloff-Smith, Dick and Thomas 2014:114). ERP is not as expensive as other neurological procedures, it does not have side effects or cause harm and it offers precise measurement on the time-factor of brain function. These benefits of EEG based diagnosis has allowed for a new interest in this procedure in research for diagnostic purposes (Bathelt, Reilly and De Haan 2014:e51705).

After measuring ERP, calculations are drawn on these electrical potentials, quantifying the amplitude, frequency, and tempo (Tenke, Kayser, Manna, Fekri, Kroppmann, Schaller, Alschuler, Stewart, McGrath and Bruder 2011:388). This provides information about the brain’s response to the event. Roughly calculated, perception occurs at 0-150 ms, phonological and syntactic functions occur at 150-350 ms and conceptual or semantic processing occurs at 350-600 ms in the brain.

An ERP is a temporal resolution in the sense that it shows at what time after presentation of the stimulus the electrical potential occurs as seen in Figure 3. The *x*-axis in this figure indicates time in milli-seconds.

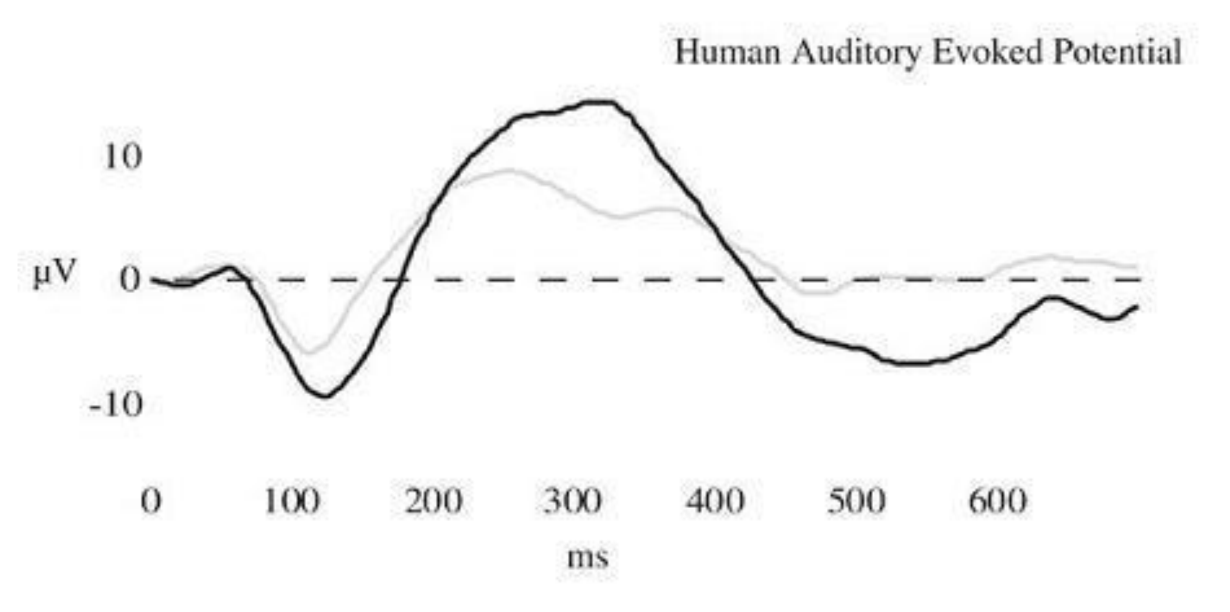


Figure 3: ERPs are named according to time of presentation post stimulus (Pakhomov 2014).

ERPs have different sources and by analyzing waveforms and other factors by new technology such as independent component analysis, their intra-cerebral origin (i.e. underlying neuronal generators) can be sourced fairly accurately (Schroeder, Steinschneider, Javitt, Tenke, Givre, Mehta, Simpson, Arezzo and Vaughan Jr 1994:55). Three indicators of a source help us to distinguish the sources more effectively. The direction of the waves refers to the negative vs. positive deflection. The latency of a wave represents the time from stimulus onset to brain response and the gross location of a wave refers to it being frontal, temporal or occipital for example. The spatial value of an ERP lies in the fact that certain functions occur in specific areas on the cortex, for example, frontal theta content will have attentional and affective implications in general. Frontal and central areas of the brain, for instance, are more related to execution of tasks and control of impulses, while more parietal locations are responsible for sensory and spatial processing (Tenke et al. 2011:388). The image below shows attentional processing occur frontally in general while sensory detection mostly occurs parietally. Memory is mostly a more temporal located function.

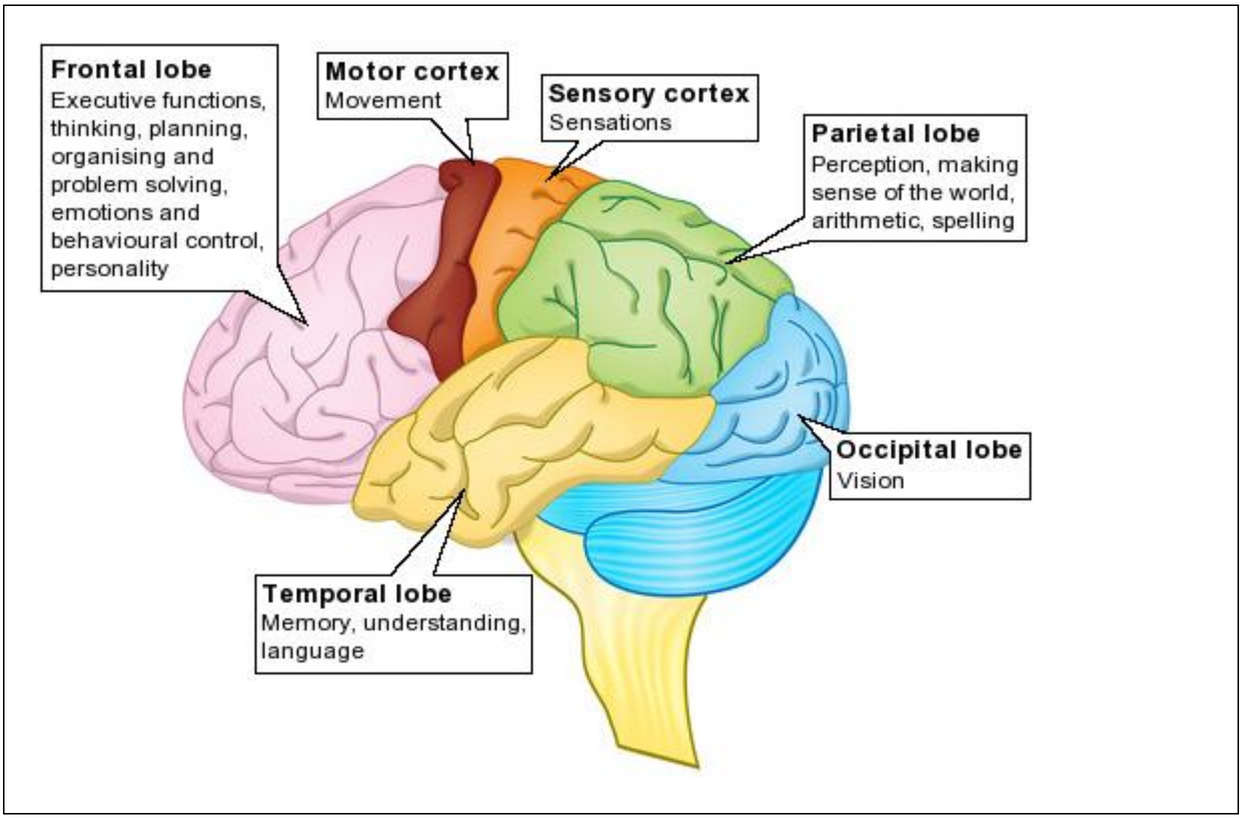


Figure 4: Spatial origin of ERP's (Headway 2015).

The electrical potential related to the auditory response of the learner is further analysed in terms of its positive and negative peaks at different points in time after the stimulus presentation. These signals are therefore named according to their positive or negative direction and according to their latency (e.g., 100 milliseconds will be P1) (Näätänen 1988:117).

Table 2: Summary of basic ERP name tags (Kropotov 2010).

P1	positive oscillation within 100 milliseconds after stimulus presentation
P2	positive oscillation within 200 milliseconds after stimulus presentation
N2	negative oscillation within 200 milliseconds after stimulus presentation
P3	positive oscillation within 300 millisecond after stimulus presentation

According to studies on components of EEG (Luck 2014) they are defined as scalp recorded brain activity. This activity is generated in a certain area of the brain and ERP research aims to group activity generated in the same area together by statistical procedure. When a specific sensory stimulus is presented repetitively, an ERP is obtained by an averaging technique. A temporal (time specific) pattern common to the event is extracted. In the present study it will be an auditory stimulus and the EEG amplitude generated in the moment at which the brain responds to the auditory stimulus several times, will be averaged to draw an auditory ERP.

The advantage of the ERP procedure is the easy application of the electrode cap. While learners are allowed to watch a movie, the application of the cap, similar to a swimming cap which involves no painful procedures, allows for recording of brain activity even in quite severe autistic spectrum learners with sensory difficulties. The ERP data is relatively fast to process depending on which database is used and the inexpensive and fast turnaround period lead to the EEG procedure being an increasingly popular tool for examination of cognitive and emotional disorders (Tenke et al. 2011:388). These findings mean we are able to prove that certain brain activity is related to certain tasks. It is exciting to follow research moving closer to breaking up brain functions into more specific target-oriented components.

10. What Studies Show on ADHD and Auditory-specific ERPs

i) The calculation of ERPs

As information is received and processed, millions of processing functions occur simultaneously. In an attempt to individualize or compartmentalize these functions in order to attempt to intervene where learners struggle academically, the ERPs of auditory processing will be attempted to be broken down. Many studies are pointing to exactly which EEG components are involved in visual (Park, Chiang, Brannon and Woldorff 2014:2239; Thorpe, Fize and Marlot 1996:520), auditory (Hakvoort, van der Leij, Maurits, Maassen and van Zuijen 2015:90; Mecklinger, Schriefers, Steinhauer and Friederici 1995:477), memory (Pivik, Andres, Snow, Ou, Casey, Cleves and Badger 2014:629.1), emotional (Sel, Forster and Calvo-Merino 2014:3263) and other cognitive processes. The ERP process allows us a little better to discriminate between moments in time including:

1. Sensory detection (Hughes 2015:8; Westerfield, Zinni, Vo and Townsend 2015:600)
2. Verification with memory database (Avancini, Soltész and Szűcs 2015:322; Renoult, Tanguay, Beaudry, Tavakoli, Rabipour, Campbell, Moscovitch, Levine and Davidson 2015)
3. Processing what is expected with the identified information (Kutas and Federmeier 2011:621; Tanner, McLaughlin, Herschensohn and Osterhout 2013:367)
4. Planning to execute the expected task (Elchlepp, Lavric, Mizon and Monsell 2012:1137; Gow, Rubia, Taylor, Vallee-Tourangeau, Matsudaira, Ibrahimovic and Sumich 2012:181).

Previous studies (Čeponien, Cheour and Näätänen 1998:345; Giard, Perrin, Pernier and Bouchet 1990:627; Korpilahti and Lang 1994:256) have helped to determine the nature of auditory and attentional signals. This makes it easier for the present study to identify which EEG signals to compare in order to test the hypothesis. These studies have already determined the ERPs related to attentional tasks and how they will differ from auditory ERPs (Amin, Abdel-Hamid and Dessouky 2012:1). It is widely accepted that measurement of the theta-to-beta ratio on the CZ central electrode on the vertex has indicated that ADHD related hormone intervention is successful. The theta/beta ratio gives an index of an individual's ability to pay attention (Morillas-Romero, Tortella-Feliu, Bornas and Putman 2015:1; Putman, Verkuil, Arias-Garcia, Pantazi and van Schie 2014:782; Sangal and Sangal 2014:1550059414527284). This ratio is negatively correlated with age, as it is expected to be higher in younger children, smaller in adulthood, and larger again in later adulthood (Putman et al. 2014:782). This is measured in the EEG where it is expected that a higher ratio will produce more errors (Kim, Lee, Kim, Lee and Min 2015:12; Kim, Lee, Han, Min, Kim and Lee 2015:532). This ratio has been demonstrated in the research of Monastra (Monastra, Lubar, Linden, VanDeusen, Green, Wing, Phillips and Fenger 1999:424; Ogrim, Kropotov and Hestad 2012:482). The two figures below indicate a raised theta ratio to beta drawn statistically from the EEG of a learner. This marker is measured centrally on the Cz electrode (Massar, Kenemans and Schutter 2014:172) and the orange indicates the raise in theta as indicated by the warmer colours on the scale.

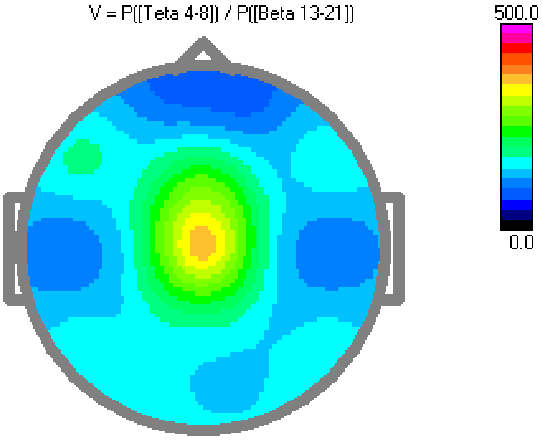


Figure 5: Spatial distribution from Mitsar WinEEG software (Mitsar 2006).

The s-Loreta image draws a better spatial view of the exact activity during an ERP task (Massar et al. 2014:172). This ERP illuminates the activity during processing of auditory information specifically in the area linked to EEG markers in attention. The P3 wave is shown here as it reflects engagement or execution during attentional tasks (Wamain, Pluciennicka and Kalénine 2014:249). The dotted line depicts the stimulis presentation whilst the third positive ossilation depicts the time at which response execution is typically measured.

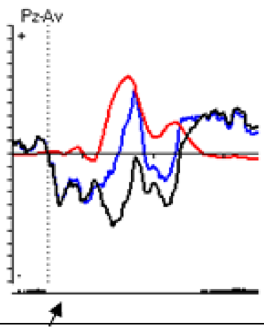
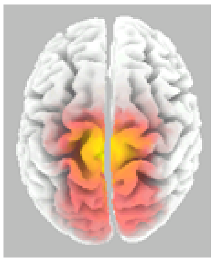
P3b Reflects engagement operation of accumulation brain resources for performing action. Corresponds to P3b wave.		Brodmann area 6 Medial Frontal Gyrus Frontal Lobe Best Match at 5 mm Brodmann area 5 Paracentral Lobule Frontal Lobe	

Figure 6: Spatial image of a Raised theta to beta ADHD distribution by the s-Loreta software (Pascual-Marqui 2002).

The theta/beta ratio is calculated from eyes-open resting state EEG. The ERP task in correlation to a high theta content normally shows a lot of omission errors during a task where the learner is expected to press a button in a "go" situation (Kim, Lee, Kim, Kang, Min, Han and Lee 2015:25). The "go" situation is explained to the learner beforehand as the longer sound. The activity related to pressing the button or execution of the task is measured at the central electrode. This activity will be analysed to obtain the execution or activation-related response the brain makes to the longer sound or "go" situation regardless of whether the "go" button has been pressed. This area and its activity is connected to ADHD, in which the EEG shows more theta activity and ERPs show lower post-task N2, amplitude and latencies in P2, N2 and P3 reponses (Lazzaro, Gordon, Whitmont, Meares and Clarke 2001:247).

ii) ADHD and APD ERP traits

EEG traits in ADHD seem to be more and more consistent as reported in research (Buyck and Wiersema 2014:391; Buyck and Wiersema 2014:3217; Cheung, Rijsdijk, McLoughlin, Brandeis, Banaschewski, Asherson and Kuntsi 2015:bjp. bp. 114.145185; Clarke, Barry, M cCarthy and Selikowitz 2001:2098; Clarke, Barry, Mc Carthy, Selikowitz and Brown 2002:1036; Lenartowicz and Loo 2014:1; Liu, Chen, Lin and Wang 2014:1550059414523959; Monastra et al. 1999:424). Auditory ERPs have been listed as a diagnostic tool for APD in the "Report of the Consensus Conference on the Diagnosis of Auditory Processing" as far back as in 2000 (Jerger and Musiek 2000:467). Some studies have shown APD in children with ADHD to be higher than in children without ADHD, but when ADHD-diagnosed and learning difficulty children have been compared with regards to auditory processing, results suggest that APD is more common in learning difficulty learners than in ADHD learners (Gomez and Condon 1999:150).

The P3 and P6 (Sassenhagen, Schlesewsky and Bornkessel-Schlesewsky 2014:29) responses have been analysed in order to investigate the role of the basal ganglia (Meulman, Stowe, Sprenger, Bresser and Schmid 2014 ; Prodoehl, Yu, Wasson, Corcos and Vaillancourt 2008:3042; Selchenkova, François, Schön, Corneyllie, Perrin and Tillmann 2014) in the cortical loop on attention, as well as on temporal activity called chunking and sequencing when analysed by audiologists (Kotz et al. 2009:982). These later ERP measures applicable to learners in a classroom are mismatched negativity (MMN) measures and P3. This is a good measure for assessing the ability to hear a difference in the pattern and measure how the brain responds to this difference, rather than to measure sustained attention. The differential diagnoses of dyslexia and specific language impairments, applies this measure (Aleksandrov, Babanin and Stankevich 2003:867; Bailey 2010:521). MMN refers to the ERP component measured 100-300 milliseconds after the start of a stimulus. The name refers to the different or mismatched wave pattern generated by negative thoughts when the brain is presented with an infrequent or different stimulus. This task provides insight into a learner's detection of repeated stimuli, but specifically on the learner's registration of a different or infrequently presented stimulus.

Figure 7 illustrates the electrical activity of ERPs. The potential 100-300ms after stimulus onset is related to the MMN component of the ERP. These components present in this measure are the N1 and P2 components and occur in conjunction with the target sound and the non-target sound.

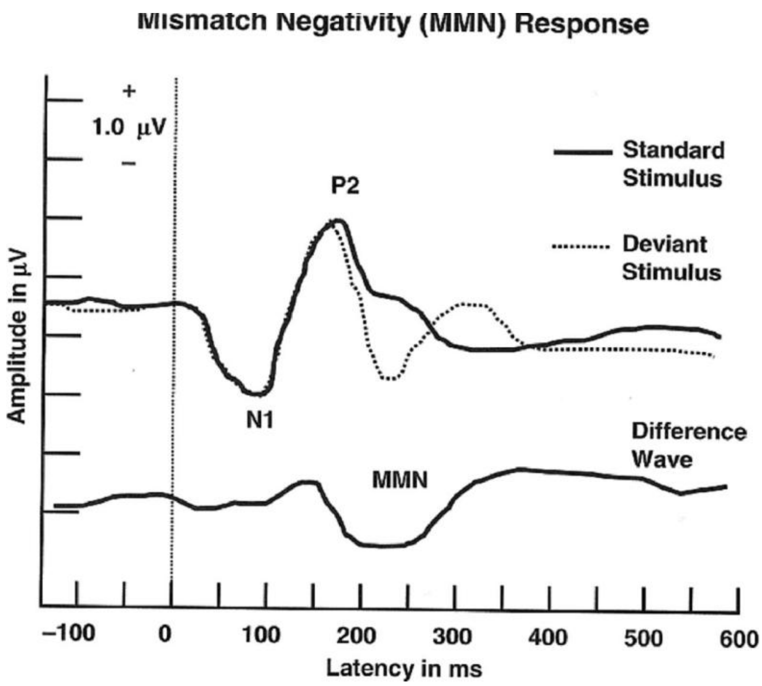


Figure 7: Auditory evoked potentials (Schraag, Bothner, Gajraj, Kenny and Georgieff 1999:1311).

The P3 wave occurs related to a response with 300 millisecond latency. This wave is the first positive wave. Higher level auditory function is also assessed by P3 as well as visual and auditory attention to novel stimuli. This wave plays a major role in assessing the efficiency of treatment of neuropsychiatric disorders including ADHD (Bailey 2010:521). The P3 wave reflects a learner's ability to focus or direct his attention to stimuli. It analyses electro physiological auditory-specific measures mostly. Auditory research in the ERP field counts it to be a reliable tool for auditory analysis, medication choices and diagnosis if it is correctly performed (Bailey 2010:521).

