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Sensitivity and Specificity of Long Wave Infrared Imaging for Attention-Deficit/ Hyperactivity Disorder

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Objective: This study was the first to investigate the efficacy of long wave infrared (LWIR) imaging as a diagnostic tool for ADHD. **Method:** This study was conducted to assess the sensitivity and specificity of LWIR imaging as a method of diagnosis among 190 patients (ages 4.4-57 years) with various diagnoses, including ADHD, who came into our office for neuropsychological evaluation. **Results:** LWIR imaging demonstrated a moderate level of sensitivity (65.71%) in identifying patients with ADHD and a high level of specificity (94%) in discriminating those with ADHD from those with other diagnoses. The overall classification rate was 73.16%. This was indicative of a high level of discriminant validity in distinguishing between patients with and without ADHD. There was a moderate level of agreement between LWIR imaging and multiple other diagnostic tests for ADHD. **Conclusions:** LWIR imaging demonstrated high sensitivity and specificity as a diagnostic tool for ADHD. These results provide evidence for the efficacy of a novel, quick, and effective way to investigate the physiological basis of one of the most prevalent childhood psychiatric disorders. *(J. of Att. Dis. 2009; 13(1) 56-65)*

Keywords: *long wave infrared imaging (LWIR); ADHD; diagnosis; validity; sensitivity; specificity*

ADHD is one of the most common neurodevelopmental disorders of childhood (Brown et al., 2001; Spencer, Biederman, Wilens, & Faraone, 2002; Vaidya, 2005), with a prevalence rate of 7.8% (11% for males, 4.4% for females) in the United States (Centers for Disease Control, 2005). In 2003, approximately 4.4 million children aged 4 to 17 years were reported to have an ADHD diagnosis; 2.5 million (56%) were receiving medication for this disorder.

Despite its prevalence, accurate diagnosis remains somewhat elusive. Furman (2005) outlined the guidelines recommended by the American Academy of Child and Adolescent Psychiatry (AACAP) for initial evaluation of ADHD as follows: (a) parent interview including the child's and family's history, (b) use of standardized rating scales, (c) school information including the results of academic assessment, (d) psychiatric child diagnostic interview, (e) family diagnostic interview, (f) comprehensive physical exam, and (g) referral for additional testing if required.

Although experts recommend the use of structured or semistructured interviews for the assessment of ADHD (Lahey & Wilcutt, 2002), there is a paucity of research investigating the accuracy of ADHD diagnosis on the basis of the clinical interview. Pelham, Fabiano, and Massetti (2005) reviewed reliability and validity data for two structured interviews: the Diagnostic Interview for Children and Adolescents–Revised (Reich, Shayka, & Taibleson, 1991) and the Diagnostic Interview Schedule for Children (Shaffer, Fisher, Lucas, Dulcan, & Schwab-Stone, 2000). Internal consistency and test–retest reliability coefficients ranged from .60 to .90. They also noted that parents' assessments are more accurate for older children and that agreement between parents and children is quite low (kappas range from .01 to .34). The semistructured interviews they reviewed, the Kiddie Schedule for Affective Disorders and Schizophrenia (Orvaschel, 1985) and the Child and Adolescent Psychiatric Assessment (Angold & Costello, 2000), did not have reliability data specifically for ADHD assessment.

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Pelham et al. (2005) concluded that structured interviews provide no incremental validity or utility over using parent and teacher ratings. They require a significant amount of clinician and parents' time, making them too costly in most clinical situations.

Wolraich et al. (2004) investigated the impact of inter-rater reliability on the diagnosis of ADHD by teachers and parents. Elementary school children (n = 6171) were screened to identify children at risk for ADHD (n = 1573) according to teacher ratings. Findings of the study indicated low agreement between parent and teacher reports of ADHD symptoms as rated on *Diagnostic and Statistical Manual of Mental Disorders*, 4th edition (*DSM-IV*)-based questionnaires: Inattentive (r = .34, κ = .27), Hyperactive/Impulsive (r = .27, κ =.22), and Performance Impairment (r = .31, κ = .07).