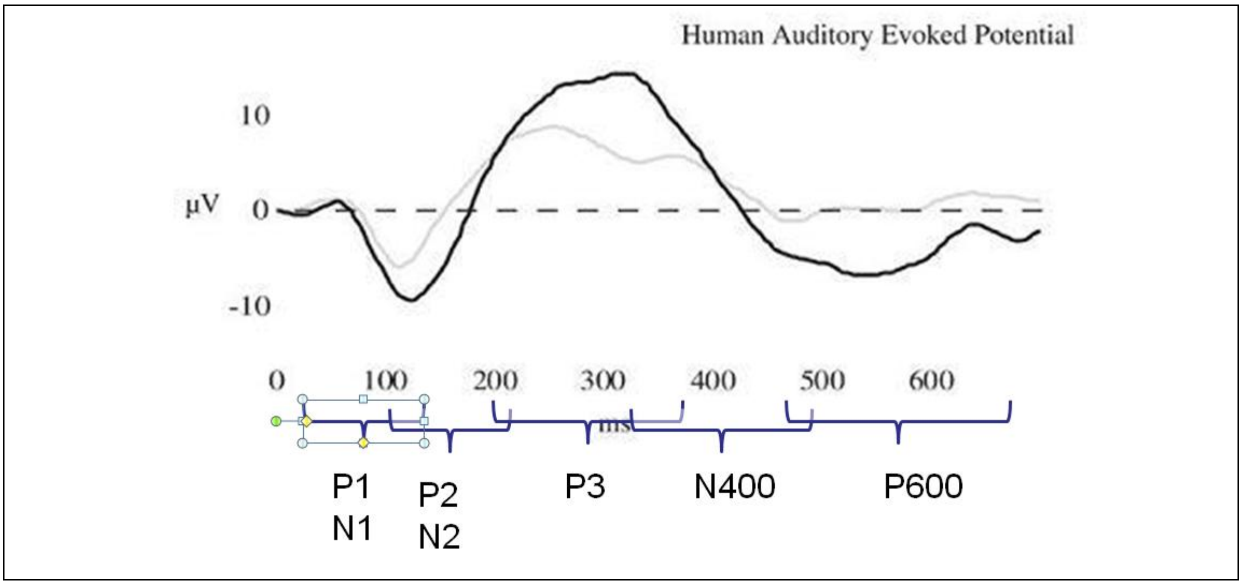


Figure 8: Graphical representation of temporal name tags given to ERPs. (Pakhomov 2014)

iii) Common auditory ERP waves

Table 3: Summary of common ERP waves

P1	50ms - auditory, 100ms – visual General attention/arousal
N1	Early attentional focus (Luck, Heinze, Mangun and Hillyard 1990:528)
P2	Low individual variability and high reproducibility Stimulus classification Sensitive to pitch and loudness (auditory)
N2	Stimulus discrimination Deviation of stimulus from expectation
P3	Stimulus classification and response preparation Varies with stimulus complexity Possibly associated with memory and attention Reflects context updating and attentional allocating (Katayama and Polich 1998:23).

iv) The most consistent Auditory ERP findings in ADHD

ADHD studies show reduced amplitude on attention-related brain function. Attention involves the ability to focus on environmental input and to compare this to the standing database of memory (Stevens, Pearlson and Kiehl 2007a:1737). Analysis of the auditory ERP in terms of amplitude and latency will determine if auditory processing plays a role in ADHD. The deviations in sensory detection areas will also be compared with areas linked to attention. This will determine the role sensory detection – conventionally described as APD - plays in ADHD and execution. The largest studies assessed in this literature overview, where vast groups of statistically very high representation of subject were present and very strict statistical procedures were followed, showed reduced P1, N1, P2, and N2 amplitudes in learners with ADHD (Stevens et al. 2007a:1737). This links the sensory detection process to attentional difficulties. The fronto-striatal process is linked to brain activity only at 300m/s after stimulus presentation and the hypothesis that 100 and 200 m/s activity plays a large role in ADHD is hoped to be supported by the present study. Considerable progress has been achieved by ERP studies with respect to cognitive processing in children and also concerning pathophysiological processes (Banaschewski and Brandeis 2007:415).

Amplitude studies on auditory brain potential voltage, shows that higher amplitude than expected is present in some abnormal groups. This can be explained in the theoretical framework of the arousal model (Zarchi, Avni, Attias, Frisch, Carmel, Michaelovsky, Green, Weizman and Gothelf 2015:782). Another study links sounds becoming louder to attentional ERPs (P3 and N1) but sounds becoming softer to only N1 (Rinne, Särkkä, Degerman, Schröger and Alho 2006:135). This could also support this framework, pointing to proper activation of the brain and proper functioning or arousal of the brain. Further interesting research shows that several brain regions are linked to attention but when specific brain areas are injured, other areas also due not work well do to lack of modulation (Herrmann and Knight 2001:465). This underlines the importance of sensory input for the brain to maintain an appropriate level of stimulation or arousal in order to function optimally.

A recent auditory study has shown that both early and later auditory potentials are involved in listening. Early auditory ERPs (100-300m/s) are involved in classrooms: "listening" when a teacher talks, but the study shows that late auditory ERPs (400-600m/s) are involved when re-evaluation of a deviant sound occurs (Choudhury, Parascando and Benasich 2015:e0138160). To break the process down more specifically some researchers explain two successive events of early and late auditory processing. This first contains the hearing and comparing to memory of what is heard and the second process adds a more attentive process (El Karoui, King, Sitt, Meyniel, Van Gaal, Hasboun, Adam, Navarro, Baulac and Dehaene 2014:bhu143). The second process is associated with attention while the early process is thought to reflect early autonomic processing of sound (Sams, Alho and Näätänen 1983:41). The findings that P3 and other later potentials are connected to more conscious processes of processing have been discussed (Sergent, Baillet and Dehaene 2005:1391). In the current theoretical overview, most of the works link earlier ERP components to detection of the sound by the brain and the later components to attentive processing of the sound.

11. Conclusion

The hypothesis that ADHD ERPs can be isolated from APD ERPs has been confirmed to the extent that hearing occurs in earlier components and attention to the sound occurs during later components. However the processing of sound happening later in the auditory process cannot be separated from the auditory or the attention process. Some components therefore seem to be present both in ADHD and APD. This does not support a complete isolation of the two processes and points to the intricate role these two disorders play within one another. The research question provided answers on how ERPs apply to ADHD by elucidating later components in the central brain regions The research question provided answers on how ERPs apply to APD by elucidating early components in parietal as well as central and frontal regions.

If isolation of ADHD and APD ERPs has been proved to some extent, this is a step closer to being able to better understand the two difficulties in the classroom. If this is better understood, the teacher will be able to assist learners better in a learning environment. Statistical analysis will be used in a follow –up paper to draw a deductive model as the statistical relevance will clarify brain area involvement in ADHD and APD.

12. Educational Implications of Research

Using event-related potentials in the study of auditory processing difficulty involves an attempt to break down the process of listening and understanding. To better understand neurobiological difficulty, analysis of time-locked EEG activity may provide a way to perform this breakdown. An event-related potential captures neural activity in a very time specific method of measuring cognitive functioning. Examining ERPs is associated with specific tasks or cognitive functions such as sensory processing, and the present study will be specifically analysing auditory encoding in order to establish this breakdown. How attention in the frontal brain regions and auditory, sensory processing in the parietal lobes affect one another needs to be better described. ERP is a method of neuropsychiatric research that may better describe the roles that APD and ADD play in relation to one another if sensory detection and sensory execution can be separated. Providing a non-invasive means to support learners and study their information processing more precisely could lead to better understanding of their difficulties. Improved understanding in turn may lead to better assistance for learners, better application of funding for learner support and the development of a better work force and stronger populations.

As it has been determined that EEG and EEG research provides clear answers towards understanding the difficulty of ADHD, it can be used to develop more productive beliefs, experiencing of more positive feelings and engagement in more self-regulated behaviours. This can lead to better intervention and attitudes towards ADHD within the South African context. As classrooms numbers are extensive compared to other countries, better understanding of these learners will lead to more effective tuition.

10. References

Adler, L.A., Newcorn, J.H. and Faraone, S.V. 2007. The Impact, Identification, and Management of Attention-Deficit/ Hyperactivity Disorder in Adults. *CNS Spectrums,* 12(Suppl 23):1.

Ahmed, M.A., Khaled, A., Mohammad, T.A., Mansour, D.F. and Ezz-Eldine, M.Y. 2014. Learning Disabilities in Different Types of Attention Deficit Hyperactivity Disorders and its Relation to Cortical and Brainstem Function. *Journal of Neurology Research,* 4(1):22.

Aleksandrov, A.A., Babanin, M.E. and Stankevich, L.N. 2003. Mechanisms of Generation of Mismatch Negativity and their role in the Recognition of brief Auditory Stimuli. *Neuroscience and Behavioural Physiology,* 33(9):867.

Amin, O.R., Abdel-Hamid, A.A. and Dessouky, H.H. 2012. Central Auditory Processing in Children with Attention Deficit Hyperactivity Disorder. Department of Psychiatry, MD Cairo University, Egypt: Univerity of Cairo.

Anderson, C. and Filley, C.M. Behavioural Neurology & Neuropsychiatry.1.

Arbel, Y. and Donchin, E. 2014. Error and Performance Feedback Processing by children with Specific Language Impairment—An ERP Study. *Biological Psychology,* 99:83.

August, G.J. and Garfinkel, B.D. Behavioural and Cognitive Subtypes of ADHD. *Journal of the American Academy of Child & Adolescent Psychiatry,* 28(5):739.

Avancini, C., Soltész, F. and Szűcs, D. 2015. Separating Stages of Arithmetic Verification: An ERP Study with a Novel Paradigm. *Neuropsychologia,* 75:322.

Bailey, T. 2010. Auditory Pathways and Processes: Implications for Neuropsychological Assessment and Diagnosis of Children and Adolescents. *Child Neuropsychology: A Journal on Normal and Abnormal Development in Childhood and Adolescence,* 16(6):521.

Bakare, M.O. 2012. Attention deficit hyperactivity symptoms and disorder (ADHD) among African children: a review of epidemiology and co-morbidities. *African Journal of Psychiatry,* 15(5):358.

Banaschewski, T. and Brandeis, D. 2007. Annotation: What Electrical Brain Activity Tells Us about Brain Function that other Techniques Cannot Tell Us–A Child Psychiatric Perspective. *Journal of Child Psychology and Psychiatry,* 48(5):415.

Banaschewski, T., Rothermel, B. and Poustka, L. 2014. Evaluation of a Head-to-Head Study of Lisdexamfetamine Dimesylate and Atomoxetine. *Expert Opinion on Pharmacotherapy,* 15(13):1961.

Barry, R.J., Clarke, A.R., Johnstone, S.J., Mc Carthy, R. and Selikowitz, M. 2009. Electroencephalogram θ/β Ratio and Arousal in Attention-Deficit/Hyperactivity Disorder: Evidence of Independent Processes. *Biological Psychiatry,* 66(4):398.

Bathelt, J., Reilly, H. and De Haan, M. 2014. Cortical Source Analysis of High-Density EEG Recordings in Children. (88):e51705.

Bellis, T.J., Billiet, C. and Ross, J. 2011. The Utility of Visual Analogs of Central Auditory Tests in the Differential Diagnosis of (Central) Auditory Processing Disorder and Attention Deficit Hyperactivity Disorder. *Journal of the American Academy of Audiology,* 22(8):501.

Bialystok, E. 2015. Bilingualism and the Development of Executive Function: The Role of Attention. Abstract only. *Child Development Perspectives,* 9(2):117.

Blaha, C.D., Yang, C.R., Floresco, S.B., Barr, A.M. and Phillips, A.G. 1997. Stimulation of the Ventral Subiculum of the Hippocampus Evokes Glutamate Receptor-mediated Changes in Dopamine Efflux in the Rat Nucleus Accumbens. *European Journal of Neuroscience,* 9(5):902.

Bush, G., Valera, E.M. and Seidman, L.J. 2005. Functional Neuroimaging of Attention-Deficit/ Hyperactivity Disorder: A Review and Suggested Future Directions. *Biological Psychiatry,* 57(11):1274.

Buyck, I. and Wiersema, J.R. 2014. Resting Electroencephalogram in Attention Deficit Hyperactivity Disorder: Developmental Course and Diagnostic Value. *Psychiatry Research,* 216(3):391.

Buyck, I. and Wiersema, J.R. 2014. State-Related Electroencephalographic Deviances in Attention Deficit Hyperactivity Disorder. *Research in Developmental Disabilities,* 35(12):3217.

Cantwell, D.P. 1996. Attention Deficit Disorder: a Review of the Past 10 Years. *Journal of the American Academy of Child & Adolescent Psychiatry,* 35(8):978.

Carbone, E. 2001. Arranging the classroom with an eye (and ear) to students with ADHD. *Teaching Exceptional Children,* 34(2):72.

Čeponien, R., Cheour, M. and Näätänen, R. 1998. Interstimulus interval and auditory event-related potentials in children: evidence for multiple generators. *Electroencephalography and Clinical Neurophysiology/Evoked Potentials Section,* 108(4):345.

Cherkasova, M. 2014. Fast Minds: How to Thrive If You Have ADHD (or Think You Might). *Canadian Journal of Psychiatry,* 59(3):172.

Chermak, G.D. 2002. Deciphering Auditory Processing Disorders in Children. *Otolaryngologic Clinics Of North America,* 35(4):733.

Chermak, G.D., Hall, J.W. and Musiek, F.E. 1999. Differential Diagnosis and Management of Central Auditory Processing Disorder and Attention Deficit Hyperactivity Disorder. *Journal of The American Academy of Audiology,* 10(6):289.

Chermak, G.D., Silva, M.E., Nye, J., Hasbrouck, J. and Musiek, F.E. 2007. An Update on Professional Education and Clinical Practices in Central Auditory Processing. *Journal of the American Academy of Audiology,* 18(5):428.

Chermak, G.D., Somers, E.K. and Seikel, J.A. 1998. Behavioural Signs of Central Auditory Processing Disorder and Attention Deficit Hyperactivity Disorder. *Journal of the American Academy of Audiology,* 9(1):78.

Cheung, C.H.M., Rijsdijk, F., Mcloughlin, G., Brandeis, D., Banaschewski, T., Asherson, P. and Kuntsi, J. 2015. Cognitive and Neurophysiological Markers of ADHD Persistence and Remission. *The British Journal of Psychiatry*:bjp. bp. 114.145185.

Choudhury, N.A., Parascando, J.A. and Benasich, A.A. 2015. Effects of Presentation Rate and Attention on Auditory Discrimination: A Comparison of Long-Latency Auditory Evoked Potentials in School-Aged Children and Adults. *PLOS ONE,* 10(9):e0138160.

Christie, G.J. and Tata, M.S. 2009. Right Frontal Cortex Generates Reward-Related Theta-Band Oscillatory Activity. *Neuro Image,* 48(2):415.

Clarke, A.R., Barry, R.J., M Ccarthy, R. and Selikowitz, M. 2001. EEG-Defined Subtypes of Children with Attention-Deficit/Hyperactivity Disorder. *Clinical Neurophysiology: Official Journal of The International Federation of Clinical Neurophysiology,* 112(11):2098.

Clarke, A.R., Barry, R.J., Mc Carthy, R., Selikowitz, M. and Brown, C.R. 2002. EEG Evidence for a New Conceptualisation of Attention Deficit Hyperactivity Disorder. *Clinical Neurophysiology: Official Journal of the International Federation of Clinical Neurophysiology,* 113(7):1036.

Cohen, N.J., Vallance, D.D., Barwick, M., Im, N., Menna, R., Horodezky, N.B. and Isaacson, L. 2000. The Interface between ADHD and Language Impairment: An Examination of Language, Achievement, and Cognitive Processing. *The Journal of Child Psychology and Psychiatry and Allied Disciplines,* 41(03):353.

Crosbie, J. and Schachar, R. 2014. Deficient Inhibition as a Marker for Familial ADHD. *American Journal of Psychiatry*:1.

Del Campo, N., Chamberlain, S.R., Sahakian, B.J. and Robbins, T.W. 2011. The Roles of Dopamine and Noradrenaline in the Pathophysiology and Treatment of Attention-Deficit/Hyperactivity Disorder. *Biological Psychiatry,* 69(12):e145.

Deonna, T., Zesiger, P., Davidoff, V., Maeder, M., Mayor, C. and Roulet, E. 2000. Benign Partial Epilepsy of Childhood: A Longitudinal Neuropsychological and EEG Study of Cognitive Function. *Developmental Medicine & Child Neurology,* 42(09):595.

Dos Santos Siqueira, A., Biazoli Junior, C.E., Comfort, W.E., Rohde, L.A. and Sato, J.R. 2014. Abnormal Functional Resting-State Networks in ADHD: Graph Theory and Pattern Recognition Analysis of fMRI Data. *BioMed Research International,* 2014:1.

Dos Santos Siqueira, A., Biazoli Junior, C.E., Comfort, W.E., Rohde, L.A. and Sato, J.R. 2014. Abnormal Functional Resting-State Networks in ADHD: Graph Theory and Pattern Recognition Analysis of fMRI Data. *BioMed Research International,* 2014:10.

Du Paul, G.J. and Jimerson, S.R. 2014. Assessing, Understanding, and Supporting Students with ADHD at School: Contemporary Science, Practice, and Policy. Abstract only. *School Psychology Quarterly,* 29(4):379.

Duffy, F.H., Hughes, J.R., Miranda, F., Bernad, P. and Cook, P. 1994. Status of Quantitative EEG (QEEG) in Clinical Practice, 1994. *Clinical EEG and Neuroscience,* 25(4):vi.

El Karoui, I., King, J., Sitt, J., Meyniel, F., Van Gaal, S., Hasboun, D., Adam, C., Navarro, V., Baulac, M. and Dehaene, S. 2014. Event-Related Potential, Time-Frequency, and Functional Connectivity Facets of Local and Global Auditory Novelty Processing: An Intracranial Study in Humans. *Cerebral Cortex*:bhu143.

Elchlepp, H., Lavric, A., Mizon, G.A. and Monsell, S. 2012. A Brain-Potential Study of Preparation for and Execution of a Task-Switch with Stimuli That Afford Only the Relevant Task. *Human Brain Mapping,* 33(5):1137.

Engelbrecht, P., Oswald, M. and Forlin, C. 2006. Promoting the implementation of inclusive education in primary schools in South Africa. *British Journal of Special Education,* 33(3):122.

Erb, B.H. 2014. *Experiences and Perceptions of Mental Health Professionals Considered Effective in the Diagnosis and Treatment of Adults with Attention Deficit Hyperactivity Disorder.* 75, ProQuest Information & Learning.

Eu 2014. Average Class Size in European Union. *Education at a Glance*:1.

Evans, J.S.B.T. and Frankish, K.E. 2009. *In Two Minds: Dual Processes and Beyond*, Oxford University Press.

Fallgatter, A.J., Ehlis, A., Seifert, J., Strik, W.K., Scheuerpflug, P., Zillessen, K.E., Herrmann, M.J. and Warnke, A. 2004. Altered Response Control and Anterior Cingulate Function in Attention-Deficit/Hyperactivity Disorder Boys. *Clinical Neurophysiology,* 115(4):973.

Faraone, S.V., Biederman, J. and Milberger, S. 1995. How Reliable are Maternal Reports of their Children's Psychopathology? One-Year Recall of Psychiatric Diagnoses of ADHD Children. *Journal of the American Academy of Child & Adolescent Psychiatry,* 34(8):1001.

Forsyth, J.K., Mc Ewen, S.C., Gee, D.G., Bearden, C.E., Addington, J., Goodyear, B., Cadenhead, K.S., Mirzakhanian, H., Cornblatt, B.A., Olvet, D.M., Mathalon, D.H., Mcglashan, T.H., Perkins, D.O., Belger, A., Seidman, L.J., Thermenos, H.W., Tsuang, M.T., Van Erp, T.G.M., Walker, E.F., Hamann, S., Woods, S.W., Qiu, M. and Cannon, T.D. 2014. Reliability of functional magnetic resonance imaging activation during

working memory in a multi-site study: analysis from the North American Prodrome Longitudinal Study. *Neuroimage,* 97:41.
Frazier, T.W., Youngstrom, E.A., Glutting, J.J. and Watkins, M.W. 2007. ADHD and Achievement: Meta-Analysis of the Child, Adolescent, and Adult Literatures and a Concomitant Study with College Students. *Journal of Learning Disabilities,* 40(1):49.
Frith, U., Morton, J. and Leslie, A.M. 1991. The Cognitive Basis of a Biological Disorder: Autism. *Trends in Neurosciences,* 14(10):433.
Giard, M., Perrin, F., Pernier, J. and Bouchet, P. 1990. Brain Generators Implicated in the Processing of Auditory Stimulus Deviance: A Topographic Event-Related Potential Study. *Psychophysiology,* 27(6):627.
Giuliano, R.J., Karns, C.M., Neville, H.J. and Hillyard, S.A. 2014. Early auditory evoked potential is modulated by selective attention and related to individual differences in visual working memory capacity. *Journal of Cognitive Neuroscience*:1.
Gomez, R. and Condon, M. 1999. Central Auditory Processing Ability in Children with ADHD with and without Learning Disabilities. *Journal of Learning Disabilities,* 32(2):150.
Gow, R.V., Rubia, K., Taylor, E., Vallee-Tourangeau, F., Matsudaira, T., Ibrahimovic, A. and Sumich, A. 2012. Abnormal Centroparietal ERP Response in Predominantly Medication-Naive Adolescent Boys with ADHD During both Response Inhibition and Execution. *Journal of Clinical Neurophysiology,* 29(2):181.
Gyldenkærne, P., Dillon, H., Sharma, M. and Purdy, S.C. 2014. Attend to this: The Relationship between Auditory Processing Disorders and Attention Deficits. *Journal of the American Academy of Audiology,* 25(7):676.
Hakvoort, B., Van Der Leij, A., Maurits, N., Maassen, B. and Van Zuijen, T.L. 2015. Basic Auditory Processing is Related to Familial Risk, not to Reading Fluency: An ERP study. *Cortex,* 63:90.
Hall, A.J. and Lomber, S.G. 2015. High-Field fMRI Reveals Tonotopically-Organized and Core Auditory Cortex in the Cat. *Hearing Research,* 325:1.
Hansen, F.H., Skjørringe, T., Yasmeen, S., Arends, N.V., Sahai, M.A., Erreger, K., Andreassen, T.F., Holy, M., Hamilton, P.J. and Neergheen, V. 2014. Missense Dopamine Transporter Mutations Associate with Adult Parkinsonism and ADHD. *The Journal of Clinical Investigation,* 124(7):3107.
Harris, K.R., Friedlander, B.D., Saddler, B., Frizzelle, R. and Graham, S. 2005. Self-Monitoring of Attention versus Self-Monitoring of Academic Performance: Effects among Students with ADHD in the General Education Classroom. *Journal of Special Education,* 39(3):145.
Headway 2015. Executive Dysfunction after Brain Injury. *The Brain Injury Association.*
Herrmann, C.S. and Knight, R.T. 2001. Mechanisms of Human Attention: Event-Related Potentials and Oscillations. *Neuroscience & Biobehavioural Reviews,* 25(6):465.
Huang-Pollock, C.L., Karalunas, S.L., Tam, H. and Moore, A.N. 2012. Evaluating Vigilance Deficits in ADHD: a Meta-Analysis of CPT Performance. *Journal of Abnormal Psychology,* 121(2):360.
Hughes, G. 2015. ERP and Behavioural Evidence of Increased Sensory Attenuation for Fear-Related Action Outcomes. *Biological Psychology,* 111:8.
Jafari, Z., Malayeri, S. and Rostami, R. 2015. Subcortical Encoding of Speech Cues in Children with Attention Deficit Hyperactivity Disorder. *Clinical Neurophysiology,* 126(2):325.

Janssen, T.W.P., Heslenfeld, D.J., Van Mourik, R., Geladé, K., Maras, A. and Oosterlaan, J. 2015. Alterations in the Ventral Attention Network During the Stop-Signal Task in Children with ADHD: an Event-Related Potential Source Imaging Study. *Journal of Attention Disorders*:1087054715580847.

Jerger, J. and Musiek, F. 2000. Report of the Consensus Conference on the Diagnosis of Auditory Processing Disorders in School-Aged Children. *Journal of the American Academy of Audiology,* 11(9):467.

John, E.R. 1990. Principles of Neurometries. *American Journal of EEG Technology,* 30(4):251.

Johnstone, S.J., Barry, R.J. and Anderson, J.W. 2001. Topographic Distribution and Developmental Timecourse of Auditory Event-Related Potentials in Two Subtypes of Attention-Deficit Hyperactivity Disorder. *International Journal of Psychophysiology,* 42(1):73.

Kamarajan, C. and Porjesz, B. 2012. Brain Waves in Impulsivity Spectrum Disorders. *In:* CYDERS, M. A. (ed.) *Psychology of Impulsivity.* Hauppauge, NY, US: Nova Science Publishers.

Karalunas, S.L., Geurts, H.M., Konrad, K., Bender, S. and Nigg, J.T. 2014. Annual Research Review: Reaction Time Variability in ADHD and Autism Spectrum Disorders: Measurement and Mechanisms of a Proposed Trans-Diagnostic Phenotype. *Journal of Child Psychology and Psychiatry,* 55(6):685.

Karch, S., Thalmeier, T., Lutz, J., Cerovecki, A., Opgen-Rhein, M., Hock, B., Leicht, G., Hennig-Fast, K., Meindl, T., Riedel, M., Mulert, C. and Pogarell, O. 2010. Neural Correlates (ERP/fMRI) of Voluntary Selection in Adult ADHD Patients. *European Archives Of Psychiatry And Clinical Neuroscience,* 260(5):427.

Katayama, J. and Polich, J. 1998. Stimulus Context Determines P3a and P3b. *Psychophysiology,* 35(1):23.

Katragadda, S. and Schubiner, H. 2007. ADHD in Children, Adolescents, and Adults. *Primary Care,* 34(2):317.

Kim, J.W., Lee, J., Kim, B., Kang, T., Min, K.J., Han, D.H. and Lee, Y.S. 2015. Theta-Phase Gamma-Amplitude Coupling as a Neurophysiological Marker of Attention Deficit/Hyperactivity Disorder in Children. *Neuroscience Letters,* 603:25.

Kim, J.W., Lee, J., Kim, H., Lee, Y.S. and Min, K.J. 2015. Relationship between Theta-Phase Gamma-Amplitude Coupling and Attention-Deficit/Hyperactivity Behaviour in Children. *Neuroscience Letters,* 590:12.

Kim, J.W., Lee, Y.S., Han, D.H., Min, K.J., Kim, D.H. and Lee, C.W. 2015. The utility of quantitative electroencephalography and Integrated Visual and Auditory Continuous Performance Test as Auxiliary Tools for the Attention Deficit Hyperactivity Disorder Diagnosis. *Clinical Neurophysiology,* 126(3):532.

Kim, S., Banaschewski, T. and Tannock, R. 2015. Color Vision in Attention-Deficit/Hyperactivity Disorder: A Pilot Visual Evoked Potential Study. *Journal of Optometry,* 8(2):116.

Knowland, V.C.P., Mercure, E., Karmiloff-Smith, A., Dick, F. and Thomas, M.S.C. 2014. Audio-Visual Speech Perception: A Developmental ERP Investigation. *Developmental Science,* 17(1):114.

Korpilahti, P. and Lang, H.A. 1994. Auditory ERP components and mismatch negativity in dysphasic children. *Electroencephalography and clinical neurophysiology,* 91(4):256.

Kotz, S.A., Schwartze, M. and Schmidt-Kassow, M. 2009. Non-Motor Basal Ganglia Functions: a Review and Proposal for a Model of Sensory Predictability in Auditory Language Perception. *Cortex; A Journal Devoted to the Study of the Nervous System and Behaviour,* 45(8):982.

Koven, S. 2015. Taking a New Approach to Psychiatric Research. *The Boston Globe*, December 2014.

Kröger, A., Hof, K., Krick, C., Siniatchkin, M., Jarczok, T., Freitag, C.M. and Bender, S. 2014. Visual Processing of Biological Motion in Children and Adolescents with Attention-Deficit/Hyperactivity Disorder: An Event Related Potential-Study. *PLOS ONE,* 9(2):1.

Kropotov, J. 2010. *Quantitative EEG, Event-Related Potentials and Neurotherapy*, Academic Press.

Kropotov, J.D. 2010. New Tools for Diagnosis and Modulation of Brain Dysfunction.

Kutas, M. and Federmeier, K.D. 2011. Thirty Years and Counting: Finding Meaning in the N400 Component of the Event Related Brain Potential (ERP). *Annual Review of Psychology,* 62:621.

La Hoste, G.J., Swanson, J.M., Wigal, S., Glabe, C., Wigal, T., King, N. and Kennedy, J.L. 1996. Dopamine D4 Receptor Gene Polymorphism is Associated with Attention Deficit Hyperactivity Disorder. *Molecular Psychiatry,* 1(2):121.

Langberg, J.M., Becker, S.P. and Dvorsky, M.R. 2014. The Association Between Sluggish Cognitive Tempo and Academic Functioning in Youth with Attention-Deficit/Hyperactivity Disorder (ADHD). *Journal of Abnormal Child Psychology,* 42(1):91.

Langberg, J.M., Becker, S.P., Epstein, J.N., Vaughn, A.J. and Girio-Herrera, E. 2013. Predictors of Response and Mechanisms of Change in an Organizational Skills Intervention for Students with ADHD. *Journal of Child and Family Studies,* 22(7):1000.

Lawton, K.E., Gerdes, A.C., Haack, L.M. and Schneider, B. 2014. Acculturation, cultural values, and Latino parental beliefs about the etiology of ADHD. *Administration and Policy in Mental Health and Mental Health Services Research,* 41(2):35.

Lawton, K.E., Gerdes, A.C., Haack, L.M. and Schneider, B. 2014. Acculturation, Cultural Values, and Latino Parental Beliefs About the Etiology of ADHD. *Administration and Policy in Mental Health and Mental Health Services Research,* 41(2):189.

Lazzaro, I., Gordon, E., Whitmont, S., Meares, R. and Clarke, S. 2001. The Modulation of Late Component Event Related Potentials by Pre-Stimulus EEG Theta Activity in ADHD. *International Journal of Neuroscience,* 107(3-4):247.

Lenartowicz, A. and Loo, S.K. 2014. Use of EEG to Diagnose ADHD. *Current Psychiatry Reports,* 16(11):1.

Liu, T., Chen, Y., Lin, P. and Wang, J. 2014. Small-World Brain Functional Networks in Children with Attention-Deficit/Hyperactivity Disorder Revealed by EEG Synchrony. *Clinical EEG and Neuroscience*:1550059414523959.

Loo, S.K., Hale, T.S., Macion, J., Hanada, G., Mc Gough, J.J., Mc Cracken, J.T. and Smalley, S.L. 2009. Cortical Activity Patterns in ADHD during Arousal, Activation and Sustained Attention. *Neuropsychologia,* 47(10):2114.

Luck, S.J. 2014. An Introduction to the Event-Related Potential Technique. MIT press.

Luck, S.J., Heinze, H.J., Mangun, G.R. and Hillyard, S.A. 1990. Visual Event-Related Potentials Index Focused Attention within Bilateral Stimulus Arrays. II. Functional Dissociation of P1 and N1 Components. *Electroencephalography and Clinical Neurophysiology,* 75(6):528.

Macdonald, A.W., Cohen, J.D., Stenger, V.A. and Carter, C.S. 2000. Dissociating the Role of the Dorsolateral Prefrontal and Anterior Cingulate Cortex in Cognitive Control. *Science,* 288(5472):1835.

Major, Z.Z. and Benga, I. 2010. Stimulus Related Potentials in ADHD-Epilepsy Comorbidity in Children. Preliminary Report. *Potentiale Dependente de Stimulin Comorbiditatea ADHD-Epilepsie La Copii. Raport Preliminar.,* 83(2):313.

Massar, S.a.A., Kenemans, J. and Schutter, D.J.L.G. 2014. Resting-State EEG Theta Activity and Risk Learning: Sensitivity to Reward or Punishment? *International Journal of Psychophysiology,* 91(3):172.

Mcburnett, K., Pfiffner, L.J. and Frick, P.J. 2001. Symptom Properties as a Function of ADHD Type: An Argument for Continued Study of Sluggish Cognitive Tempo. *Journal of Abnormal Child Psychology,* 29(3):207.

Mecklinger, A., Schriefers, H., Steinhauer, K. and Friederici, A.D. 1995. Processing Relative Clauses Varying on Syntactic and Semantic Dimensions: An Analysis with Event-Related Potentials. *Memory & Cognition,* 23(4):477.

Merolla, P.A., Arthur, J.V., Alvarez-Icaza, R., Cassidy, A.S., Sawada, J., Akopyan, F., Jackson, B.L., Imam, N., Guo, C. and Nakamura, Y. 2014. A Million Spiking-Neuron Integrated Circuit with a Scalable Communication Network and Interface. *Science,* 345(6197):668.

Meulman, N., Stowe, L.A., Sprenger, S.A., Bresser, M. and Schmid, M.S. 2014. An ERP Study on L2 Syntax Processing: When do Learners Fail? *Frontiers in Psychology,* 5.

Mitchell, G. 2015. Arousal in Psychology: Definition. *Social Psychology* [Online], Chapter 4 Available: http://study.com/cimages/multimages/16/hebbianyerkesdodson.jpg [Accessed 19 September 2015].

Mitsar 2006. WinEEG software. Mitsar Medical, St-Petersburg, Russia.

Monastra, V.J., Lubar, J.F., Linden, M., Vandeusen, P., Green, G., Wing, W., Phillips, A. and Fenger, T.N. 1999. Assessing Attention Deficit Hyperactivity Disorder via Quantitative Electroencephalography: An Initial Validation Study. *Neuropsychology,* 13(3):424.

Morillas-Romero, A., Tortella-Feliu, M., Bornas, X. and Putman, P. 2015. Spontaneous EEG Theta/Beta Ratio and Delta–Beta Coupling in Relation to Attentional Network Functioning and Self-Reported Attentional Control. *Cognitive, Affective, & Behavioural Neuroscience*:1.

Musiek, F.E., Baran, J.A., Shinn, J.B., Guenette, L., Zaidan, E. and Weihing, J. 2007. Central Deafness: An Audiological Case Study. *Sordera Central. Un Caso Audiológico de Estudio.,* 46(8):433.

Näätänen, R. 1988. Implications of ERP Data for Psychological Theories of Attention. *Biological Psychology,* 26(1):117.

Nikkelen, S.W.C., Vossen, H.G.M., Valkenburg, P.M., Velders, F.P., Windhorst, D.A., Jaddoe, V.W.V., Hofman, A., Verhulst, F.C. and Tiemeier, H. 2014. Media Violence and Children's ADHD-Related Behaviours: A Genetic Susceptibility Perspective. *Journal of Communication,* 64(1):42.

Nimh. 2015. *The Road to Precision Medicine Starts Here*. USA patent application. 1 May 2015.

Ogrim, G., Kropotov, J. and Hestad, K. 2012. The quantitative EEG theta/beta ratio in attention deficit/hyperactivity disorder and normal controls: sensitivity, specificity, and behavioural correlates. *Psychiatry Research,* 198(3):482.

Pakhomov 2014. Neuroimaging for Cognitive Research. rxinformatics.umn.edu.

Park, J., Chiang, C., Brannon, E.M. and Woldorff, M.G. 2014. Experience-dependent hemispheric specialization of letters and numbers is revealed in early visual processing. *Journal of cognitive neuroscience,* 26(10):2239.

Parker, D.R., Hoffman, S.F., Sawilowsky, S. and Rolands, L. 2013. Self-control in postsecondary settings: students' perceptions of ADHD college coaching. *Journal Of Attention Disorders,* 17(3):215.

Pascual-Marqui, R.D. 2002. Standardized low resolution brain electromagnetic tomography (sLORETA). *The KEY Institute for Brain-Mind Research, University Hospital of Psychiatry*.

Pastor, M.A., Vidaurre, C., Fernández-Seara, M.A., Villanueva, A. and Friston, K.J. 2008. Frequency-specific coupling in the cortico-cerebellar auditory system. *Journal Of Neurophysiology,* 100(4):1699.

Paus, T., Zatorre, R.J., Hofle, N., Caramanos, Z., Gotman, J., Petrides, M. and Evans, A. 1997. Time-related changes in neural systems underlying attention and arousal during the performance of an auditory vigilance task. *Cognitive Neuroscience, Journal of,* 9(3):392.

Pinkerton, F., Watson, D.R. and Mc Clelland, R.J. 1989. A Neurophysiological Study of Children with Reading, Writing and Spelling Difficulties. *Developmental Medicine & Child Neurology,* 31(5):569.

Pivik, R., Andres, A., Snow, J., Ou, X., Casey, P., Cleves, M. and Badger, T. 2014. Semantic Memory Processing is Enhanced in Preadolescents Breastfed Compared to those Formula-Fed as Infants: An ERP N400 Study of Sentential Semantic Congruity. . *The FASEB Journal,* 28(1 supplement):629.1.

Pliszka, S.R., Mc Cracken, J.T. and Maas, J.W. 1996. Catecholamines in Attention-Deficit Hyperactivity Disorder: Current Perspectives. *Journal of the American Academy of Child and Adolescent Psychiatry,* 35(3):264.

Pluta, A., Wolak, T., Czajka, N., Lewandowska, M., Cieśla, K., Rusiniak, M., Grudzień, D. and Skarżyński, H. 2014. Reduced Resting-State Brain Activity in the Default Mode Network in Children with (Central) Auditory Processing Disorders. *Behavioural and Brain Functions: BBF,* 10(1):33.

Poldrack, R.A. and Gorgolewski, K.J. 2014. Making Big Data Open: Data Sharing in Neuroimaging. *Nature Neuroscience,* 17(11):1510.

Prodoehl, J., Yu, H., Wasson, P., Corcos, D.M. and Vaillancourt, D.E. 2008. Effects of Visual and Auditory Feedback on Sensorimotor Circuits in the Basal Ganglia. *Journal of Neurophysiology,* 99(6):3042.

Ptak, R. 2012. The frontoparietal attention network of the human brain action, saliency, and a priority map of the environment. *The Neuroscientist,* 18(5):502.

Putman, P., Verkuil, B., Arias-Garcia, E., Pantazi, I. and Van Schie, C. 2014. EEG Theta/Beta Ratio as a Potential Biomarker for Attentional Control and Resilience Against Deleterious Effects of Stress on Attention. *Cognitive, Affective, & Behavioural Neuroscience,* 14(2):782.

Renoult, L., Tanguay, A., Beaudry, M., Tavakoli, P., Rabipour, S., Campbell, K., Moscovitch, M., Levine, B. and Davidson, P.S.R. 2015. Personal Semantics: Is it Distinct from Episodic and Semantic Memory? An Electrophysiological Study of Memory for Autobiographical Facts and Repeated Events in Honor of Shlomo Bentin. *Neuropsychologia*.

Retz-Junginger, P., Retz, W., Blocher, D., Weijers, H.G., Trott, G.E., Wender, P.H. and Rössler, M. 2002. Wender Utah Rating Scale. The Short-Version for the Assessment of the Attention-Deficit Hyperactivity Disorder in Adults. *Der Nervenarzt,* 73(9):830.

Rinne, T., Särkkä, A., Degerman, A., Schröger, E. and Alho, K. 2006. Two Separate Mechanisms Underlie Auditory Change Detection and Involuntary Control of Attention. *Brain Research,* 1077(1):135.

Ruocco, L.A., Treno, C., Carnevale, U.a.G., Arra, C., Mattern, C., Huston, J.P., De Souza Silva, M.A., Nikolaus, S., Scorziello, A. and Nieddu, M. 2014. Prepuberal Intranasal Dopamine Treatment in an Animal Model of ADHD Ameliorates Deficient Spatial Attention, Working Memory, Amino Acid Transmitters and Synaptic Markers in Prefrontal Cortex, Ventral and Dorsal Striatum. *Amino Acids,* 46(9):2105.

Russo, F. 2011. Explaining Causal Modelling. Or, What a Causal Model Ought to Explain. *New Essays in Logic and Philosophy of Science, College Publications, London*:1.

Rutishauser, U., Ross, I.B., Mamelak, A.N. and Schuman, E.M. 2010. Human Memory Strength is Predicted by Theta-Frequency Phase-Locking of Single Neurons. *Nature,* 464(7290):903.

Sadock, J. and Sadock, V.A. 2011. *Kaplan and Sadock's Synopsis of Psychiatry: Behavioural Sciences/Clinical Psychiatry*, Lippincott Williams & Wilkins.

Sahli, S. 2009. Auditory Processing Disorder in Children: Definition, Assessment and Management. *Int. Adv. Otol,* 5(1):105.

Sams, M., Alho, K. and Näätänen, R. 1983. Sequential Effects on the ERP in Discriminating Two Stimuli. *Biological Psychology,* 17(1):41.

Sangal, R.B. and Sangal, J.M. 2014. Use of EEG Beta-1 Power and Theta/Beta Ratio Over Broca's Area to confirm Diagnosis of Attention Deficit/Hyperactivity Disorder in Children. *Clinical EEG and Neuroscience*:1550059414527284.

Sassenhagen, J., Schlesewsky, M. and Bornkessel-Schlesewsky, I. 2014. The P600-as-P3 Hypothesis Revisited: Single-Trial Analyses Reveal that the Late EEG Positivity Following Linguistically Deviant Material is Reaction Time Aligned. *Brain and Language,* 137:29.

Schachar, R. 2014. Genetics of Attention Deficit Hyperactivity Disorder (ADHD): Recent Updates and Future Prospects. *Current Developmental Disorders Reports,* 1(1):41.

Schochat, E., Scheuer, C.I. and Andrade, Ê.R. 2002. ABR and Auditory P300 Findings in Children with ADHD. *Arquivos de Neuro-Psiquiatria,* 60(3B):742.

Schraag, S., Bothner, U., Gajraj, R., Kenny, G.N.C. and Georgieff, M. 1999. The Performance of Electroencephalogram Bispectral Index and Auditory Evoked Potential Index to Predict Loss of Consciousness During Propofol Infusion. *Anesthesia & Analgesia,* 89(5):1311.

Schroeder, C.E., Steinschneider, M., Javitt, D.C., Tenke, C.E., Givre, S.J., Mehta, A.D., Simpson, G.V., Arezzo, J.C. and Vaughan Jr, H.G. 1994. Localization of ERP generators and identification of underlying neural processes. *Electroencephalography and Clinical Neurophysiology. Supplement,* 44:55.

Sel, A., Forster, B. and Calvo-Merino, B. 2014. The emotional Homunculus: ERP Evidence for Independent Somatosensory Responses During Facial Emotional Processing. *The Journal of Neuroscience,* 34(9):3263.

Selchenkova, T., François, C., Schön, D., Corneyllie, A., Perrin, F. and Tillmann, B. 2014. Metrical Presentation Boosts Implicit Learning of Artificial Grammar.

Sergent, C., Baillet, S. and Dehaene, S. 2005. Timing of The Brain Events Underlying Access to Consciousness During the Attentional Blink. *Nature Neuroscience,* 8(10):1391.

Shai, G. 2014. *Neurometrix* [Online]. Available: http://neuronetrix.com/technology-i-36.html [Accessed 31 January 2015.

Shephard, E., Jackson, G.M. and Groom, M.J. 2015a. The Effects of Co-Occurring ADHD Symptoms on Electrophysiological Correlates of Cognitive Control in Young People with Tourette Syndrome. *Journal of Neuropsychology*:1.

Shephard, E., Jackson, G.M. and Groom, M.J. 2015b. The Effects of Co-Occurring ADHD Symptoms on Electrophysiological Correlates of Cognitive Control in Young People with Tourette Syndrome. *Journal of Neuropsychology*:1.