Gualtieri and Johnson (2005) described the use of computerized continuous performance tests (CPTs) to assess vigilance and sustained attention as part of a standard evaluation for ADHD. The Conners' CPT and the Test of Variables of Attention (TOVA) were reported to be the most frequently used CPTs. The Conners' CPT and TOVA each have sensitivity levels (rate of identifying attentional deficits in children diagnosed with ADHD) equal to 85%. However, high rates of false positives (30%) in normal controls and children with other psychiatric disorders (28%) have been reported for the TOVA. Schatz, Ballantyne, and Trauner (2001) compared the sensitivity and specificity of the TOVA and Conners' Rating Scales. They reported a sensitivity of 85.7% for the TOVA and 78.6% for the Conners' Hyperactivity Index. The specificity of the TOVA was 70%, whereas it was found to be 100% for the Conners' scale in this particular study. However, these numbers are likely overestimates as the specificity was not compared with any other psychiatric groups, only normal controls. Furthermore, parents who completed the Conners' scales already knew whether their children had ADHD from previously being diagnosed. Others have reported low rates of sensitivity (72.7%) and specificity (46%) for the Intermediate Visual and Auditory (IVA)-CPT (Pan, Ma, & Dai, 2007) and that CPTs generally have acceptable levels of sensitivity, though poor specificity (Riccio & Reynolds, 2001). Others have found that CPTs add no diagnostic utility of ADHD (McGee, Clark, & Symons, 2000).

Preston, Fennell, and Bussing (2005) assessed the degree to which the TOVA distinguished children with ADHD (n = 116) from children with subclinical levels of attention/behavior problems (n = 51). Findings of the research indicated that there were no significant differences between the groups. Therefore, CPT performance did not reliably predict group membership. Gualtieri and Johnson (2005) also described CPT tests (such as the TOVA and Conners') as lacking acceptable levels of test–retest reliability, reporting low levels of specificity and sensitivity.

The AACAP's final recommendation for additional testing refers to neuropsychological evaluation, which also has been demonstrated to be inadequate. Chhabildas, Pennington, and Willcutt (2001) compared the neuropsychological profiles on the *DSM-IV* subtypes of ADHD. Participants included 4 groups of children (mean age = 10.32 to 12.00 years): (a) controls without ADHD (n = 82), (b) inattentive subtype of ADHD (ADHD-IA; n = 67), (c) hyperactive–impulsive subtype of ADHD (ADHD-HI; n = 14), and (d) combined ADHD subtype (ADHD-C; n = 33). Neuropsychological tests of vigilance (Gordon Diagnostic System), processing speed (Wechsler Intelligence Scale for Children Coding; Trail Making Test), and inhibition (Stroop Task) were administered to assess the discriminant validity of these measures. Findings indicated that inattention best predicted performance on all dependent measures. Children with ADHD-HI had no significant deficits when the subclinical symptoms of inattention were controlled. Symptoms of inattention rather than hyperactivity appear to be associated with neuropsychological impairment. Therefore, neuropsychological assessment alone did not have discriminant validity in predicting the categorical dimensions of ADHD subtypes (Chhabildas et al., 2001).

Kaplan and Stevens (2002) reviewed neuropsychological as well as neuroimaging studies of ADHD. Studies conducting neuropsychological testing of individuals with ADHD indicated normal performance on many neuropsychological measures; however, performance on tasks of memory and vigilance may be impaired. As a result, some neuropsychological tests provide sensitivity in distinguishing cognitive deficits and severity of impairment, but they may lack specificity in differentiating ADHD from other psychiatric disorders with similar symptoms.