Sky, N. 2014. What are the different EEG Band Frequencies? :1.

Snyder, J.S., Yerkes, B.D. and Pitts, M.A. 2015. Testing Domain-General Theories of Perceptual Awareness with Auditory Brain Responses. Abstract only. *Trends in Cognitive Sciences,* 19(6):295.

Sokolova, E., Hoogman, M., Groot, P., Claassen, T., Vasquez, A.A., Buitelaar, J.K., Franke, B. and Heskes, T. 2015. Causal Discovery in an Adult ADHD Data Set Suggests Indirect Link Between DAT1 Genetic Variants and Striatal Brain Activation During Reward Processing. *American Journal of Medical Genetics Part B: Neuropsychiatric Genetics,* 168(6):508.

Spreng, R.N., Sepulcre, J., Turner, G.R., Stevens, W.D. and Schacter, D.L. 2013. Intrinsic architecture underlying the relations among the default, dorsal attention, and frontoparietal control networks of the human brain. *Journal of Cognitive Neuroscience,* 25(1):Abstract only.

Statistics, N.I.F.E. 2011. Schools and Staffing Survey. *In:* EDUCATION (ed.).

Steger, J., Imhof, K., Steinhausen, H. and Brandeis, D. 2000. Brain Mapping of Bilateral Interactions in Attention Deficit Hyperactivity Disorder and Control Boys. *Clinical Neurophysiology: Official Journal of the International Federation of Clinical Neurophysiology,* 111(7):1141.

Stevens, M.C., Pearlson, G.D. and Kiehl, K.A. 2007a. An fMRI Auditory Oddball Study of Combined-Subtype Attention Deficit Hyperactivity Disorder. *The American Journal of Psychiatry,* 164(11):1737.

Stevens, M.C., Pearlson, G.D. and Kiehl, K.A. 2007b. An FMRI Auditory Oddball Study of Combined-Subtype Attention Deficit Hyperactivity Disorder. *American Journal of Psychiatry,* 164(11):1737.

Tanner, D., Mclaughlin, J., Herschensohn, J. and Osterhout, L. 2013. Individual Differences Reveal Stages of L2 Grammatical Acquisition: ERP Evidence. *Bilingualism: Language and Cognition,* 16(02):367.

Taylor, E., Sergeant, J., Doepfner, M., Gunning, B., Overmeyer, S., Möbius, H.J. and Eisert, H.G. 1998. Clinical guidelines for hyperkinetic disorder. *European Child & Adolescent Psychiatry,* 7(4):184.

Tenke, C.E., Kayser, J., Manna, C.G., Fekri, S., Kroppmann, C.J., Schaller, J.D., Alschuler, D.M., Stewart, J.W., Mcgrath, P.J. and Bruder, G.E. 2011. Current Source Density Measures of Electroencephalographic Alpha Predict Antidepressant Treatment Response. *Biological Psychiatry,* 70(4):388.

Thome, J., Ehlis, A., Fallgatter, A.J., Krauel, K., Lange, K.W., Riederer, P., Romanos, M., Taurines, R., Tucha, O., Uzbekov, M. and Gerlach, M. 2012. Biomarkers for Attention-Deficit/Hyperactivity Disorder (ADHD). A Consensus Report of the WFSBP Task Force on Biological Markers and the World Federation of ADHD. *The World Journal of Biological Psychiatry: The Official Journal of the World Federation of Societies of Biological Psychiatry,* 13(5):379.

Thorpe, S., Fize, D. and Marlot, C. 1996. Speed of Processing in the Human Visual System. *Nature,* 381(6582):520.

Tomlin, D., Dillon, H., Sharma, M. and Rance, G. 2015. The Impact of Auditory Processing and Cognitive Abilities in Children. *Ear and Hearing,* 36(5):527.

Tristão, R.M., F., H., Pratesi, R., Gandolfi, L., Nobrega, Y.K.M. and Caixeta, R. 2014. Timing in Auditory Processing in Children with ADHD with Sleep Disorder. *Procedia-Social and Behavioural Sciences,* 126:217.

Ullebø, A.K., Posserud, M., Heiervang, E., Obel, C. and Gillberg, C. 2011. Prevalence of the ADHD phenotype in 7- to 9-year-old children: effects of informant, gender and non-participation. *Social Psychiatry and Psychiatric Epidemiology,* 47(5):Abstract only.

Vaidya, C.J. and Stollstorff, M. 2008. Cognitive Neuroscience of Attention Deficit Hyperactivity Disorder: Current Status and Working Hypotheses. *Developmental Disabilities Research Reviews,* 14(4):261.

Van De Glind, G., Konstenius, M., Koeter, M.W.J., Van Emmerik-Van Oortmerssen, K., Carpentier, P., Kaye, S., Degenhardt, L., Skutle, A., Franck, J., Bu, E., Moggi, F., Dom, G., Verspreet, S., Demetrovics, Z., Kapitány-Fövény, M., Fatséas, M., Auriacombe, M., Schillinger, A., Møller, M., Johnson, B., Faraone, S.V., Ramos-Quiroga, J.A., Casas, M., Allsop, S., Carruthers, S., Schoevers, R.A., Wallhed, S., Barta, C., Alleman, P., Levin, F.R. and Van Den Brink, W. 2014. Variability in the prevalence of adult ADHD in treatment seeking substance use disorder patients: Results from an international multi-center study exploring DSM-IV and DSM-5 criteria. *Drug and Alcohol Dependence,* 134:158.

Visser, S.N., Bitsko, R.H., Danielson, M.L., Perou, R. and Blumberg, S.J. 2010. Increasing Prevalence of Parent-Reported Attention-Deficit/Hyperactivity Disorder among Children. *Morbidity and Mortality Weekly Report,* 59(44):1439.

Vossel, S., Geng, J.J. and Fink, G.R. 2014. Dorsal and Ventral Attention Systems Distinct Neural Circuits but Collaborative Roles. *The Neuroscientist,* 20(2):150.

Wallace, B.E., Wagner, A.K., Wagner, E.P. and Mcdeavitt, J.T. 2001. A history and Review of Quantitative Electroencephalography in Traumatic Brain Injury. *The Journal of Head Trauma Rehabilitation,* 16(2):165.

Wallis, D. 2010. The Search for Biomarkers for Attention Deficit/Hyperactivity Disorder. Abstract only. *Drug News & Perspectives,* 23(7):438.

Wamain, Y., Pluciennicka, E. and Kalénine, S. 2014. Temporal Dynamics of Action Perception: Differences on ERP Evoked by Object-Related and Non-Object-Related Actions. *Neuropsychologia,* 63:249.

Wangler, S., Gevensleben, H., Albrecht, B., Studer, P., Rothenberger, A., Moll, G.H. and Heinrich, H. 2011. Neurofeedback in Children with ADHD: Specific Event-Related Potential Findings of a Randomized Controlled Trial. *Clinical Neurophysiology: Official Journal of the International Federation of Clinical Neurophysiology,* 122(5):942.

Westerfield, M.A., Zinni, M., Vo, K. and Townsend, J. 2015. Tracking the Sensory Environment: An ERP Study of Probability and Context Updating in ASD. *Journal of Autism and Developmental Disorders,* 45(2):600.

Whalley, K. 2015. Psychiatric Disorders: A Zebrafish Model of ADHD. *Nature Reviews Neuroscience,* 16(4):188.

Willcutt, E.G., Doyle, A.E., Nigg, J.T., Faraone, S.V. and Pennington, B.F. 2005. Validity of the Executive Function Theory of Attention-Deficit/Hyperactivity Disorder: A Meta-Analytic Review. *Biological Psychiatry,* 57(11):1336.

Woldorff, M.G., Gallen, C.C., Hampson, S.A., Hillyard, S.A., Pantev, C., Sobel, D. and Bloom, F.E. 1993. Modulation of early sensory processing in human auditory cortex during auditory selective attention. *Proceedings of the National Academy of Sciences,* 90(18):8722.

Yang, M., Hsu, C., Yeh, P., Lee, W., Liang, J., Fu, W. and Lee, C.W. 2015. Attention Deficits Revealed by Passive Auditory Change Detection for Pure Tones and Lexical Tones in ADHD Children. *Frontiers in Human Neuroscience,* 9.

Zarchi, O., Avni, C., Attias, J., Frisch, A., Carmel, M., Michaelovsky, E., Green, T., Weizman, A. and Gothelf, D. 2015. Hyperactive Auditory Processing in Williams Syndrome: Evidence from Auditory Evoked Potentials. *Psychophysiology,* 52(6):782.

An ERP analysis of Auditory and Attentional processes with the aim of better clarification of the electrical process involved in ADHD

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Abstract

Objective: The objective of this paper is to explore the significance of neural correlates in Attention Deficit Hyperactivity Disorder (ADHD) through investigating the electro encephalograph (EEG) during auditory processing. ADHD is mostly described in terms of executive functions and frontal lobe involvement, but auditory involvement and sensory input from the parietal lobes are proving more and more to be integral parts of attention systems in ADHD. **Method:** Auditory event-related potential (ERP) patterns were investigated in order to better explain the involvement of brain areas. Auditory and attentional tasks were given to ADHD and non-ADHD learners to better clarify the involvement of auditory processing during attentional networks. The EEG was recorded during this behavioural task by a total of 33 participants (mean age 11.8, SD 3.2, females 10, males 23). Eighteen-channel ERP recordings were recorded and differences in response latencies, response amplitudes, and overall amplitude were measured. **Results:** The P2 amplitude was not found to be elevated similar to findings in parallel studies. N2 and P3 ERP components were elevated, but failed to reach statistical significance. The use of Independent Component Analysis (ICA) has been applied to differentiate different areas of cortical firing during cognitive task execution. Specifically auditory task processing has been mapped by this procedure. **Conclusion:** A correlation between lower N2 and P3 amplitudes and lower performance was also found. Further research in terms of how medication influences earlier and later ERP components may benefit intervention in school learners even further. The value of this for future research lies therein that it includes multivariate analyses and resolution of EEG signals into their neural generators and places EEG on a path to transition from a research tool to an aid in clinical evaluation of ADHD which leads to a better understanding of the disorder.

Keywords: *Attention Deficit Hyperactivity Disorder, Auditory Processing, Event Related Potential, Electroencephalography, Diagnosis, Independent Component Analysis.*

1. Introduction

The specific use of ERP in the fields of diagnosis of attention deficit hyperactivity disorder (ADHD) and auditory processing is the focus of the present study. One of the discriminating aspects of human beings is their ability to process and maintain abstract concepts. We have this capacity due to our highly developed frontal lobes (Farina, Hussey and Roche 2015:168). ADHD is a prevalent developmental disorder, characterized by varying levels of inattention, hyperactivity, and impulsivity symptoms (Kuntsi, Pinto, Price, van der Meere, Frazier-Wood and Asherson 2014:127) linked to the frontal lobes. Examining ERP findings in ADHD learners provides an analysis system to investigate their neural organization. It confirms to be one of the most popular assessment tools emerging in the field of ADHD research (Rabiner 2013:1). ERP methods can identify different processes in the brain and link them to a stimulus related to this activity based on the recorded process underlying the response to this stimulus. ERP can also discriminate between early sensory versus later cognitive aspects of processing. It provides information concerning the latency or timing. It makes discrimination of components related to background stimuli and "go" stimuli possible. This elucidates what the brain does in an active attention period or an activation execution period when response is expected from the subject (Karayanidis, Robaey, Bourassa, De Koning, Geoffroy and Pelletier 2000:319).

Abnormal ERP findings are found to be present in ADHD learners when compared to norms (Gow, Rubia, Taylor, Vallée-Tourangeau, Matsudaira, Ibrahimovic and Sumich 2012:181). To determine whether auditory processing is integral to a diagnosis of ADHD or has completely different underlying brain patterns, the ERPs of auditory processing difficulties such as in auditory processing disorders have also been investigated. ADHD is often seen as a homogenous group of learners. Through the investigation of the differences in EEG's ADHD learners, in comparison with neuro-normal children, specific EEG deviances in individual children with ADHD can be identified (Brown, Clarke, Barry, Mc Carthy, Selikowitz and Magee 2005:94). If it is considered that learners with a diagnosis of ADHD may form part of a heterogeneous group with different underlying electrical patterns, then auditory processing difficulty could be one of the subgroups of this heterogeneous disorder.

Grouping ADHD into better defined functional subgroups could be very helpful in the learning environment.

N1, P2, N2 and P3 are the most commonly analysed ERPs in auditory processing (Jonkman, Kemner, Verbaten, Koelega, Camfferman, vd Gaag, Buitelaar and van Engeland 1997:690). These four ERP conditions will be analysed. The most consistent finding regarding the ERPs of ADHD learners show enhanced P2 and reduced N2 components in the frontal regions in target (requires a response from learner) and non-target (should be ignored by learner) conditions compared to controls (Barry, Clarke, Mc Carthy, Selikowitz, Brown and Heaven 2009:124). ERP research on auditory processing concerning oddball tasks has shown that P2 differs during visual and auditory tasks (Kemner, Verbaten, Cuperus, Camfferman and Van Engeland 1994:225; Oades 1998:83; Satterfield, Schell and Nicholas 1994:1). This makes it possible to study auditory specific potential without studying visual processing. Further findings during auditory processing is a smaller P3 amplitude at parietal regions during the target condition (Karayanidis et al. 2000:319) in ADHD learner groups.

In location research on auditory ERPs, the origin of these potentials have been on the temporal lobes (Tarkka, Stokić, Basile and Papanicolaou 1995:538). Physical lesion damage to the temporal lobes supported these findings. When injury occurred to temporal-parietal areas, speech and auditory processing was defective or disappeared and there was a loss of the P3 waveform (Smith, Halgren, Sokolik, Baudena, Musolino, Liegeois-Chauvel and Chauvel 1990:235). The present study tries to determine that in some learners, execution of tasks does not occur due to a lack of sensory detection on auditory level, not due to an executive lobe dysfunction. By highlighting this within the South African context, it is hoped that further research and and better intervention strategies will follow as it demontrates that too many learners who have auditory processing difficulties are diagnosed as ADHD while their difficulties lie at an earlier processing level. Learners need to receive correctly before they can give back correctly. P3 execution occurs 300m/s after stimulus presentation while sensory detection at P2 occurs 100m/s before a learner could execute. If the 200m/s process is compromised, it will lead to a lack of 300m/s brain function even if this is not the main area of dysfunction.

Independent component analysis (ICA) has been utilized by the present study to better illustrate and isolate areas of the highest activation during ERP analysis.

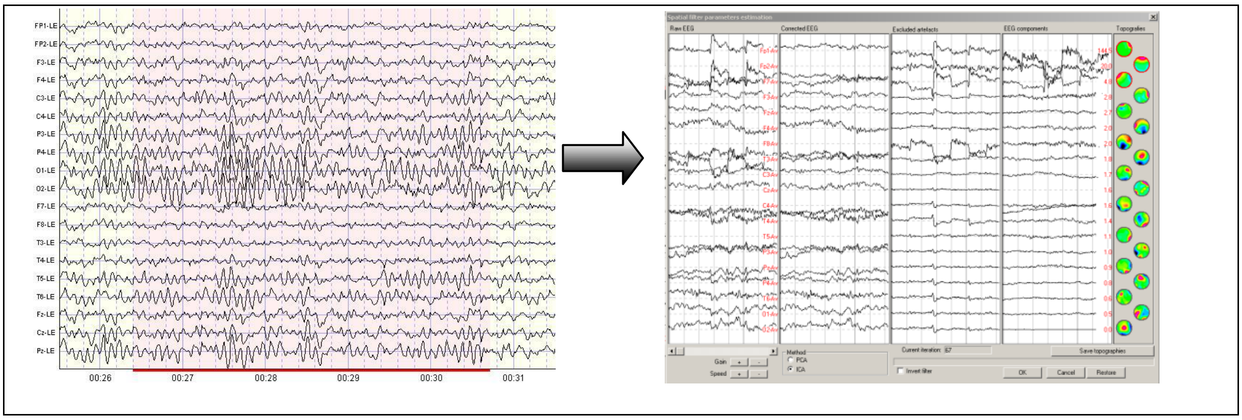


Figure 1: ICA process isolates signals by WINEEG software (Song, De Ridder, Schlee, Van de Heyning and Vanneste 2013:1855)

ICA has the advantage of creating a more graphic or physical presentation of electrical activity. Figure 1 shows the raw EEG and the individual EEG tendencies which re-occurred often in the raw data set as isolated extractions on the right hand side as coloured areas on the scalp. This tool allows for the imaging of a functional process which is in general harder to illustrate graphically than with a structural analysis of the brain. In recent years, the use of ICA has become an increasingly popular means to identify important aspects of EEG data in neuro-science. It helps identify functionally meaningful EEG (Debener, Ullsperger, Siegel, Fiehler, Von Cramon and Engel 2005:11731). ICA is a reliable method to analyse data. EEG data consist of a constant repetition of activity characteristic to an individual. Some aspects repeat more frequently and some less frequently, but the same activity constantly occurs on the same electrode sites. This data is then put through a vector processor in order to obtain statistical and mathematical values and graphs to better illustrate patterns in brain activity. Simplified, this means EEG is a continuous electrical current but can be broken down into separate smaller signals. This is similar to the tide coming in on the beach. As a video of this on fast forward will show a constant drop and raise of water levels, it can be broken down to illustrate the process occurring wave by wave. As the fast forward images shows rising and falling of the tide, single decomposed screen shots in slow motion show single waves.

ICA is a statistical method of extracting useful data from an EEG based on the area of research for example auditory functions of the brain. In order to identify a blind source, ICA computes statistically to find which output originates from which source (Raimondo, Kamienkowski, Sigman and Fernandez Slezak 2012:206972).

An analysis of performance of the ADHD and norm groups were added to the ERP analysis and ICA processes to determine if interesting trends occur. The results during an attention task such as discussed in the methodology were used.

2. Theoretical Framework

The present study aimed to explain the ERP findings in ADHD and Auditory Processing Disorder (APD) learners respectively by using two separate theoretical frameworks. These frameworks have been applied with the aim of understanding the statistical findings of the present study. It is commonly found in attentional cognitive research that execution of information is found in frontal lobe brain regions. If the present study supports frontal lobe differences in ADHD learners, it can successfully link the Causal modeling framework (Frith, Morton and Leslie 1991:433) to the diagnosis. If frontal lobes support execution as an integral attentional process and if this is found to be different in ADHD learners from in the neuro-normal control, then a causal explanation for the non-attentional or non-executional processes in ADHD learners has been confirmed and supported by the present study.

Secondly, the model of arousal explains that APD and ADHD learners differ from norms due to the lower arousal levels noted in these two groups compared to the norm group (Loo, Hale, Macion, Hanada, Mc Gough, Mc Cracken and Smalley 2009:2114). Some studies, for example have found that noise may help learners to focus rather than distract their attention as expected. Noise evokes arousal or awakening of the brain (Söderlund and Sikström 2008:1). If under-arousal is part of the basis for difficulties experienced by students with ADHD, then some of the performance differences between learners with and without ADHD during low arousal conditions should disappear under conditions of high arousal. This possibility has been researched by selecting ADHD and normal learners as identified by their teachers and showing them a high-action movie that heightened heart rate and skin conductance levels. After raising arousal levels of the ADHD learners, they responded similarly to the norm group based on the set expectations of the study (Shaw and Brown 1999:227). Although this data cannot confirm the hypothesis that cortical under-arousal may be the neurological underpinning of ADHD, it is consistent with the proposition. It had scientifically been confirmed in the present study that the actual brain activity level, measured in amplitude (micro volts), was lower in the ADHD group than in the controls over three ERP components extracted for analysis. This supports the proposed idea of low arousal being related to ADHD on a neuro-scientific basis as hypothesized. It is consistent with the arousal level study by the researchers who found better performance after rising heart rate and skin conductance as well (Shaw and Brown 1999:227), even though these were clinical task completion measurements, and not neurological measurements. Similar studies to the present study support lower levels of ERP signals or lower arousal in ADHD just as this performance test illustrated higher performance in higher arousal environments (Gellatly and Meyer 1992:694).

3. Research Problem and Questions

The need of assisting tools in the diagnosis of ADHD exists. Current tools rely on patient and parent reports and the clinical diagnosis of the specialist, but a need for a biological measurement exists. This needs to be a consistently re-producible and a completely objective measure.

The following questions guide this research:

1. What knowledge is currently available about auditory ERPs in ADHD and auditory processing difficulty groups?
1. How do these ERPs findings in ADHD and APD differ from EEG patterns in neuro normal groups?
2. How does the presence of auditory difficulties according to ERPs in the ADHD learners affect their functioning?
3. Can the use of ERPs successfully isolate APD from ADHD?

As sensory detection (and this implies auditory detection) has been confirmed to be an early ERP occurring mainly in the parietal brain region, it highlighted the usefulness of the ERP process once again for the present study. The hypothesis is made that certain ADHD learners may show temporal lobe difficulty rather than frontal and central lobe difficulty. A further hypothesis is made that auditory processing task performance will be worse in the ADHD population. Both these statements will confirm auditory difficulty as part of the process of ADHD.

4. Aims

The aim of the present study was to establish if ERP markers could find auditory origins towards explaining ADHD. The aim was to isolate ADHD learners from learners who experience mostly auditory difficulty. In order to do this, the ERP process will be applied to isolate time brackets in which certain brain areas fire in relation to a stimulus. ICA will then be performed to establish which topographic brain area is involved during information processing.