Because clinician interviews, CPTs, rating scales, and neuropsychological testing all have been found to be less than adequate in making an accurate diagnosis, clinicians are seeking a more objective method to identify ADHD. Although there is no objective test of ADHD, evidence indicates a neurobiological basis for the disorder based on deficits in the prefrontal cortex and related subcortical systems. Functional neuroimaging methods are now being employed to investigate this neurobiological basis.

Monastra et al. (2005) reviewed research on the quantitative electrophysiology of ADHD. A common electrophysiological pattern is underactivity over the frontal, central, and midline cortical regions in 85% to 90% of patients with ADHD. Another pattern is excessive activity or hyperarousal over frontal regions in individuals with ADHD. This profile was common in patients who did not respond well to stimulant medication and may represent a clinical syndrome which deviates from the more common ADHD subtype. Quantitative electroencephalography (QEEG) may be the best method of diagnosis known to date. Chabot, Merkin, Wood, Davenport, and Serfontein (1996) showed that QEEG could be used to distinguish between children with specific developmental learning disorders and children with ADHD as well as from a normal population with levels of accuracy between 85% and 95%. Furthermore, QEEG was found to reliably distinguish between children who respond favorably to dexamphetamine from those who respond to methylphenidate.

Although neuroimaging research has found differences in multiple brain regions (Castellanos et al., 2002), perhaps the most well-recognized and established neuroimaging research reveals evidence of abnormalities in frontal system function. The neural networks of the anterior brain are known to contain the major components for attentional and executive functioning (Fuster, 1997), whereas the prefrontal cortex regulates planned behavior in the form of integration of actions. Damage to this region is characterized by syndromes of impulsive and disinhibited behavior (Kaplan & Stevens, 2002). In ADHD, the prefrontal cortex is reduced in size, especially in the right hemisphere. Reduced white matter volumes have been noted in the right anterior brain regions in the prefrontal cortex and corpus callosum (Filipek et al., 1997).

A review of single photon emission computed tomography (SPECT) and positron emission tomography (PET) studies of brain metabolism in ADHD indicated low metabolic activity in the frontal and striatal regions during auditory tasks and hyperperfusion in the frontal and parietal areas as well as the limbic region (Vaidya, 2005). Others have found dysfunction in the anterior cingulate cortex in both adults (Bush et al., 1999) and children (Levesque, Beauregard, & Mensour, 2006) with ADHD.

Functional magnetic resonance imaging (fMRI) studies have revealed reduced brain activation in the right-hemispheric mesial frontal cortex during two higher order motor control tasks (Rubia et al., 1998). ADHD was associated with decreased activation of the prefrontal system which regulates higher order motor control. Recently, fMRI research studies have also investigated the resting-state brain function in ADHD. Cao et al. (2006) found that boys with ADHD showed decreased regional homogeneity in frontal–striatal–cerebellar regions during the resting state. Investigations of the resting-state low-frequency fluctuations in blood oxygen level dependent fMRI have demonstrated that ADHD patients exhibit abnormally high levels of functional connectivity between dorsal anterior cingulate cortex and bilateral regions of thalamus, cerebellum, insula, and pons (Tian et al. 2006). Others have found decreased amplitude of low-frequency fluctuations during a resting state in boys with ADHD in right inferior frontal cortex and bilateral cerebellum (Zang et al., 2007). Amplitude was increased, however, in right anterior cingulate cortex, left sensorimotor, and bilateral brainstem. Zhu et al. (2008) found that resting-state fMRI (85%) was significantly more accurate at discriminating ADHD than structural gray matter analyses (55%). Specifically, they found that prefrontal cortex, anterior cingulate, and the thalamus were identified as abnormal in ADHD subjects.

A more recently developed neuroimaging technique, which is somewhat similar to fMRI, is near infrared spectroscopy (NIRS). This technology uses light in the near infrared range (700-1000 nanometers) to determine cerebral oxygenation, blood flow, and metabolic processes of the brain (National Institute of Neurogical Disorders and Stroke, 1997). Light in this range can pass through skin, bone, and other tissue relatively easily and enter the head through light emitting diodes in a headband placed on the forehead. Detectors in the headband can measure light which is reflected back based on known absorption properties of oxygenated and deoxygenated hemoglobin.