5. Methodology

The present study has been set up in order to test ADHD participant brain responses compared to a normative group. The overall design of this article will take a quantitative approach, meaning it will use a formal objective, systematic approach to the process followed. Data will be utilized in order to test the hypothesis that many ADHD learners may have been wrongly diagnosed and rather show APD related ERP markers. The independent variable is the auditory stimulus given to the brain. The dependent variable is the ADHD or ARP marker or components identified during the brain response.

5.1 Participants

The sampling was purposive, not random, but the ADHD learners were brought to the researcher for learning assistance by their parents. The researcher did not approach the participants and therefore were not sought out particularly for the purpose of the present study. The participants had only been selected if they had a prior objective ADHD diagnosis made by an independent pediatrician. Parent interviews were conducted in order to establish the nature of school-related difficulties and severity of ADHD related symptoms experienced. Only learners between the ages of 7 and 17 years with ADHD participated in the present study. A total of 33 participants (mean age 11.8, SD 3.2, females 10, males 23) took part. Moreover, 33 matched controls by age and gender were included in the study for comparative purposes. These learners were pre-recorded neuro-normal datasets used with permission from the owners of the HBI normative database (Muller, Candrian and Kropotov 2011:132). Learners suffering from a neurological disorder other than ADHD were not allowed to form part of the ADHD group. These included severe co-morbidities, or traumatic brain injury. Learners who were taking stimulants or other medication for their ADHD symptoms were asked to refrain from taking the medication 24 hours prior to the testing if it was a fast release product, which would not have a bad withdrawal response. In the case of medications which could show withdrawal difficulties, learners were allowed to take their normal medication dose for ethical reasons.

Healthy controls may not have been diagnosed with ADHD according to the DSM-IV rating scale or clinical analysis or parent interview. The normative group also does not include individuals if they met any criteria for another psychiatric disorder or have any history of past treatment with medication for psychological or academic difficulties. Control children were not taking any medications at the time of the study.

Ethical approval was obtained (Clearance number: UFS-EDU-2014-016) from the ethical board of the Faculty of Education of the University of the Free State (see Annexure A). Written informed consent from parents was obtained as well as consent from the children, in accordance with ethical requirements (see Annexure B).

5.2 Procedure and behavioural task

The EEG was recorded using a Mitsar-EEG-202®, PC-controlled digital electroencephalographic system with a DC-coupling and a 24-bit resolution. This is a binary digit rate which allows for enough information to be processed per clock cycle to be optimal during the present study. The input signals referenced against the linked ears montage and filter settings were set between 0.5 and 50 Hertz (Hz) according to South African electric supply interference levels. The sampling rate was set at 250 Hz. Impedance was kept below 5k Ohm for all electrodes. Electrodes were placed according to the International 10-20 system using a 19-channel electrode cap with tin electrodes (Electro-cap International Inc.) onto sites Fp1, Fp2, F3, F4, F7, F8, Fz, C3, C4, Cz, T3, T4, T5, T6, P3, P4, Pz, O1 and O2 (See Figure 2 below).

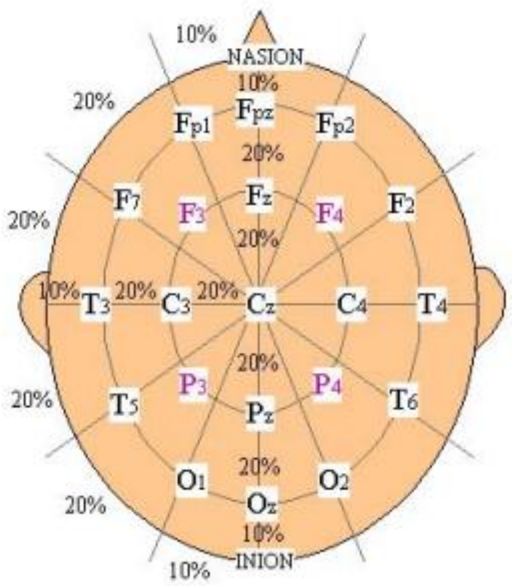


Figure 2: Electrode positions (Teplan 2002:7).

Eye blink artefacts were excluded by means of extracting ICA identifications of the eyeball movements due to the polarized characteristic of the eye. Further, epochs or parts of the filtered electroencephalogram with excessive amplitude (>100 µV) and/or excessive (threshold = z-score of 6) 0 to 3 Hz frequency activities were automatically excluded from the current analysis. A notch filter (50 Hz) as was appropriate for South African electrical supply conditions was applied to the data to exclude artefact from the electrical supply entering in from the mains. Finally, the EEG was manually inspected by the eye to verify or exclude additional artefacts which were missed by the software settings.

The 33 participants were each tested during a single recording procedure lasted approximately 2.5 hours. During this period all participants had an EEG cap applied while enjoying tea and biscuit snacks and watching a movie of their choice. During this time they were allowed to move minimally. Recording times lasted 5 minutes, 5 minutes and 20 minutes each while learners were made comfortable and asked to remain as still as possible. During the 20 minute recording, learners did their auditory task while pressing a mouse button on the Go-task. This was performed while participants were seated in a reclined position. Auditory stimuli (using sound cards and speakers) were presented by Psytask software. To measure the reaction time, a second computer and mouse were used.

Figure 3: The EEG cap is connected to a MITSAR amplifier and an EEG recording computer (Image researcher's own with permission granted.)

Psytask works together with WinEEG software and provides a synchronous stimuli presentation on the second computer with EEG acquisition being done on the main computer. In the present study the two computers were connected via COM ports. The Psytak program ran on a second computer called a slave computer and the WinEEG program ran on the recording computer. The WinEEG program sends synchronization codes to the Psytask program to control its work and provide a synchronous stimuli presentation with EEG acquisition. The auditory oddball task consisted of 994 auditory stimuli. Among them, 800 stimuli were short tones (standard tone or short condition, 100m/s long) and 194 stimuli were long tones (long tone or target condition, 400m/s long). Participants had to press the mouse button as fast as possible after hearing the 400m/s target tone. These 194 target tones were divided in 100 long tones that appeared 2, 3 or 4 stimuli after a short tone (long 234 condition) while the other 94 appeared 5,6,7 or 8 stimuli after a short tone (long 5678 condition). Participants were excluded from the study if the remaining epochs for short and long (both long 234 and long 5678) conditions were above 30, which constitute an initial plateau for a reliable measurement. Consequently a total of 33 participants remained for further analysis (mean age = 11.8, SD = 3.2, females = 10).

Due to the number of participants involved in the present study, the ICA *Infomax* algorithm was selected (Theis, Jung, Puntonet and Lang 2003:419). This is a version of the *Matlab* software allowing computationally for very efficient algorithms, graphical user interface, one-by-one estimation of the independent components and estimation of both sub- and super gaussian independent components (Schobben, Stone, Yeredor, Cardoso, Eriksson, Akuzava, Bro and Sidiropoulos 2014:1). ERPs of 33 healthy participants between 7-17 years old from the HBI normative database were used where the same auditory task has been applied. The ICA input data were from the two-dimensional 19-scalp-locations x 108-ERP-time-series matrix. Conditions were referred to as "no-go" or "standard" condition when a short tone was given to the learner and "deviant-standard" or "go condition" when a long tone was given and a response was expected from the learner. The independent ERP components N2, P2 and component P1 were extracted during the standard condition by applying ICA to the 100-350 m/s time interval after the short stimulus. The P3 component was extracted during the deviant-standard condition when a long tone was given 700m/s after stimulus presentation. These target conditions occurred when the participant should have pressed the button on the long 400m/s tone in the present study. The ERP components were extracted from the electrode with the highest activation for that component.

Finally the analysis was done between EEG findings and performance of ADHD learners and norms. This was inspected in order to see if correlations between the EEGs and the performance of the two groups (ADHD and norm) occur.

5.3 Measurement of Latency and Amplitude of ERP Components

A student's *t*-test statistical analysis was applied. The categorical independent variables were the ADHD and control/norm groups and the dependent variable was the APD group tested for differences in the means of the dependent variable broken down by the levels of the independent variable. The ADHD group was compared to the norms based on ERP findings in order to distinguish if a third group of APD learners could be isolated based on ERP differences from ADHD and norm groups.

In order to measure the amplitude and latency of the ERPs, first the conventional peak measurement method was used, which defines latency and amplitude at the point in time when the potential reaches its maximum/minimum within a predefined window. Secondly, the area approach was used, in which the onset was defined as the point where the amplitude reached 50% of the maximum/minimum within the predefined window and the offset was defined as the time point when the waveform reached the same amplitude on the other side. Then, the amplitude of the wave was measured as the mean amplitude on the area. The latency of the wave was measured as the latency to the maximum in the area. Subsequently, the total time window for calculation was limited in calculation of area as follows: 270–420 m/s for the N2 in F3, Fz and F4 electrode in "standard" or "no go" condition, 300–420 m/s for the N2 in F3, Fz and F4 electrode in "target" or "go" condition, 470–700 m/s for the P3 in Pz electrode in "target" or "go" condition. A difference curve was drawn during the target-standard condition (mismatch negativity, MMN).

ICA was applied in order to separate independent sources linearly mixed in several sensors (Makeig, Jung, Bell, Ghahremani and Sejnowski 1997a:10979). In this method, ERP data was composed into a number of components or findings other than normal eyes- open EEG. This method was then applied to detect target ERPs from an auditory experiment by deriving an algorithm. The components were extracted, each representing a major response peak. These components were then mapped on a scalp distribution map. Some of the components were drawn during the target situation when a learner was supposed to respond and others were drawn in the non-target situation when no response was needed. The groups on target and on non-target peaks extracted were then investigated.

6. Results

Through several experimental methods and topographic mapping and the averaging of signals in ERP signal and electrical source analysis, it has been possible to draw meaningful conclusions towards application of ERPs in auditory research(Patel and Azzam 2005:147). In the present study the mean ERP waves have been drawn in order to compare ADHD learners with controls. The distinction between ADHD learners and neuro-typical learners (or norms based on auditory attentional tasks) have been drawn and illustrated. Most of the results follow a similar trend with common findings in this field.

6.1 Raw ERP component results

a) Raw N2 component (200–350 m/s)

According to previous research findings, N2 is a negativity of frontal cortical distribution seen only during conscious attention to a stimulus. During this research it was recorded while a learner concentrated or listened to the sounds during an auditory task. As found in the research literature, N2 arises frontally and centrally during classification tasks in general while a participant would be trying to listen to the long and short tones. The N2 component corresponds to voluntary processing and is evoked when participants selectively attend to deviations in a pattern, also called oddball situations (Patel and Azzam 2005:147). The standard situation in the present study occurred when a certain number of repeating short tones was presented and the standard-deviant or “go” situation was the situation when long tones were given at random moments in-between short tone sequences.

The conclusion from the present study for the N2 component in the frontal electrodes was that amplitude is lower in the ADHD sample, as seen in Figures 4, 5 and 6. The voltage (µV) or amplitude of the electrical potential is presented on the y-axis while the time (m/s) of presentation of the component is presented on the x-axis. The P or positive components occur above the x-axis while the N or negative components occur below the x-axis.

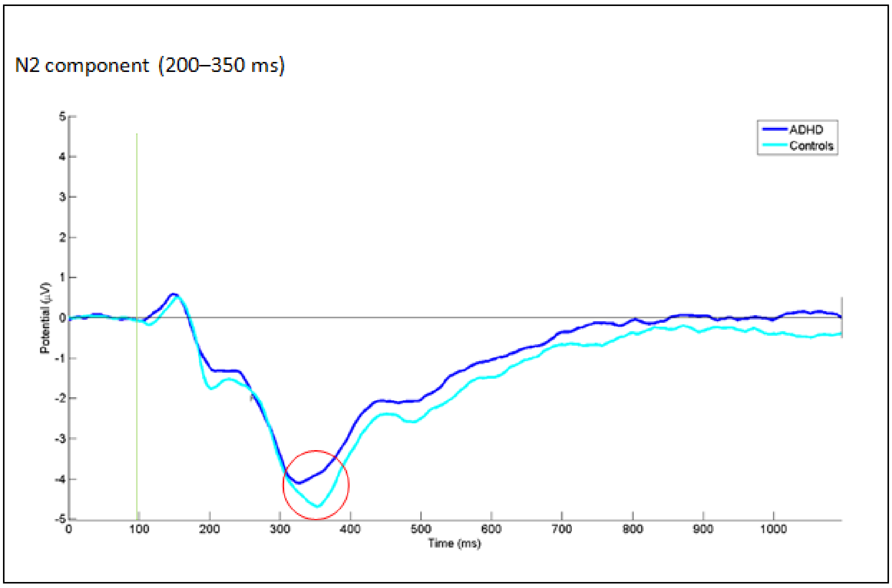


Figure 4: N2 computed at FZ (frontal lobe) during standard tone
Onset of stimulus 100m/s- green line

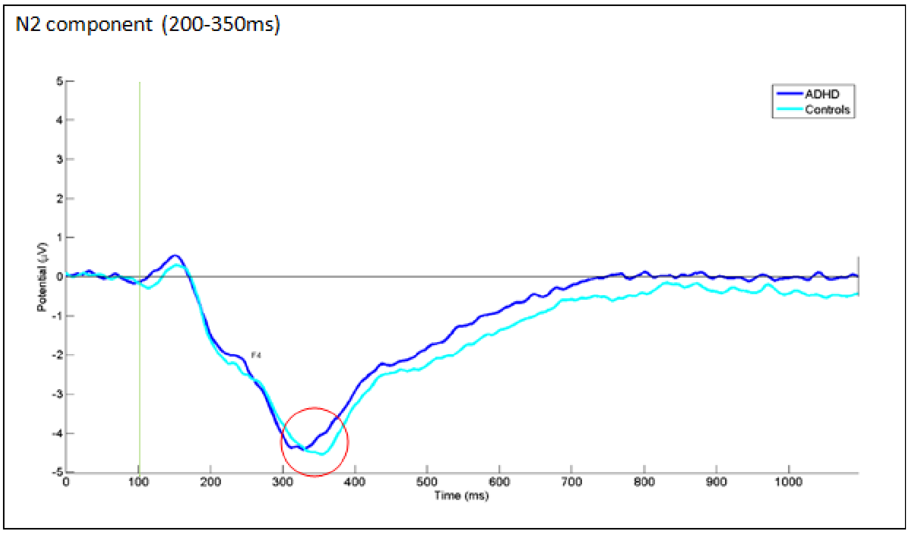


Figure 5: N2 computed at F4 (frontal lobe) during standard tone
Onset of stimulus 100 m/s – green line

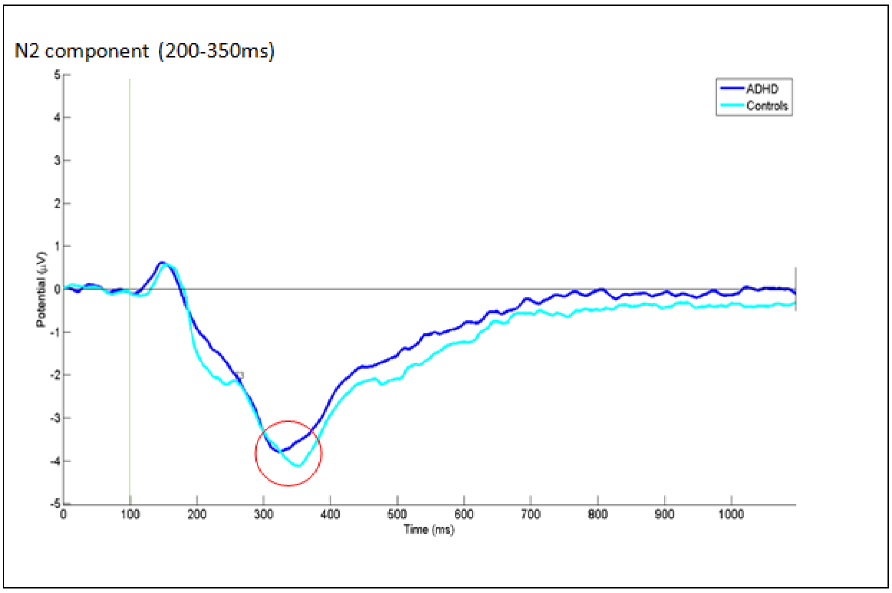


Figure 6: N2 computed at F3 (frontal lobe) during standard tone
Onset of stimulus 100 m/s – green line

This finding in the ADHD learners illustrates that their brains generated smaller activity measured in voltage or supported a lower level of arousal than in the case of the control group. This was measured while the learners were all focussing on what they were hearing.

The ADHD learners follow the dark lines in which the negativity curve is smaller than the lighter line in all three electrodes sites Figures 4-6. C3, left frontal on the hairline, Cz, above the nose and C4, right frontally are frontal electrodes sites involved. The frontal area has been found to contain the largest negative waves during the 200m/s period and this is why the negative wave 200m/s after the stimulus presentation is drawn from these electrodes. The stimulus is presented 100m/s into the measurement period. ± 250m/s after stimulus presentation (in the total measurement window of the x-axis more or less on 350m/s) the N2 wave presents and is seen as the larger wave on the lighter line in Figures 4-6 in the control group.

b) Raw P2 component (150–270 m/s)

The P2 component peaks at around 150-200m/s in central cortical regions and is generally found to be larger in ADHD learners than in controls during attention or focus (Barry, Johnstone and Clarke 2003:184). Studies also found the P2 component to be larger in ADHD learners than in controls during auditory processing tasks (Holcomb, Ackerman and Dykman 1985:656; Kemner, Verbaten, Koelega, Buitelaar, Van der Gaag, Camfferman and Van Engeland 1996:522; Oades, Dittmann-Balcar, Schepker, Eggers and Zerbin 1996:163; Satterfield et al. 1994:1). It can be concluded that the P2 component is involved in cognitive matching compares sensory inputs with stored memory (Key, Dove and Maguire 2005:183). This is a potential or wave related to processing.

Contrary to the literature supporting an elevated P2 in central regions for the ADHD population as discussed, the opposite result is observed here, as in Figure 7. Previous findings failed to be supported by the present study for P2 findings. As seen in Figure 7 the controls had higher amplitude (light blue line).

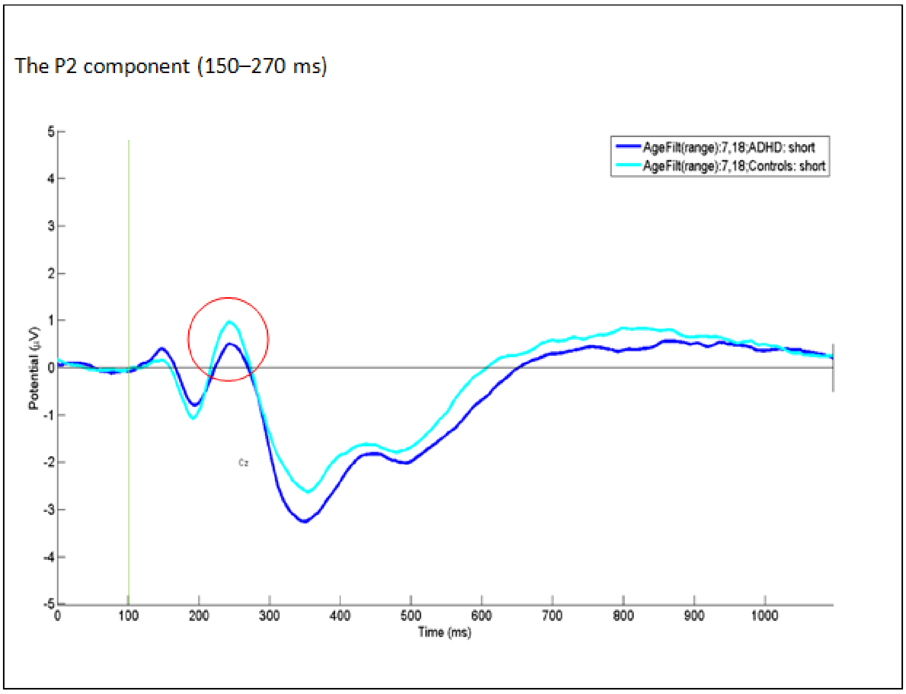


Figure 7: P2 component computed at Cz (central lobe) during standard tone
Onset of stimulus at100 m/s – green line

c) Raw P3 component (290–700 m/s)

The P3 component was first described as early as in the 1960s (Sutton, Braren, Zubin and John 1965:1187). P3 is involved during the cognitive processes of selective attention and information processing (Patel and Azzam 2005:147). The P3 wave is active during target conditions. The target occurs when the learner is supposed to hit the button when a longer tone is given. The P3 component is evoked during recognition and memory updating processes in the brain. During the recognition and memory comparison process the brain compares a stimulus to what it remembers as the target stimulus. This process is also called match/mismatch in ERP circles. (Näätänen 1990:201). In the present study, the learners knew they had to press the response button upon hearing a long sound. When this occurred, the brain recognised the long tone and then during the time in which the positive oscillation around 300 m/s after stimulus presentation occurred, compared it to what the memory data base has stored as being a longer sound than the shorter ones. When the direction from which a P3 voltage is fired is mathematically investigated, it points to the hippocampal and parietal cortical regions (Nakajima, Miyamoto and Kikuchi 1994:1059). The P3 wave was therefore measured on the parietal Pz electrode, found more or less on the crown of a learner's head. This was done during the target condition or when the long tone appeared and the learner had to press the button.

The most consistent finding in relation to ADHD on P3 components in related research is reduced parietal P3 amplitude in the auditory oddball task. The P3 component was lower in amplitude for the ADHD sample than for the control group during the target condition, as shown in Figure 8 of the present study and in the difference curve in Figure 9. This result is consistent with relevant research on the P3 component (Barry et al. 2003:184; Satterfield, Schell, Nicholas, Satterfield and Freese 1990:879).

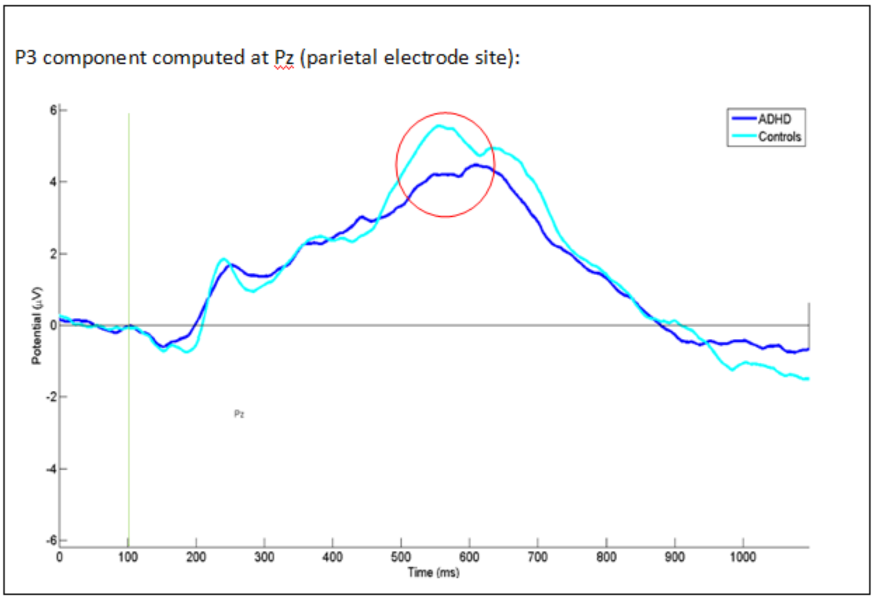


Figure 8: Original ERP wave at Pz electrode (target tone).
Onset of stimulus 100 m/s.

The long-short condition difference curve is presented in Figure 9 and was found to be lower in the ADHD sample. However, analyzing the ERP data group differences using paired-sample *t*-tests led to statistically insignificant results.

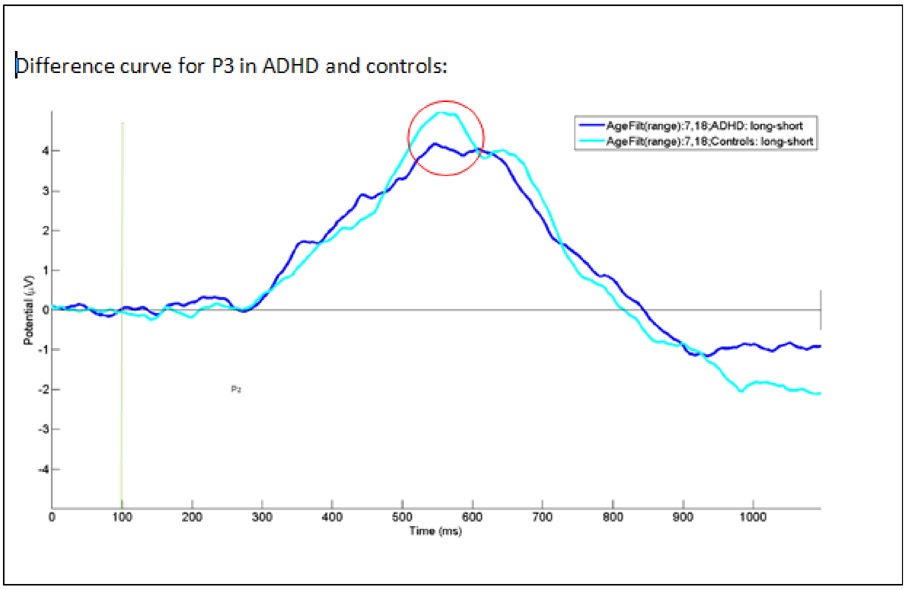


Figure 9: Original ERP wave at Pz electrode (target-standard tone).
Onset of stimulus 100 m/s.

6.2 Activation curves and ICA for components during standard tone

ICA images use colour to point out the electrical activity underlying the tasks, in order to highlight areas that are most involved. The areas less involved are cooler colours and the areas highly involved in electrical firing are indicated by the warmer colours – red indicating most highly involved.

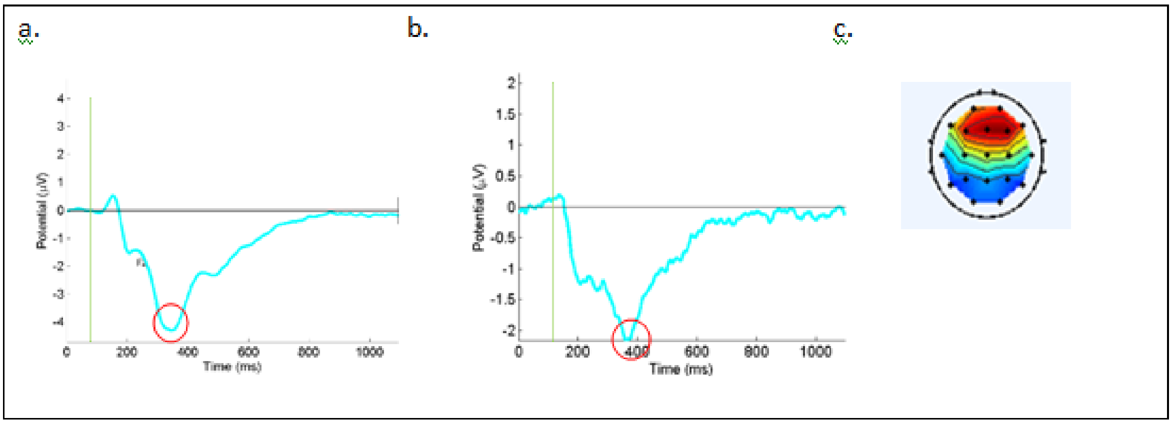
The findings are presented in three points a, b and c for each component:

a. Independent components decomposed from raw ERPs for all participants are illustrated in images a. respectively in Figures 10-13. The average of all the participants' ERP components measured at the Fz electrodes during the short tone situations are illustrated here. An ERP is usually an average of different sources of the brain and does not come from an independent source. There are more than one underlying processes. When ERP is measured at the Cz electrode, the signal may be coming from different regions and these signals total up. The graphs in the images named a. were drawn before any filtering was done in order to identify source areas.

b. ICA is used to "unmix" source signals which are mixed as measured for raw ERPs. ICA filters identify independent EEG sources contributing to the averaged ERP. ICA separates ERP responses into signals which occurred at the same time and in the same areas on the cortex. The images in b. respectively illustrate the ERP components after filtering as seen in Figures 10-13. In other words, the ICA method has been applied to raw ERPs in the images named b. in order to obtain a number of topographies each corresponding to one component. After each of the topographies containing a specific ERP had been filtered out, these topographies were back-projected to raw ERPs in order to obtain an independent component curve as in the b. images in Figures 10-13. The raw ERP data has been filtered by using topographies of the ICA components of graphs in the images in c. to establish the curves for the images for b. respectively in Figures 10-13.

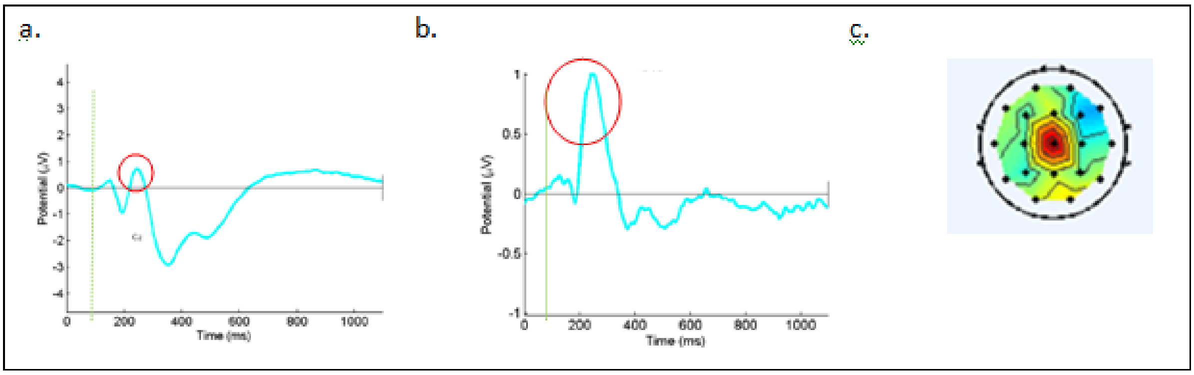
c. This image throughout the section shows the topographic image for area involvement drawn by ICA. The most likely area of neuron involvement is identified by selecting the electrodes where the highest voltage of activity took place during a specific time of component withdrawal. The ICA is drawn from the component activation while the ADHD learners listened to the standard tones.

Figure 10: The N2 component (200–350 m/s)



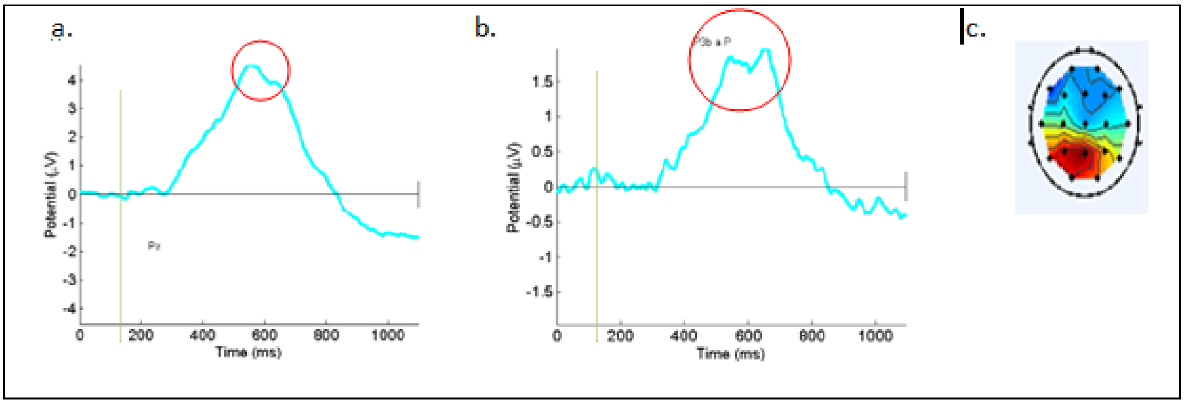
a. Grand average of N2 component at Fz (frontal electrode) during standard tone
b. Activation curve of N2 during standard tone back-projected from Fz electrode
c. ICA topography of N2 component during standard tone

Figure 11: The P2 component (150–270 m/s)



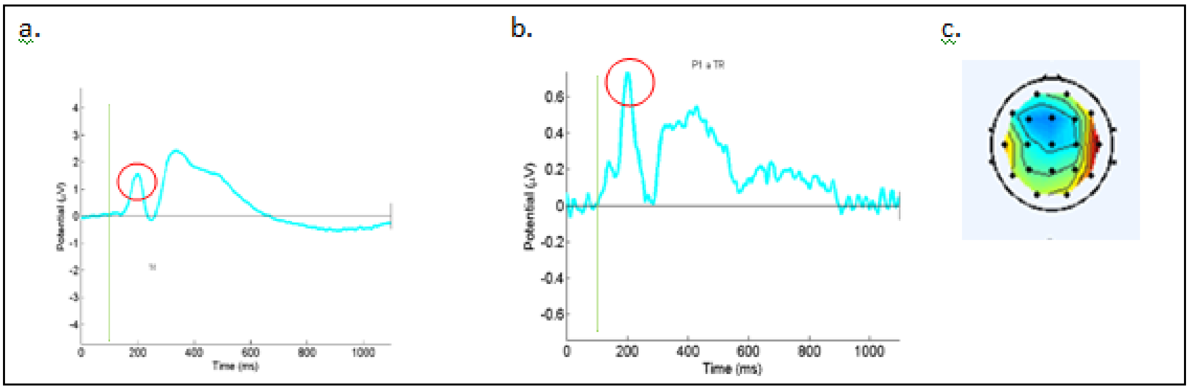
a. Grand average of P2 wave at Cz electrode for standard tone condition
b. Activation curve of the P2 component for the standard tone back-projected from Cz electrode
c. Topography of the P2 component for the standard tone condition

Figure 12: The P3 component (290–700 m/s)



a. Grand average of P3 wave at Pz electrode during the oddball/long condition
b. Activation curve of P3 component for the oddball/long tone back-projected from Pz electrode
c. Topography of P3 component for the oddball/long tone

Figure 13: The P1 component (50-100m/s)



a. Grand average of P1 wave at T4 electrode (standard tone condition)
b. Activation curve of P1 component during standard tone back-projected from T4 electrode
c. Topography of P1 component during standard tone

6.3 ICA of specific tasks

The example of different voices reaching a microphone is often used to explain the ICA process similarly to the example of waves on the beach. In the microphone example, a process of separating the voices from different people, would also effectively describe the process of ICA. Lots of neurons fire in different areas during a certain task. Through mathematical computation a likely source neuron or group of source neurons for this specific task, is then identified by the ICA process. On a cortical level, when many brain signals or electrical potentials reach an electrode, ICA determines which is which and presents this by an image.

a) Attentional tasks

The N2 and P3 ERP components are the potentials measured during cognitive processes especially perception and selective attention (Patel and Azzam 2005:147).

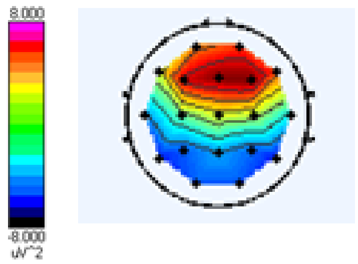


Figure 14: Frontal areas as reported by most other studies to be one of the main areas involved in ADHD-related difficulties.

Figure 14 shows the ICA image of electrical involvement during the participants' engagement in attentional tasks during the present study. The red area is the area of highest engagement of electrical activity during tasks which involved focus and concentration. It confirms that the frontal lobes are the main area of involvement in the first 100 milliseconds after stimulus presentation during initial attention. Frontal and central electrode sites were highlighted as the most active parts in the brain during periods of attentional focus.

b) Auditory tasks

During ERP ICA studies during auditory vigilance tasks, ten components were identified. The major response peaks during ERP tasks were processed by ICA to point to specific scalp distributions. Three of the ERP components were active during the target condition process when the subject had to press the button or execute. Three ERP components were active when the target went undetected and one ERP component was active in both cases. Three other components showed up during the long background sounds which were non-target sounds (Makeig, Jung, Bell, Ghahremani and Sejnowski 1997b:10979). This makes it possible to differentiate between the execution ERPs and the attention ERPs. As some ERP studies are visual task assessments and others are auditory tasks, it is also possible to set apart the visual processing and auditory processing ERPs.

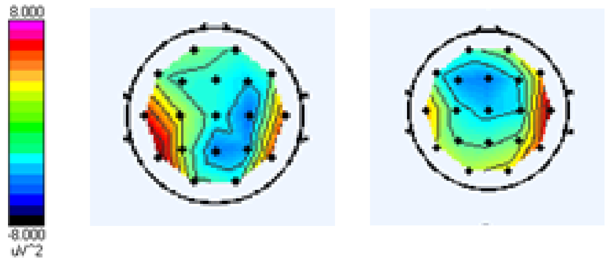


Figure 15: The temporal lobes are indicated by the red warmest colours as the most active when ICA head maps are drawn to pull out the active area during the auditory stimulus.

Figure 15 shows the ICA images of electrical involvement during the participants' engagement in auditory tasks during the present study. The red area is the area of highest engagement of electrical activity during tasks which involved listening or paying attention to a sound or auditory stimulus.

c) Execution tasks

ICA and functional Magnetic Resonance imaging (fMRI) studies confirm that motor execution occurs centrally (Wang, Chen, Gong, Shen and Gao 2010:653). The pressing of the button in the present study for a certain target sound required execution or motor engagement by pressing the button.

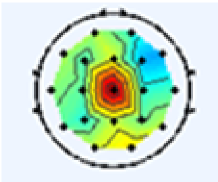


Figure 16: Central activation at the Cz electrodes, as discussed to be the most relevant area in ADHD studies of ERP, showed to be involved in the execution of auditory ERP tasks, as expected.

Figure 16 shows the ICA image of electrical involvement during the participants' engagement in execution tasks during the present study. The red area is the area of highest engagement of electrical activity during tasks which involved response to a certain stimulus or executing the press of the button related to a sound or auditory stimulus.

6.4 Adding performance of ADHD and norm groups to ERP findings to see if trends occur

Participants were further divided into groups of stronger and weaker performers. Learners with omission errors missed the target tone. A target tone occurs during the go-situation when the learner is expected to press the button on a long tone. More errors than the median number in the two groups were classified as weaker performers and learners who had fewer errors were classified as stronger performers.

Table 1: Number in the groups used for analysis of stronger and weaker performance

	Stronger performers	**Weaker performers**
Control group	17	12
ADHD group	13	20
Control and ADHD together	30	32

The *t*-criteria statistical method was used for comparison of mean amplitude of the ERP components in distinct intervals.

Strong - versus weak - performers ADHD:

P2: t (28) = 2.95, $p < 0.006$

P3: t (29) = 2.53, $p < 0.02$

The *p*-values are under 0.05 (the significance level). This means that the hypothesis that the distributions of stronger and weaker performers will have equal distribution curves is successfully rejected. The difference in means is statistically significant.

Strong - vs. weak - performers controls

There were no statistical differences in the components.

The hypothesis that certain ADHD learners may show temporal lobe difficulty rather than frontal and central lobe difficulty was positively confirmed. The further hypothesis that auditory processing task performance will be worse in the ADHD population positively supports the fact that auditory processing plays a role in the process of ADHD.

Stronger performers of ADHD group show significantly higher P3 component (Pz) and lower P2 component (Cz). Furthermore, P3 component is higher in stronger performers when both ADHD and controls are taken together. Table 2 summarises the link found between stronger performance and higher P3 amplitude as found in the study.

Table 2: Summary of ERP findings during an auditory processing task

ERP components	**P3**	**N2**	**P2**
	Amplitude lower in ADHD as in similar studies.	Amplitude lower in ADHD as in similar studies.	Amplitude not more elevated in ADHD as in similar studies.
Confirms similar findings	✓	✓	✗
Significance reached	✗	✗	✗
Performance linked to amplitude	Higher amplitude in stronger performers in ADHD and norm groups	Higher amplitude in stronger performers in ADHD group	Lower amplitude in stronger performers in ADHD group.

Table 3: Summary of attention and auditory findings during an auditory processing task

	Attention	**Auditory processing**	**Execution**
ICA distribution	Frontal	Temporal	Frontal

This finding isolates the areas of attention and auditory processing. It points to the possible value of further research in the behaviour of temporal and frontal lobes of ADHD learners in the diagnosis of ADHD. This also confirms the research question of auditory difficulties having an influence on ADHD. It suggests that APD may be a free-standing diagnosis often not isolated effectively as a reason for weaker educational performance in ADHD learners.

As ADHD markers are commonly described to contain frontal lobe neurological markers, the misdiagnosis of APD may be a common problem in the absence of the use of ERPs.

7. Discussion

7.1 The N2 component

This component is drawn during the standard stimulus – short, deviant-long conditions. The findings for the N2 component for the ADHD group in standard long tone showed smaller amplitude on the frontal lobes during the N2 task. This was more evident on the F3 and Fz electrode sites than on F4. This finding is consistent with both the theoretical framework of arousal as well as parallel research in the field. The theoretical framework of arousal describes brain activation. The frontal N2 component has earlier been described to correspond to voluntary processing and is evoked during the process of waiting for a certain stimulus on which response is expected. The brain waits for a change in the pattern while generating P2 wave forms. This concludes that lower levels of arousal or levels of brain activation are linked to ADHD, as is consistent in other studies (Eason, Harter and White 1969:283).

7.2 The P2 component

The finding in similar research that P2 is larger in ADHD learners than in norms was not confirmed by the present study.

7.3 The P3 component

Consistent with other ERP research, the P3 amplitude was lower in the ADHD population than in the normative group. Once again this supports the arousal model. The extent to which the lower amplitude in EEG during detection on the P1 and N2 components has an influence on later P3 ERPs is not clear but an interesting topic for future research. The attempt to confirm auditory processing difficulty to be a part of the problem in ADHD cannot be positively confirmed but is suggested by this finding.

7.4 ICA findings

It has also been confirmed in the present study that temporal lobes are activated during auditory processing and frontal lobes are involved during attentional processing, as expected. This implies that the disorders ADHD and APD should in some aspects be treated differently.

The process of stimulus detection or sensory detection is more temporal and parietal lobe oriented while the process of task execution is more frontal lobe oriented. The process of stimulus detection also occurs earlier than task execution. If we see that receiving a task happens in a different time period and also a different area of the brain than the attentional task, then we can successfully discriminate between the two processes. This isolates the detection and execution processes as different process operations in the brain and differentiates between the auditory and attentional processes.