As opposed to other neuroimaging techniques (fMRI, PET), NIRS studies have the benefit of being used in more ecologically valid settings. Hada, Abo, Kaminaga, and Mikami (2006) used NIRS to detect changes in cerebral blood flow following stimulation of primary motor cortex with repetitive transcranial magnetic stimulation. They observed greater decrements in total- and oxyhemoglobin concentrations and increment of deoxyhemoglobin during and after repetitive transcranial magnetic stimulation. This study was of notable importance because of problems related to temporal resolution and magnetic field artifacts caused by TMS with other imaging techniques including PET, SPECT, and fMRI.

Although still a relatively new technique, numerous studies have been conducted to validate the use of NIRS through comparison with other functional neuroimaging procedures such as fMRI and PET (Mehagnoul-Schipper et al., 2002; Villringer et al. 1997). Mehagnoul-Schipper et al. (2002) conducted a simultaneous fMRI/NIRS study in both healthy young and elderly subjects to investigate the effects of age on cortical activation responses. Participants performed a finger-tapping task in which they tapped as quickly as possible. Blood oxygen level dependent fMRI and NIRS measurement showed good correlations with both the young ($r = -.70$) and the elderly ($r = -.82$). NIRS measurements demonstrated age-dependent decreases in task-related cerebral oxygenation responses.

Although NIRS has greater ecological validity than fMRI, it still requires direct contact with the subject. However, a similar, newly developed technology which still uses infrared light but is contact free is thermoencephaloscopy, a form of long wave infrared (LWIR) imaging. LWIR reveals activated (heated) and deactivated (cooler) regions of cerebral cortex through thermovision and image processing techniques which are sensitive to neural activity, local metabolism, local cerebral blood flow, and thermoconductivity of activated zones of cortex (Shevelev, 1992, 1998). This technique has a temporal resolution of 40 milliseconds (ms), spatial resolution of up to 70×70 μm pixel^{-1} (Shevelev, 1998). LWIR imaging has been used during intraoperative procedures on 30 neurosurgical patients (Ecker et al., 1999), including provision of real-time perfusion imaging during neurovascular surgery, localization of seizure foci corresponding to electrocorticographically mapped areas, identification of functional cortex during resection and cortical stimulation, and localization of brain tumors. Recently, Iznak and Nikishova (2007) used this technique in a group of depressive patients, demonstrating functional changes in frontal associative areas of the right hemisphere to emotionally significant visual stimuli. Other uses of LWIR imaging have included assessing myocardial blood flow (Adachi, Becker, & Ambrosio, 1987) and detection of breast cancer (Anbar, Milescu, & Naumov, 2001).

We propose that LWIR imaging may be used as a diagnostic tool to accurately identify patients with known brain dysfunction; and in this case, those with ADHD. LWIR imaging is useful for several reasons. First, it is a biological marker, as it measures brain activity. This takes out much of the bias that comes from the subjectivity of both the clinician's evaluation as well as parents' ratings. Specifically, LWIR imaging measures brain activity in the prefrontal cortex, an area previously shown to be affected in ADHD and involved in attention, executive functioning, and able to differentiate those with ADHD from those without based on resting-state activity. In addition, no physical contact is necessary, unlike with NIRS, and the images are obtained in just a few seconds.

Coben and Padolsky (in press) recently assessed the test–retest stability of LWIR imaging measured at both 60-second and 30-minute intervals. They demonstrated high correlations for all LWIR measures performed, with mean correlation coefficients of .903, indicating a high degree of reliability.