To be able to differentiate between the areas of the brain in which a learner shows deviant activity, the use of EEG and ERP may be helpful. The implication of the findings may support wider use of EEG during the assessment of learners with ADHD, as suggested by the FDA's David Rabiner. In a study on the use of EEG, he found that when different assessment methods were used by multidisciplinary experts such as pediatricians, psychologists and teachers, there was a dispute in 40% of the cases when EEG had not been used, but when application of EEG was used to diagnose ADHD the rate of dispute on a diagnosis dropped to 12% (Rabiner 2013:1).

8. Conclusion

The present study aimed to look at what is known about auditory ERPs and its relation to auditory processing difficulty. The focus was to isolate ADHD and APD ERPs. This was done in order to determine if the heterogeneous group of ADHD learners can be better addressed by isolating auditory difficulty learners based on their neurological processing deviances from norm learners on the basis of a neurological assessment tool.

EEG was recorded while two groups, ADHD learners and norm learners completed an auditory task. The brain electricity was then analysed in order to determine if ADHD learners had different patterns that could possibly point towards their behaviour. ERP was used to decompose brain activity related to different tasks. The performance on the task was also compared to the EEG findings to determine if a positive correlation occurs.

From the data analyses in the present study it has been confirmed that amplitudes were lower in ADHD groups than in controls. This supports the notion that arousal levels should be adequate to sustain cognitive processing in classroom-like activities at school. This finding is consistent with other auditory ERP investigations of ADHD learners. The use of the arousal model to explain the difference between ADHD and auditory processing difficulty has been successful. Further studies on the implications for the use of stimulation ADHD would be an interesting way forward. The question of how medication influences arousal levels naturally arises as the next question.

The three-stage model of Morton and Frith viewing construction of knowledge as a function of the interaction between three related factors, namely genetic, cognitive, and behavioural, and how these elements are affected by environmental factors (Frith et al. 1991:433) has also been used to explain ADHD and APD. The frontal lobes of ADHD learners had been showing lower amplitude than those of norms. This finding confirms that execution and impulse control which are frontal lobe functions will be affected. According to the behavioural factor of ADHD describing the disorder, the frontal lobe difference supports the model. The frontal lobes regulate the execution of a task or the inhibition of behaviour like pressing the button constantly while it should only be pressed in the "go" situation. Deviances from norms here could easily lead to impulsive pressing of a button or in the case of inattentive type ADHD a learner would not respond when needed. It has therefore positively been confirmed by the present study that the behaviour of an ADHD learner will be affected by the frontal lobe difficulties identified. The frontal lobes showed activity in the ICA mapping during execution moments as decomposed during the ERP withdrawal. Less amplitude therefore successfully explains less control over behaviour in the identified location. Furthermore the brain electricity generated at the frontal lobes shows in research to occur around 350m/s. Withdrawal of this electricity in normal ERP methods showing lower amplitude confirms a functional deviation. This is due to the lower amplitudes found while the ICA is a structural proof of the frontal lobe deviation, supporting the use of the behavioural model (Frith et al. 1991:433) to better research ADHD.

In the present study, the P2 amplitude was not elevated, although other studies have indicated that elevated P2 might be expected for ADHD groups. The researchers are not sure why this occurred. The recognition ERP, P3 in the parietal area, is also not smaller for ADHD. In most ADHD studies a smaller P3 is noted in ADHD learners than in controls. This finding precludes the present study from discriminating between slow and fast auditory processing in an efficient enough way to include or exclude ADHD from APD.

The spatial presentation during ICA withdrawal provided confirmation of previous studies. The frontal, central and temporal electrodes showed involvement during attentional and auditory tasks respectively. These findings link individual brain regions to ADHD and APD and support a viewpoint of ADHD being a heterogeneous disorder. With EEG it is possible to establish different types of patterns of ADHD based on spatial as well as temporal factors. This supports the aim of the study to differentiate positively between ADHD and auditory difficulties. The research question if ERP can isolate APD form ADHD has been positively confirmed. If an auditory ERP is measured in parietal or temporal lobe and attention execution related ERPs in the frontal lobes and these two components also occur at different times, then the study has confirmed APD to be a different process from ADHD.

Lower amplitudes were noted in the ADHD group both during earlier components of detection as well as later components of execution. How much the activation of the brain by sensory detection is compromised by less sensory input and how this affects the attention process remains an unanswered question. The present study however found low amplitudes in posterior (N1 early processing) as well as anterior (P3 later processing) electrodes sites in ADHD learners during the receiving and giving back processes of auditory processing as well as attentional execution processes.

9. Recommendation

The present study provides ADHD and auditory processing data within the South African context. It confirms similar findings to other countries. It was determined in the local context that attentional and auditory sensory processing activates different areas in the brain. This may be of value during assessment of a child in the local context when attempting to establish whether auditory intervention or attentional intervention during treatment plans is the best option.

The present study suggests that the incorporation of EEG during assessment procedures in the learning environment may lead to higher success rates in therapy and learner support. EEG should not be intended for use as a stand-alone test, but could reduce the rate of misdiagnosis and will improve learner intervention, according to the FDA (Rabiner 2013:1).

The implications of the effective use of EEG are well explained by the announcement of the FDA to include the EEG in assessments of children suspected of having ADHD. They concluded that if clinicians' findings are supported by EEG findings, the clinicians will have more confidence in their diagnoses and be better able to reassure parents. These parents will have greater confidence in the findings, too, and will be more willing to pursue treatment recommendations offered. If EEG findings are different from clinician findings, this would encourage the clinician to reconsider or to find alternative assessments to explain the child's problems. A specialist may then become involved. If a clinician believed that a child did not have ADHD but the EEG results were positive, the diagnosis would not be made. According to Diagnostic and Statistical Manual of Mental Disorders (DSM) criteria and clinician assessment would accompany the EEG. It could, however lead a clinician to re-examine the clinical findings (Rabiner 2013:1).

In an article published on the current use of EEG in the evaluation of ADHD, it was commented that the use of EEG, that includes multivariate analyses and resolution of EEG signals into their neural generators, places EEG on a path to transition from a research tool to an aid in clinical evaluation of ADHD (Lenartowicz and Loo 2014:1).

10. References

Barry, R.J., Clarke, A.R., Mc Carthy, R., Selikowitz, M., Brown, C.R. and Heaven, P.C.L. 2009. Event-Related Potentials in Adults with Attention-Deficit/Hyperactivity Disorder: an Investigation Using an Inter-Modal Auditory/Visual Oddball Task. *International Journal of Psychophysiology: Official Journal of the International Organization of Psychophysiology,* 71(2):124.

Barry, R.J., Johnstone, S.J. and Clarke, A.R. 2003. A Review of Electrophysiology in Attention-Deficit/Hyperactivity Disorder: II. Event-Related Potentials. *Clinical Neurophysiology: Official Journal of the International Federation of Clinical Neurophysiology,* 114(2):184.

Brown, C.R., Clarke, A.R., Barry, R.J., Mc Carthy, R., Selikowitz, M. and Magee, C. 2005. Event-Related Potentials in Attention-Deficit/Hyperactivity Disorder of the Predominantly Inattentive Type: an Investigation of EEG-Defined Subtypes. *International Journal of Psychophysiology: Official Journal of The International Organization of Psychophysiology,* 58(1):94.

Debener, S., Ullsperger, M., Siegel, M., Fiehler, K., Von Cramon, D.Y. and Engel, A.K. 2005. Trial-by-trial coupling of concurrent electroencephalogram and functional magnetic resonance imaging identifies the dynamics of performance monitoring. *The Journal Of Neuroscience: The Official Journal Of The Society For Neuroscience,* 25(50):11731.

Eason, R.G., Harter, M.R. and White, C.T. 1969. Effects of Attention and Arousal on Visually Evoked Cortical Potentials and Reaction Time in Man. *Physiology & Behaviour,* 4(3):283.

Farina, F., Hussey, I. and Roche, R. 2015. Event-Related Brain Potentials Reveal Correlates of the Transformation of Stimulus Functions through Derived Relations in Healthy Humans. *Brain Research,* 1599:168.

Frith, U., Morton, J. and Leslie, A.M. 1991. The Cognitive Basis of a Biological Disorder: Autism. *Trends in Neurosciences,* 14(10):433.

Gellatly, I.R. and Meyer, J.P. 1992. The effects of goal difficulty on physiological arousal, cognition, and task performance. *Journal of Applied Psychology,* 77(5):694.

Gow, R.V., Rubia, K., Taylor, E., Vallée-Tourangeau, F., Matsudaira, T., Ibrahimovic, A. and Sumich, A. 2012. Abnormal Centroparietal ERP Response in Predominantly Medication-Naive Adolescent Boys with ADHD during both Response Inhibition and Execution. *Journal of Clinical Neurophysiology,* 29(2):181.

Holcomb, P.J., Ackerman, P.T. and Dykman, R.A. 1985. Cognitive Event-Related Brain Potentials in Children with Attention and Reading Deficits. *Psychophysiology,* 22(6):656.

Jonkman, L.M., Kemner, C., Verbaten, M.N., Koelega, H.S., Camfferman, G., Vd Gaag, R.J., Buitelaar, J.K. and Van Engeland, H. 1997. Effects of Methylphenidate on Event-Related Potentials and Performance of Attention-Deficit Hyperactivity Disorder Children in Auditory and Visual Selective Attention Tasks. *Biological Psychiatry,* 41(6):690.

Karayanidis, F., Robaey, P., Bourassa, M., De Koning, D., Geoffroy, G. and Pelletier, G. 2000. ERP Differences in Visual Attention Processing between Attention-Deficit Hyperactivity Disorder and Control Boys in the Absence of Performance Differences. *Psychophysiology,* 37(3):319.

Kemner, C., Verbaten, M.N., Cuperus, J.M., Camfferman, G. and Van Engeland, H. 1994. Visual and Somatosensory Event-Related Brain Potentials in Autistic Children and three Different Control Groups. *Electroencephalography and Clinical Neurophysiology,* 92(3):225.

Kemner, C., Verbaten, M.N., Koelega, H.S., Buitelaar, J.K., Van Der Gaag, R.J., Camfferman, G. and Van Engeland, H. 1996. Event-Related Brain Potentials in Children with Attention-Deficit and Hyperactivity Disorder: Effects of Stimulus Deviancy and Task Relevance in the Visual and Auditory Modality. *Biological psychiatry.,* 40(6):522.

Key, A.P.F., Dove, G.O. and Maguire, M.J. 2005. Linking Brainwaves to the Brain: An ERP Primer. *Developmental Neuropsychology,* 27(2):183.

Kuntsi, J., Pinto, R., Price, T.S., Van Der Meere, J.J., Frazier-Wood, A.C. and Asherson, P. 2014. The Separation of ADHD Inattention and Hyperactivity-Impulsivity Symptoms: Pathways from Genetic Effects to Cognitive Impairments and Symptoms. *Journal of Abnormal Child Psychology,* 42(1):127.

Lenartowicz, A. and Loo, S.K. 2014. Use of EEG to Diagnose ADHD. *Curr Psychiatry Rep,* 16(498):1.

Loo, S.K., Hale, T.S., Macion, J., Hanada, G., Mc Gough, J.J., Mc Cracken, J.T. and Smalley, S.L. 2009. Cortical Activity Patterns in ADHD during Arousal, Activation and Sustained Attention. *Neuropsychologia,* 47(10):2114.

Makeig, S., Jung, T., Bell, A.J., Ghahremani, D. and Sejnowski, T.J. 1997a. Blind Separation of Auditory Event-related Brain Responses into Independent Components. *Proc. Natl. Acad. Sci. USA,* 94:10979.

Makeig, S., Jung, T.P., Bell, A.J., Ghahremani, D. and Sejnowski, T.J. 1997b. Blind separation of auditory event-related brain responses into independent components. *Proceedings Of The National Academy Of Sciences Of The United States Of America,* 94(20):10979.

Muller, A., Candrian, G. and Kropotov, J. 2011. *ADHS-Neurodiagnostik in der Praxis,* Heidelberg, Berlin, Springer.

Näätänen, R. 1990. The Role of Attention in Auditory Information Processing As revealed by Event-Related Potentials and other Brain Measures of Cognitive Function. *Behavioural and Brain Sciences.,* Sciences(13):201.

Nakajima, Y., Miyamoto, K. and Kikuchi, M. 1994. Estimation of Neural Generators of Cognitive Potential P300 by Dipole Tracing Method. *Nō To Shinkei = Brain And Nerve,* 46(11):1059.

Oades, R.D. 1998. Frontal, temporal and lateralized brain function in children with attention-deficit hyperactivity disorder: a psychophysiological and neuropsychological viewpoint on development. *Behavioural Brain Research,* 94(1):83.

Oades, R.D., Dittmann-Balcar, A., Schepker, R., Eggers, C. and Zerbin, D. 1996. Auditory event-related potentials (ERPs) and mismatch negativity (MMN) in healthy children and those with attention-deficit or tourette/tic symptoms. *Biological Psychology,* 43(2):163.

Patel, S.H. and Azzam, P.N. 2005. Characterization of N200 and P300: Selected Studies of the Event-Related Potential. *International Journal of Medical Sciences,* 2(4):147.

Rabiner, D. 2013. Helping Parents, Professionals and Educators Stay Informed about New Research on ADHD. *Attention Research Update* [Online]. Available: http://www.helpforadd.com/2013/september.htm [Accessed 30.10.2015].

Raimondo, F., Kamienkowski, J.E., Sigman, M. and Fernandez Slezak, D. 2012. CUDAICA: GPU Optimization of Infomax-ICA EEG Analysis. *Computational Intelligence And Neuroscience,* 2012:206972.

Satterfield, J.H., Schell, A.M. and Nicholas, T. 1994. Preferential Neural Processing of Attended Stimuli in Attention-Deficit Hyperactivity Disorder and Normal Boys. *Psychophysiology,* 31(1):1.

Satterfield, J.H., Schell, A.M., Nicholas, T.W., Satterfield, B.T. and Freese, T.E. 1990. Ontogeny of Selective Attention Effects on Event-Related Potentials in Attention-Deficit hyperactivity Disorder and Normal Boys. *Biological Psychiatry,* 28(10):879.

Schobben, D., Stone, J., Yeredor, A., Cardoso, J., Eriksson, J., Akuzava, T., Bro, R. and Sidiropoulos, N. 2014. ICA algorithms available via ICA Central. 2015.

Shaw, G. and Brown, G. 1999. Arousal, Time Estimation, and Time Use in Attention-Disordered Children. *Developmental Neuropsychology,* 16:227.

Smith, M.E., Halgren, E., Sokolik, M., Baudena, P., Musolino, A., Liegeois-Chauvel, C. and Chauvel, P. 1990. The Intracranial Topography of the P3 Event-Related Potential Elicited During Auditory Oddball. *Electroencephalography and Clinical Neurophysiology,* 76(3):235.

Söderlund, G. and Sikström, S. 2008. Positive Effects of Noise on Cognitve Performance: Explaining the Moderate Brain Arousal Model. *In:* LUND UNIVERSITY COGNITIVE SCIENCE (LUCS), S. (ed.).

Song, J., De Ridder, D., Schlee, W., Van De Heyning, P. and Vanneste, S. 2013. “Distressed aging”: the differences in brain activity between early-and late-onset tinnitus. *Neurobiology of Aging,* 34(7):1855.

Sutton, S., Braren, M., Zubin, J. and John, E.R. 1965. Evoked-Potential Correlates of Stimulus Uncertainty. *Science* 150(3700):1187.

Tarkka, I.M., Stokić, D.S., Basile, L.F. and Papanicolaou, A.C. 1995. Electric Source Localization of the Auditory P300 Agrees with Magnetic Source Localization. *Electroencephalography and Clinical Neurophysiology,* 96(6):538.

Teplan, M. 2002. Fundamentals of EEG measurement. *Measurement Science Review,* 2(2):7.

Theis, F.J., Jung, A., Puntonet, C.G. and Lang, E.W. 2003. Linear Geometric ICA: Fundamentals and Algorithms. *Neural Computation,* 15(2):419.

Wang, Y., Chen, H., Gong, Q., Shen, S. and Gao, Q. 2010. Analysis of functional networks involved in motor execution and motor imagery using combined hierarchical clustering analysis and independent component analysis. *Magnetic Resonance Imaging,* 28(5):653.

Annexures

Annexure A: **Ethical clearance**

Annexure B: **Consent form to parents**

Annexure C: **Clarification of terms**

Annexure D: **Certification of proof reading**

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16 April 2014

ETHICAL CLEARANCE APPLICATION:

UTILISING INDEPENDENT EVENT RELATED POTENTIALS TO DETERMINE IF LEARNERS CAN BE CLASSIFIED AS ADHD BASED ON THEIR AUDITORY DIFFICULTIES

Dear Ms Paquet

With reference to your application for ethical clearance with the Faculty of Education, I am pleased to inform you on behalf of the Ethics Board of the faculty that you have been granted ethical clearance for your research with the following stipulations (comments by reviewers):

- It has been noted that this research may be subject to external funding. Please clarify if this is the case, as the application did not acknowledge this.
- The mentoring role of Prof Venter should be elaborated on as he will be relied upon for health-related risks.

Your ethical clearance number, to be used in all correspondence, is:

UFS-EDU-2014-016

This ethical clearance number is valid for research conducted for one year from issuance. Should you require more time to complete this research, please apply for an extension in writing.

We request that any changes that may take place during the course of your research project be submitted in writing to the ethics office to ensure we are kept up to date with your progress and any ethical implications that may arise.

Thank you for submitting this proposal for ethical clearance and we wish you every success with your research.

Yours sincerely,

Andrew Barclay
Faculty Ethics Officer

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Prof Andre Venter
Dr Analene v Staden
University Free State
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Date: __________

INFORMED CONCENT:

Dear Clientnt
I would like to invite you to take part in this research project:

Utelising Independent Event Related Potentials to determine if Learners can be classified as ADHD based on their Auditory difficulties.

This study is about **auditory processing and the role it plays in attention**. We would like you to participate with us in this research because of **a possible attention difficulty.**

The reason we are doing this study is to **see how auditory processing difficulties can be related to attentional difficulty and better be diagnosed and addressed.**
The possible risks to you in taking part in this study are …. And we have taken the following steps to protect you from these risks. **All data will be allocated numbers and participant details will be confidential at all times.**

I am sure you will benefit from this study as **auditory processing difficulties can be related to attentional difficulty and better be diagnosed and addressed.**
While I greatly appreciate your participation in this important study and the valuable contribution you can make, your participation is entirely voluntary and you are under no obligation to take part in this study.

If you do choose to take part, and an issue arises which makes you uncomfortable, you may at any time stop your participation with no further repercussions. If you experience any discomfort or unhappiness with the way the research is being conducted, please feel free to contact me directly to discuss it, and also note that you are free to contact my study supervisor (indicated above).

Should any difficult personal issues arise during the course of this research, I will endeavour to see that a qualified expert is conducted and able to assist you.

Yours sincerely,

Lorraine Paquet
082 876 6375

Please fill in and return this page. Keep the letter above for future reference.

Name and Surname: ____

Age: ________________

ADHD diagnosis made by: ______________________________________

Contact number: __________________________________

- I hereby give free and informed consent to participate in the abovementioned research study.
- I understand what the study is about, why I am participating and what the risks and benefits are.
- I give the researcher permission to make use of the data gathered from my participation, subject to the stipulations he/she has indicated in the above letter.

Signature: ________________________________ Date: _____________________

Clarification of Terms

Attention Deficit/ Hyperactivity Disorder (ADHD)

ADHD is one of the most common psychiatric disorders amongst children with an incidence as high as 3-5%. The main identifying symptoms are difficulty concentrating on work and completing tasks, restlessness and impulsivity (Chandler, Apnea and Apnea 2002:2007). ADHD is seen more and more as a complex impairment of the cognitive management centre in the brain and of executive functions (Shah 2015:174).

Auditory Processing Disorder (APD)

APD represents a difficulty in the processing of acoustic information and hence auditory perception difficulties (Cacace and McFarland 2005:112). This leads to an abnormal processing of auditory information in spite of normal auditory thresholds (Lazarus 2014:3).

Electro Ecaphalogram (EEG)

An EEG is a medical procedure measuring and amplifying scalp electrical activity generated by brain structures. This imaging technique uses metal electrodes to record brain activity by means of a conductive medium (Teplan 2002:1). The EEG represents the activity of the brain created by neurons generating electrical signals.

Event Related Potential (ERP)

An ERP is a voltage fluctuation or a potential derived from the EEG, but it is time-locked to a specific sensory event (Kuperberg 2008:117). The ERP reflects the summated activity of the brain during a specific task and is represented as a waveform with a positive or negative deflection (Rangaswamy and Porjesz 2008:238). The ERP has a voltage x time x location interest.

Independent Component Analysis (ICA)

The ICA is an extraction method to draw certain data from an EEG set in order to separate signals. This is a statistical extraction technique which separates certain signals in order to reveal hidden data that is underlying to certain variables (Hyvärinen and Oja 2000:411) .

Electrical Potential

An electrical potential is brain activity measured in amplitude. The measurement is done in voltage or micro volts as it is a very small electrical measurement. Brain function occurs due to flow of electrical potential which is generated by ions moving through membranes on cortical level (Pettersen 2007:Abstract only). As the ions move through the membranes, currents are generated and these are measured by means of an electrode similar to en electrician measuring electrical circuits with a multi-meter tool.

Stimulus

A stimulus is an event presented to the subject in order to take a measurement in relation to the event. Stimuli in neuro science are analysed in terms of the brain's ability to detect and the brain's ability to discriminate the different aspects of the stimulus (Van den berghe, Dupont, De Bruyn, Bormans, Michicls, Mortelmans and Orban 1996:1263).