Our study investigated the diagnostic accuracy of LWIR imaging in identifying deficits of frontal activation as reflected by thermoregulation within frontal brain regions. Here, we provide initial research on the validity of LWIR imaging as an assessment instrument. Specifically, we assessed the clinical utility based on the sensitivity and specificity of LWIR imaging as a diagnostic tool for identifying and differentiating ADHD from other diagnoses.

We hypothesized that LWIR imaging over the prefrontal cortex would identify patients with a known diagnosis of ADHD. Furthermore, we hypothesized that it would be able to differentiate patients with a diagnosis of ADHD from patients with other diagnoses.

Methods

Participants

A total of 190 patients (141 male, 49 female) with various diagnoses, who came into our clinic between January 2004 and March 2006 participated. Of them, 171 were Caucasian, 9 were African American, 8 were Hispanic, one was Indian, and one was Asian. The mean age was 16.2 years ($SD = 11.7$), with only 29 patients older than the age of 21 years. Overall, 140 patients had a diagnosis of ADHD. The remaining 50 had various diagnoses which included other developmental disorders, concussion, cerebrovascular accident, depressive, and anxiety disorder.

Procedure

A diagnostic interview was conducted with the patients to ascertain the core behavioral, cognitive, and social/emotional issues of concern as part of a comprehensive neurodevelopmental history. Consent was obtained and procedures were explained. All participants underwent LWIR imaging at our neuropsychological clinic as part of our standard evaluation procedure. A positive LWIR diagnosis of ADHD was operationally defined as the minimum thermal reading over Fpz (the most frontal midline electrode based on the international 10-20 system of electrode placement; Jasper, 1958) lower than the average temperature of the entire prefrontal area of an individual subject

Table 1
Specifications for ThermoVision A20M

Field of view	25° degrees × 19°/0.3 m
Detector type	Focal plane array (FPA) uncooled microbolometer
Spectral range	7.5-13 µm
Thermal sensitivity	At 50/60 Hz: 0.12°C at 30°C
Accuracy (% of reading):	±2°C or ±2%
Individual emissivity settings	Individually settable
Measurement corrections	Reflected ambient, distance, relative humidity, external optics. Automatic, based on user input
Power source	AC operation: AC adapter 110/220 VAC; 50/60 Hz (included). DC operation: 12/24 V nominal, <6W

Note: Specifications were obtained from FLIR Systems (2005a).

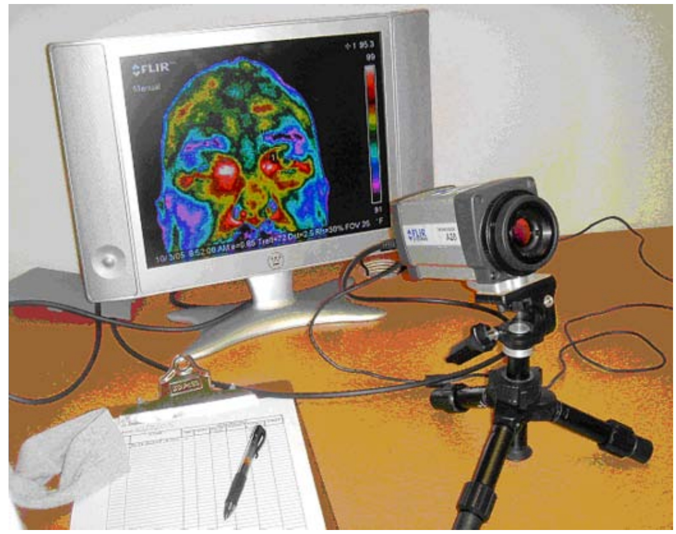
by 1.5 *SD*. This area was chosen because it is the most anterior location of the frontal lobes and is in front of the anterior cingulated gyrus, shown to be implicated in ADHD. This data was then compared with the true diagnosis, determined by a combination of a battery of neuropsychological tests, rating scales, interview by a licensed clinical psychologist (R.C.), the IVA continuous performance test, and QEEG.

Measures

LWIR imaging is an assessment tool that uses an infrared video system to record thermal images of multiple brain regions rather than just one area. Research indicates that LWIR imaging of thermal activity is a valid and reliable measure of brain activity, metabolic processes, and regional cerebral blood flow (Carmen, 2002; Coben, 2005a, 2005b; Coben, Carmen, & Falcone, 2005; Toomim et al., 2004).

A ThermoVision A20M camera from FLIR Systems (2005a) was used for infrared Imaging (please refer to Table 1 for camera specifications). As part of the imaging procedure, the camera (mounted on a tripod) was set up approximately one and a half feet from the patient and aimed at their face. The video camera records temperatures from one and a half feet from the patient's forehead, allowing it to measure multiple points at once while the subject is at rest. Near infrared, in contradistinction typically requires the individual to perform some cognitive task. The thermal image was projected onto a screen (please refer to Figure 1). Specifications programmed into the camera included: emissivity (.90), distance (1.5 ft.), reflected temperature (72), ambient temperature (72), atmospheric transmission (1), humidity (50%), external optic temperature (68), external optic transmission (1), and reference temperature (68).

Figure 1
Infrared Imaging System Projecting a Thermal Image

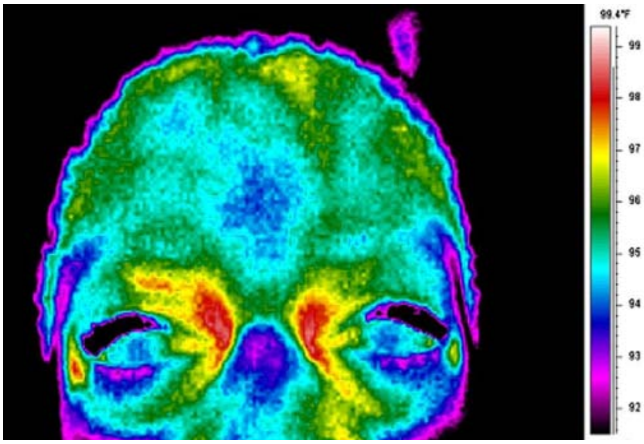


Images from the camera are downloaded onto a computer for analysis using Thermocam Researcher (FLIR Systems, 2005b). The software calculates the specific temperatures by measuring the amount of radiation the camera receives from the object being measured. The components of the image which undergo analysis are selected by the researcher. The image is cropped by selecting various points over the forehead. These points are then automatically connected by the program, which then provides a mean and standard deviation of the temperature in the area selected. Thermal images are color coded and range from black with the least thermal output to red with the greatest thermal output. Figure 2 demonstrates an LWIR image from a child with ADHD. It shows the typical profile with an area of diminished thermal output at the frontal midline, which exemplifies why we have chosen that location for the operational definition of ADHD.

Data Analysis

The sensitivity of LWIR was evaluated by determining the number of patients correctly identified as ADHD out of all patients. This was computed by dividing the number of cases with ADHD identified by LWIR imaging (true

Figure 2
Individual ADHD Subject Showing Reduced Thermal Activity at Fpz



positives, TP) by the number of cases with ADHD identified by LWIR imaging (true positives) plus those cases that LWIR imaging did not identify (false negatives, FN), but really did have ADHD. The diagnosis of ADHD by LWIR was defined as the minimum thermal reading over Fpz being 1.5 *SD* lower than the average prefrontal temperature. In other words, the average prefrontal temperature was first calculated. A diagnosis of ADHD would then be made if the temperature over Fpz was more than one and a half standard deviations below the average temperature of the prefrontal area. The true condition was defined by the measures stated above in the procedures section. A chi-square test was used to evaluate the significance of the results as well as a kappa statistic to determine the degree of agreement between LWIR imaging and the actual diagnosis. A false negative rate (β) was computed as $\beta = FN/(TP + FN)$.