ERP Component

The ERP has a voltage x time x location interest. The tendency of parts of the ERP to co-vary in relation to specific experimental manipulation is grouped together as a component (Coles, Gratton and Fabiani 1990:57).

Executive functions

Executive function is the ability to absorb information, interpret this and then make a decision based on the information and then respond. It is a set of skills which allows learners to control their behavior rather than giving the automatically easy response . Tasks controlled by the executive functions of the brain are listed as planning tasks, problem solving tasks and organizing tasks for example (Doty 2012:1).

References:

Cacace, A.T. and Mcfarland, D.J. 2005. The importance of modality specificity in diagnosing central auditory processing disorder. *American journal of audiology,* 14(2):112.

Chandler, J., Apnea, S. and Apnea, D.S. 2002. What is ADHD. *Retrieved April,* 15:2007.

Coles, M.G.H., Gratton, G. and Fabiani, M. 1990. Event-related brain potentials.57.

Doty, D. 2012. Executive Function & Memory/Cognition Changes. Florida.

Hyvärinen, A. and Oja, E. 2000. Independent component analysis: algorithms and applications. *Neural networks,* 13(4):411.

Kuperberg, G.R. 2008. Electroencephalography, event-related potentials, and magnetoencephalography. *Essentials of Neuroimaging for Clinical Practice*:117.

Lazarus, K. 2014. Auditory Processing Disorder. *Psychology of Learning Disabilities (SPE 740) Department Of Special Education.* Nigeria: UNIVERSITY OF IBADAN.

Pettersen, K.H. 2007. *Electric Potentials in the Brain and the Underlying Neural Activity.* (PhD, Norwegian University of Life Sciences, Department of Mathematical Sciences and Technology.

Rangaswamy, M. and Porjesz, B. 2008. From event-related potential to oscillations: genetic diathesis in brain (dys) function and alcohol dependence. *Alcohol Research & Health,* 31(3):238.

Shah, S.M. 2015. A New Approach to Understand ADHD. *Editorial Board,* 4(4):174.

Teplan, M. 2002. Fundamentals of EEG measurement. *Measurement science review,* 2(2):1.

Van Den Berghe, R., Dupont, P., De Bruyn, B., Bormans, G., Michicls, J., Mortelmans, L. and Orban, G.A. 1996. The influence of stimulus location on the brain activation pattern in detection and orientation discrimination. *Brain,* 119(4):1263.

Declaration of Proof-reading

I, Catherine Elizabeth van Wyk, ID: 7107180102085, hereby declare that I have proof-read the following two articles:

A Research Overview on Neuro-Electrical Findings in ADHD and APD in order to Draw Inter-Relational Conclusions.

And

An EPR analysis of Auditory and Attentional processes with the aim of better clarification of the electrical process involved in ADHD

Date: 24 April 2016

Signature:

Short Curriculum Vitae of Catherine van Wyk

- BA, BA Honours (Eng), HOD, MA (English literature)
  - All degrees from University of Pretoria
- 22 years of teaching English First and First Additional Language to high school learners (Capricorn High, Hoërskool Waterkloof, Lowveld High, Hoërskool Nelspruit)
  - Best Educator in Ehlanzeni for 2012 Matrics (best English results)
  - Best Educator in Mpumalanga for 2015 Matrics (best English results)
- Translation of a book from Afrikaans to English, "The Wonder of Jesus in the Old Testament" by Danie Haasbroek
- Proof-reading of a Veterinary magazine in Pretoria for 2 years
- Proof-reading of a dissertation by Gerhard van der Spuy (2016)

An academic overview of the use of Electro Encephalography and Event Related Potentials in the fields of Attention Deficit and/ Hyperactivity Disorder and Auditory Processing Disorder.

This article forms the theoretical overview of Electro Encephalography (EEG) and Event Related Potential (ERP) research findings in the field of Attention Deficit and/Hyperactivity Disorder (ADHD) and Auditory Processing Disorder (APD). The role APD plays in ADHD will be analysed by means of brain electricity patterns and responses. ADHD is commonly described as an executive dysfunction in the frontal lobes, but the role auditory and sensory processes play in the attention process is more and more commonly researched. ERP can determine if sensory detection occurs at an earlier point in time than execution. This fact makes Auditory ERP an interesting role player in the analysis process of determining underlying brain patterns in ADHD. Information flow patterns during the attention process as well as the auditory process will be retrieved in order to determine if mutual grounds or clear distinctions between ADHD and auditory processing occur. ADHD is a very prevalent condition with too few defined biomarkers. A better understanding of ADHD within the school environment would aid in more accurate intervention strategies for ADHD learners.

In order to explain the involvement these processes have within one another, EEG will be recorded to serve as a precision tool in the field of cognitive function analysis. EEG and ERP serves as a reproducible procedure which provides a biological reading and information as to the exact time a neurological process occurred and the individual is not subjected to an invasive or stressful process. It is being hypothesised that ADHD comprises of more heterogeneous difficulties than only later brain response execution in the frontal lobe as was commonly explained in literature in the past few decades. If ERP can show that ADHD involves more than one neurological circuit and shows EEG processes involved frontally as well as parietally, it has implications for further research into the ontology of ADHD. The value of the ERP lies therein that it can distinguish co-morbid difficulties and disorders within the homogenous ADHD diagnosis by identifying their spatial and temporal processes as being separate. This means that the ERP statistics derived from EEG can tell us when in time a process occurred as well as where in the brain. This makes ERP a system which relies on brain anatomy, chemistry and genetic research rather than mainly patient symptom analysis. It is also the reason that major research institutions are making ERP application compulsory in the field of psychiatrics and considering it more and more to be a biological marker.

Auditory difficulties influence all forms of school work as the auditory areas of the brain are involved in sensory arousal and input. This input energises the rest of the brain on a biological level, which makes the interplay between APD and ADHD very complex. Some brain activity occurs early during the input stage of sensory processing while other brain activity occurs during the output stage. To determine where ADHD and APD lie on this continuum became a main question as a literature overview progressed. ERP provides a means to gain supplementary information during the psychological evaluation process. The brain function underlying to the verbal report of the parent of the ADHD learner and the clinical presentation of what-comes-down-to-paper in the written assessment becomes apparent. As it is measured over 100 presentations of a certain stimulus, it provides a reliable idea of what the brain does with a stimulus. The P1, P2, N2 and P3 components have been successfully identified by the present study as most significant in the fields of ADHD and APD. Large percentages of the investigated studies had further shown a slower or lower brain arousal in the Theta frequency band over the central cortex to be related to attention difficulty.

The present study has successfully concluded P1, P2, N2 and P3 ERP components as the most functional in terms of EEG during attention and auditory processes. This study has furthermore succeeded in summarizing the EEG and ERP research in the fields of ADHD and APD in order to underline the importance of analysing the interaction between the two difficulties. A better insight into these two fields, form the basis for of a empirical paper on the nature of these disorders.

An Event Related Potential analysis of Auditory and Attentional processes with the aim of better clarification of the electrical process involved in Attention Deficit/ Hyperactivity Disorder

ADHD is a prevalent developmental disorder, characterized by varying levels of inattention, hyperactivity, and impulsivity symptoms linked to the frontal lobes. Examining ERP findings in Attention Deficit/ Hyperactivity Disorder (ADHD) learners, provides an analysis system to investigate their neural organization. This technique is emerging as one of the most popular assessment tools in the field of ADHD. By Event Related Potential (ERP) analysis, the researcher was enabled to discriminate between earlier and later cognitive processes. Brain responses within 100 milliseconds from stimulus presentation are called early responses and those only after 200 milliseconds from stimulus presentation are referred to as "later responses". By applying the ERP process specific stimulus related responses can be identified and monitored. The aim was to determine if Auditory Processing Disorder (APD) is integral to ADHD in some learners, or if the neurological patterns are more separate and homogenous in nature. Specific brain responses to signals were analysed. N1, P2, N2 and P3 findings show to be the most consistently involved in ADHD and APD research and were therefore chosen for this study.

For the present study Independent Component Analysis (ICA) was applied in addition to ERP extraction as statistical tool in order to effectively extract the brain area of origin of a specific group of neurons engaged during a stimulus response. The topographic head map presentation of the ICA tool allows for identification of isolated areas of involvement during a brain response. Furthermore brain pattern images showing neural involvement have been analysed parallel to the performance of the ADHD and APD groups. The theoretical frameworks of causal modelling and arousal have both been applied to better explain the neurological process of ADHD. A goal of the current study was to determine if ERP markers could find auditory origins towards explaining ADHD. An Electro Encephalogram (EEG) was recorded during an active task engagement situation. Learners listened to short tones but

had to respond by pressing a button on a long tone. The long tone was the target response situation during which execution responses in the brain were recorded. A student's t-test statistical analysis by *Matlab* software was done in order to determine if APD appears deviant or similar to ADHD and normative response measured by *WinEEG* software recordings.

N2 is a negative wave pattern commonly associated with paying attention to a target sound. N2 commonly shows lower amplitudes for ADHD learners in frontal the lobes than for normative group learners in research findings and this was confirmed and repeated by the present study. P2, measured on the central lobe region of the cortex, is commonly larger in ADHD learners than in controls during attention. This was not confirmed by the present study and the P2 component showed lower amplitude in the ADHD group. The P3 component is involved in the cognitive process of selective attention and information processing. P3 is associated with the target condition of the ERP procedure and presents recognition and memory-updating processes. The largest number of research findings on P3 show reduced amplitude in ADHD learners during an auditory tasks. This study confirmed the findings on P3.

Independent components for the different ERP components were analysed in order to separate brain signals spatially and temporally. ICA selects the area of highest activity. The process was applied in order to confirm that neural activity occurs in the spatial area where research says it occurs. Spatial findings were confirmed in this study for the respective components. N2 activity occurred frontally, P2 occurred central, P3 on the parietal area and N1 on the temporal lobes. Attention tasks, execution tasks and auditory tasks respectively were analyzed by ICA. The findings confirm prior research with initial attention measured on parietal lobes, execution on central lobes. Auditory task activity measured highest at temporal lobe sites.

The performance results on the auditory test – pressing the button on long tones only – were divided into two halves. The norm group presented better performers while the ADHD group presented weaker performers. A statistically significant difference was noticed between performance of the ADHD and norm groups. The current study has shown that the inclusion of EEG findings with clinical diagnosis may provide useful information in the South African context of diagnosing ADHD and co-morbid disorders.

‘n Akademiese oorsig in die gebruik van die Elektro-enkefalogram en Gebeurtenis Verwante Potensiale in die veld van Aandag Afleibaarheid en/of Hiperaktiwiteit Sindroom en Ouditiewe Prosessering Afwyking

Hierdie artikel vorm die teoretiese oorsig in die gebruik van die Elektro-enkefalogram (EEG) en gebeurtenis-verwante-potensiaal of “Event Related Potential” (ERP). Navorsingsbevindinge in die veld van Aandag Afleibaarheid- en/of Hiperaktiwiteit Sindroom (AAHS) en Ouditiewe Prosessering Afwyking (OPA) toon dat die rol wat OPA in AAHS speel, word ondersoek deur middel van die analise van die brein se elektriese aktiwiteit en elektriese response op stimuli. AAHS word gewoonlik as ‘n uitvoerende disfunksie met frontale lob betrokkenheid beskryf, maar die rol wat die ouditiewe en sensoriese komponente speel, word toenemend as integrale komponente tydens die aandagprosesse in AAHS leerders beskryf. ERP tegnologie kan bepaal of sensoriese ontvangs vroeër as uitvoering in die kognitiewe proses plaasvind. Dit maak ouditiewe ERPs ‘n interessante rolspeler in die analisering van patrone onderliggend tot AAHS. Inligtingsvloeiprosesse in beide AAHS en OPA is onttrek om te bepaal of die afwykings oorvleuel of konkreet aparte prosesse toon. AAHS is ‘n baie algemene afwyking met te min gedefinieerde biologiese merkers. ‘n Beter begrip van AAHS binne die skoolomgewing sal bydra tot meer akkurate intervensiestrategieë vir AAHS leerders.

EEG sal opgeneem word om ‘n presisie-meting te kan gee om die betrokkenheid wat die prosesse van ADHD en OPA ten opsigte van mekaar toon beter toe te lig. EEG en ERP bied ‘n eksak-herhaalbare, biologiese lesing van die individu se liggaam wat inligting bied omtrent die spesifieke tyd waarop kognitiewe funksie plaasgevind het sonder om die individu aan ‘n emosioneel stresvolle prosedure te onderwerp. Daar word gehipotetiseer dat AAHS uit meer heterogene uitdagings bestaan as slegs laat-uitvoerende responsprosesse in die frontale breinlobbe soos wat algemeen die veronderstelling was die afgelope paar dekades. Indien ERP navorsing kan toon dat AAHS uit meer komplekse stroombane bestaan as bloot die frontale stroombaan - en ook pariëtale, vroeë breinresponse insluit - kan dit omvangryke implikasies hê vir toekomstige omskrywing van die karakteristiek van AAHS. Die waarde van die ERP lê daarin dat dit ko-morbide afwykings tot AAHS kan identifiseer binne die AAHS diagnose deur hul onderskeie tyds- en liggingsaspekte te skei. Dit beteken dat ERP statistiek wat vanuit ’n EEG onttrek word oor die vermoë beskik om aan te dui presies wanneer in tyd en waar in die korteks ‘n breinsrespons voorkom. Die ERP proses bied dus ‘n sisteem wat op breinanatomie, chemiese prosesse van die brein en neuro-genetika berus, eerder as op slegs die simptome van die pasiënt. Dit is dan ook die rede waarom prominente navorsingsrade wêreldwyd toenemend begin vereis dat navorsing in psigiatrie en pediatrie op bio-merker en EEG-bevindinge berus.

Ouditiewe uitvalle het ‘n wye invloedsfeer as dit kom by skolastiese vordering, veral omdat dit deel vorm van sensoriese ontvangs en wekking in die brein. Hierdie ontvangs stimulasie voorsien wekkingsenergie vir die brein op biologiese vlak, wat dan juis die interaksie tussen OPA en AAHS baie kompleks maak. Sommige breinprosesse is vroeër breinresponse tydens die ontvangsfase op stimuli, terwyl ander breinprosesse tydens die weergee-fase gemeet word. Om te bepaal waar AAHS en OPA op hierdie kontinuum lê, het as die hoofvraag ontrafel tydens die navorsingsoorsig in die velde van AAHS en OPA. ERP’s bied bydraende inligting tot die verbale verslag aan AAHS kinders se ouers en die kliniese presentering van wat-deurkom-papier-toe tydens ‘n sielkundige evaluasie van hierdie leerders. ERP word opgeneem tydens 100 herhalings van ‘n spesifieke stimulus en bied dus ‘n statisties verantwoordbare beeld van wat die brein se reaksie op daardie spesifieke stimulus is. Die P1, P2, N2 en P3 komponente is suksesvol deur die huidige studie as die mees prominente breinresponse tydens die AAHS en OPA prosesse geïdentifiseer. ‘n Groot persentasie van die ondersoekte navorsing toon stadiger sowel as laer amplitude elektriese breinaktiwiteit in AAHS leerders as in normatiewe groepe.

Hierdie ondersoek het suksesvol bevestig dat die P1, P2, N2 and P3 ERP komponente die mees funksionele breinresponse is in terme van die EEG tydens aandag- en ouditiewe prosesse. Die huidige studie het verder daarin geslaag om EEG en ERP navorsing in die veld van AAHS en OPA suksesvol op te som om sodoende die belangrikheid van die interaksie tussen die twee afwykings te demonstreer. Beter insig bied dan die basis vir ‘n empiriese navorsingsartikel oor die twee afwykings.

‘n Gebeurtenis Verwante Potensiaal Ondersoek van Ouditiewe en Aandag prosesse met die Oog op Beter Omskrywing van die Elektriese Prosesse betrokke in Aandag Afleibaarheid en/of Hiperaktiwiteit Sindroom

Aandag Afleibaarheid/ Hiperaktiwiteit Sindroom (AAHS) is ‘n algemene ontwikkelingsafwyking onder skoolgaande leerders en word gekarakteriseer deur verskeie vlakke van aandagafleibaarheid, hiperaktiwiteit en impulsiwiteit simptome. AAHS word algemeen beskryf as ‘n frontale lob afwyking. Die ondersoek van die Gebeurtenis Verwante Potensiaal (Event Related Potential – ERP) bied ‘n analiserings-sisteem waarbinne neurologiese organisering van patrone van breinaktiwiteit bestudeer kan word. Hierdie tegniek is ‘n toenemend gewilde assesseringsmiddel in die veld van AAHS. Die aanwending van die ERP metode bied aan die navorser die vermoë om vroeër en later kognitiewe prosesse van mekaar te onderskei. Prosesse binne die eerste 100 millisekondes vanaf stimuluspresentering word dus vroeë response genoem en response na 200 millisekondes vanaf stimuluspresentering word later response genoem. Met behulp van die ERP tegniek kon die navorser spesifieke response op spesifieke stimuli identifiseer en monitor. Die hoofdoelwit van die studie was om te bepaal of Ouditiewe Prosseserings Awyking (OPA) ‘n integrale rol speel by sommige AAHS leerders en of die neurologiese patrone apart plaasvind of meer homogeen van aard is. Spesifieke breinresponse op veral die ouditiewe en aandagstimuli is geanaliseer. N1, P2, N2 en P3 komponente het getoon om die mees konstant betrokke te wees in AAHS en OPA navorsing en is daarom gekies om gemonitor te word tydens die huidige studie.

Die studie het ook Onafhanklike Komponent Analise (Independent Component Analysis- ICA) aangewend as statistiese applikasie saam met ERP komponent-onttrekking om die ligging van ‘n spesifieke groep neurone betrokke by ‘n respons effektief te kon isoleer. Die topografiese kopkaart presentering van die ICA metode bied die geleentheid om geïsoleerde areas van betrokkenheid tydens breinresponse te identifiseer. Verder is die topografiese

voorstellings van neurologiese aktiwiteit parallel met die betrokke AAHS en OPA leerders se prestasie geanaliseer. Die teoretiese raamwerke van die Gebeurlikheidsmodel en die Breinwekkingsmodel is aangewend om die neurologiese proses van die AAHS leerder beter toe te lig. 'n Doelwit van hierdie studie was om te bepaal of ERP biologiese merkers ouditiewe wortels kon vind in die AAHS afwykingspatroon. 'n Elektro-Enkefalogram (EEG) opname is gemaak tydens 'n aktiewe taakvoltooiing situasie. Leerders moes na kort tone luister en moes reageer deur 'n knoppie te druk wanneer hul 'n lang toon hoor. Die lang toon dien as die teiken-reaksie situasie waartydens uitvoerings-response in die brein opgeneem is. 'n Studente *t*-toets statistiese analise is met behulp van *Matlab* sagteware gedoen om sodoende te bepaal of OPA verskil of dieselfde lyk as AAHS wanneer dit teen normatiewe verwagtings gemeet is. Die EEG is opgeneem met *WINEEG* sagteware.

N2 is 'n negatiewe golfpatroon algemeen geassosieer met aandag gee aan die teiken toon. N2 toon gewoonlik laer amplitudes in frontale lobbe in die AAHS groep as in normatiewe leerders volgens navorsing. Hierdie verskynsel is bevestig in die huidige studie. P2 word op die sentrale korteks opgeneem en toon volgens die teoretiese oorsig 'n hoër amplitude in AAHS leerders tydens die aktiewe aandag situasie as in die normgroep. Hierdie verskynsel is nie deur die huidige studie bevestig nie. Die teenoorgestelde het voorgekom en die amplitude van die P2 komponent het 'n laer aktivering getoon. Die P3 komponent is betrokke in die kognitiewe proses van selektiewe aandag en inligtingprosessering. P3 word ook met die teiken situasie geassosieer in ERP opnames en verteenwoordig die proses van erkenning en die geheue-opdateringsproses. Die meeste navorsing rondom P3 toon verlaagde amplitude gedurende 'n ouditiewe taak in AAHS leerders.

ICA van die onderskeie ERP komponente is ondersoek om brein aktiwiteit te isoleer op grond van die areas van oorsprong en tydstip van aktivering. Hierdie prosedure berus op die grondslag van opname van die area van die hoogste wekking. Die waarde van die ICA metode in hierdie studie was om te bevestig dat neurologiese funksies wel voorkom in die areas wat navorsing aangee as die aktiefste areas tydens onderskeidelik aandag, ouditiewe prosessering en uitvoerings areas. Al die areas van aktiwiteit het wel ooreengestem in die huidige studie. N2 aktiwiteit het frontaal voorgekom, P2 het sentraal voorgekom, P3 het ~~parietaal~~ voorgekom en N1 het op die temporal lobbe voorgekom.

Die resultate van die ouditiewe toets waartydens leerders die knoppie moes druk indien hul ‘n lang toon hoor, is in twee groepe verdeel. Die normatiewe groep het meer leerders bevat wat beter presteer het, terwyl die swakker presteerders grotendeels binne die AAHS groep geval het. ‘n Statisties noemenswaardige verskil tussen die AAHS en normatiewe leerders se prestasievlakke is gevind. Die wekkingsmodel is ‘n effektiewe model om breinwekkingsvlakke en effektiwiteit te beskryf. Die gebeurlikheidsmodel beskryf breinpatrone aan die hand van genetiese en omgewingsinvloede en was minder geskik om bevindinge te help omskryf. Die insluiting van EEG bevindinge by die kliniese diagnose van AAHS kon sinvolle inligting na vore bring ten opsigte van ko-morbiede diagnoses tot die afwyking binne die Suid-Afrikaanse konteks.