The specificity of LWIR imaging was defined by how well it correctly identified those cases that did not have a diagnosis ADHD. This was computed by dividing the number of cases without ADHD identified by LWIR imaging by the number of cases without ADHD identified by LWIR imaging plus those cases identified by LWIR imaging as having an ADHD diagnosis when in fact they did not. The true diagnosis was again determined by a combination of a battery of neuropsychological tests, rating scales, interview by a licensed clinical psychologist (R.C.), the IVA continuous performance test, and QEEG. A chi-square test was computed to assess the significance of the results. Finally, a false positive (FP) rate (α) was computed as $\alpha = FP/(FP + TN)$.

Results

Ninety-two patients were identified by LWIR imaging as positive for a diagnosis of ADHD (minimum thermal reading over Fpz 1.5 *SD* lower that the average prefrontal temperature). The sensitivity (rate of correctly identifying patients with ADHD) of LWIR imaging as a diagnostic measure was 65.71% (92 out of 140), resulting in a false negative rate of 34.29%. Further analyses using the chi-square test yielded significant findings, $\chi^2(1) = 52.55$, $p < .001$. A kappa value of .463 was significant ($t = 7.25$, $p < .001$), indicating a moderate degree of agreement.

The specificity of LWIR imaging was 94% (47 true negatives/47 true negatives plus 3 false positives), with a false positive rate of 6%, indicating a high level of discriminate validity in accurately distinguishing between patients with ADHD, comorbid, and non-ADHD diagnoses. Thus, the overall accuracy of this technique was 73% ([92 + 47]/190).

Discussion

LWIR imaging has been found to be a reliable assessment procedure which is sensitive to brain activation as indicated by thermoregulation (Coben & Podalsky, in press). In our study, the clinical utility, sensitivity, and specificity of LWIR imaging as a diagnostic measure was confirmed by correctly identifying a higher rate of patients (92 out of 140; 65.71%) with ADHD than reported by most other diagnostic measures. The specificity of IR imaging was 94% (47 of 50), indicating a high level of discriminant validity in accurately distinguishing between patients with ADHD, comorbid, and non-ADHD diagnoses.

All of the current approaches to ADHD diagnosis have limitations. CPTs have been found to have high rates of false positives (30%) in normal controls and children with other psychiatric disorders (28%; Gualtieri & Johnson, 2005). Wolraich et al. (2005) reviewed limitations of rating scales, such as only moderate levels of agreement between teacher and parent ratings. In addition, both structured and semistructured interviews have been shown to have levels of reliability as low as .60 (Pelham et al., 2005), and neuropsychological testing has poor discriminant validity (Chhabildas et al., 2001). Current research indicates that the best identifiers of ADHD are those that use a biological marker. Quintana, Snyder, Purnell, Aponte, and Sita (2007) recently conducted a comparison of rating scales with EEG in the diagnosis of children with suspected ADHD. Although rating scales had acceptable levels of sensitivity (81%), they proved to be quite nonspecific (22%) in their ability to discriminate between children with symptoms associated with ADHD and children with an actual diagnosis of ADHD. EEG once again demonstrated both high levels of sensitivity (94%) as well as a high level of specificity (100%). The level of accuracy we achieved (73%) is one of the highest levels of any current diagnostic measure. Used in conjunction with other methods, particularly QEEG because it has demonstrated high validity already, IR imaging may contribute to more accurate diagnosis, thereby enhancing treatment.

Previously, both PET and fMRI studies have shown frontal areas to be differentially activated in ADHD as compared with non-ADHD children. Although this was the fist time LWIR imaging was used to measure brain activity in a population with ADHD, a recent study showed that NIRS was used to show differences in oxyhemoglobin and deoxyhemoglobin in boys with ADHD (Weber, Lutschg, & Fahnenstich, 2005), specifically in frontal areas. Non-ADHD children showed lateralized oxygen consumption in left prefrontal areas during an extended attention task, whereas ADHD diagnosed children showed an imbalance between oxygenated and deoxygenated blood during such tasks. Although we were unable to use a control site to compare with frontal activation, our findings contribute to evidence implicating the importance of the prefrontal cortex in attentional processes by using a specific frontal area (Fpz) to identify participants with an attentional disorder.

Because this is the first study utilizing this technique, many more studies need to be conducted before implementing its use in clinical practice. Given the reliability and validity of LWIR imaging, this tool appears to be a good candidate for use as a measure of outcome in treatment studies. It may even be able to facilitate treatment, as QEEG was shown to discriminate patients who responded to different medications (Chabot et al., 1996). Future studies should also address whether LWIR imaging can differentiate between children with ADHD and children with subclinical levels of attention problems.

Clinical Implications

This is the first study of its' kind to demonstrate the utility of LWIR imaging in the diagnosis of ADHD. The data produced in this study are the first to investigate the use of this technique for the accurate classification of ADHD quickly, easily, and cost efficiently. As with all psychiatric disorders with no definitive biological marker, a diagnosis of ADHD will always have a certain amount of subjectivity and bias. The use of LWIR imaging may help clinicians make a more accurate diagnosis by eliminating some of this subjectivity. This technique is just one of the many tests which examine the physiological basis of ADHD. Interviews and rating scales can only account for a limited amount of the variance in an accurate diagnosis. Using imaging techniques such as QEEG, SPECT, fMRI, and LWIR will move us closer to a more biologically based assessment of ADHD.

Identifying patients with ADHD often requires extensive time and effort for both the patient and clinician; including interviews, rating scales, and behavioral tests such as a CPT. LWIR imaging is simple for both the clinician and patient. Imaging may be completed in as little as 15 seconds and does not require the patient to do anything while being imaged. This fact is important because measurements do not depend on the full cooperation or effort of the child. Determining the level of effort children put forth on a long and tedious test such as a CPT is often a highly confounding variable when performance is poor. Finally, the facility and promptness of administration are likely to reduce many of the health care costs associated with traditional diagnostic procedures.

Limitations

Several factors limit the generalizability of our findings, most of which are related to our study participants. First, our sample was self-selected based on the typical group of patients seen at our office. Future studies should use a population of school children to increase the ecological validity of these findings. There was also no randomization of patients, another factor that should be taken into account in future research.

These studies were conducted primarily with adolescents, so further research is needed to investigate whether these results would generalize to adults. However, because ADHD is classified as a developmental disorder and symptoms must be present before age 7, this is a good age group with which to begin such an investigation. There were large age ranges in this study due to the inclusion of all patients who came for evaluation. When eliminated from the data analysis, age did not appear to be a factor mitigating against the sensitivity of the technique (i.e., we were able to use the technique successfully on all aged participants). Despite a wide age range across participants, the high reliability scores indicate that LWIR produces consistent measures in various age groups (Coben & Padolsky, in press).

There were a greater number of males than females in our studies, limiting the generalizability to females. Again, this represents a true gender difference in the prevalence of ADHD, so this is not a great detriment. Our study also contained a preponderance of Caucasians. Future studies are needed to determine whether other ethnic groups would have obtained similar results. Also, the comparison group used to determine the specificity of LWIR imaging included numerous different diagnoses. Future studies are needed to look at other ethnic groups and the ability to distinguish between those with ADHD, those with no diagnosis, or some of the more common specific neurodevelopmental disorders. Finally, a limitation of LWIR itself is that it is not possible to measure nonfrontal sites, as infrared light does not pass through hair.

This study was the first to investigate the validity of a new diagnostic tool, which may identify a biological/physiological marker of ADHD. LWIR has the benefit of cutting down on the subjectivity of rating scales and the problems associated with psychometric tests (e.g., effort). We found the sensitivity and specificity to be accurate in this population. Thus, used in conjunction with existing methods of diagnosis, we may be able to improve the accuracy of diagnosing ADHD and other neurodevelopmental disorders.

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