A wearable interface that helps the diagnosis of ADHD behavior based on biofeedback technology

Eduardo Ayala Pérez
University of British Columbia
Vancouver, Canada
+1(778) 316-2212
edaype@alumni.ubc.ca

Andy Liu Mengxi
University of British Columbia
Vancouver, Canada
+1(604) 349-7461
mengxi_liu@gnwc.ca

ABSTRACT

The purpose of this research is to help diagnose children between the ages 5 and 8 with Attention Deficit Hyperactivity Disorder (ADHD) by combining statistical analysis based on established behavioral patterns and activity monitors using biofeedback technology. In this paper we are proposing a wearable device (armband), whose intention is to help monitor heart rate, skin conductance (skin galvanic response) activity related to standing, sitting and walking using an accelerometer. The proposed system will track and record these activities over certain period of time and by comparing the data recorded against the average data collected from subjects with no indication of ADHD, it can help determine if one child might have the disorder. In the initial stage our approach has the focus on helping with the diagnosis of ADHD by preventing unnecessary tests and interviews to parents and teachers of individuals with behavior similar to ADHD patients, as well as to use the device as an indicator if further testing is required on the patient based on the data collected.

Categories and Subject Descriptors

H.5.2 [Information Systems]: Evaluation methodology
H.1.2 [Information Systems]: Human factors

General Terms
Measurement, Design, Human Factors

Keyword


Permission to make digital or hard copies of all or part of this work for personal or classroom use is granted without fee provided that copies are not made or distributed for profit or commercial advantage and that copies bear this notice and the full citation on the first page. To copy otherwise, to republish, to post on servers or to redistribute to lists requires specific permission and/or a fee.

HIT2012, Vancouver, BC, Canada. © UBC 2012

1. OBJECTIVE

The interface’s intention is to help with the diagnosis of ADHD in children aged between 5 and 8 by using a wearable device equipped with sensors to measure their physical activities and body responses over certain periods of time. This device will function as an initial test for potential patients by helping determine if the child is a candidate to be diagnosed with ADHD.

2. INTRODUCTION

2.1 ADHD

Recent studies have shown that 3 to 5% school-age children suffer from the Attention Deficit Hyperactivity Disorder (ADHD) in the United States, which represents approximately 2 million children (1 out of 25) [1], affecting their every day activities. This disorder was first introduced by the Diagnostic and Statistical Manual of Mental Disorders version 2 (DSM-II), introducing the observations about the ADHD as “Hyperkinetic Behavior Syndrome in children” in 1968. Later the DSM-III included this disorder as attention deficit disorder with hyperactivity in 1980.

The concept has been redefined and in the DSM-IV published in 1994, the latest version at this time, states that the ADHD can be categorized as Attention Deficit Disorder with hyperactivity in three subcategories: predominantly hyperactive-impulsive, predominantly inattentive, and combined hyperactive-impulsive and inattentive, being the last type the most common in children [2].

The diagnosis of this condition is conducted by a series of interviews, lengthy questionnaires and an extensive number of observations described in tests like the Conners Rating Scales and the Hyperactivity subscales, focusing on the parents and teachers of the children to describe their observations and findings about the patient behavior. According to the Agency for Healthcare Research and Quality, these are the most common tests targeting the behavior and sometimes the tests are not accessible to all the children who might have the condition [3]. During our research we found that there are some tests involving video games like T.O.V.A, however this type of tests require the children to be outside their environment, which may result in the patients to be predisposed to certain behaviors and bias the test results.

2.2 Neurofeedback and Biofeedback

Neurofeedback is a type of biofeedback and this technique is used to record signals at the scalp. These signals captured from the brain activity are processed by a complex series of algorithms to translate them and convert them into computer cursor movements. This requires a considerable training time for the patient to develop certain control over the cursor, which is the most common calibration method [4]. Later, this principle became useful as a non-drug treatment for ADHD and has been proven effective for children who manifest certain psychological disorders to help their treatment for anxiety, cystic fibrosis and show some stress. Even though biofeedback technologies have been used to treat patients with mental and psychological disorders such as bipolar disorders like in the “PSYCHE” project. These techniques of neurofeedback and biofeedback have not been implemented in the diagnosis process of ADHD because the examination and diagnosis tends to be more behavioral orientated.
A growth of 15% was detected in 2006-2008, with an additional 1.8 million US children with ADHD cases [8], which could lead to a portion of patients that are misdiagnosed as well as an imminent increase in diagnoses. This became our motivation to propose a system that facilitates the diagnosis process for ADHD patients at a certain age range.

2.3 Our Approach

What we are trying to achieve with this research is use a device that helps collecting data from the children during a regular day of activities and an environment, to avoid biases, with the purpose of helping diagnose positively ADHD or discard it. The wearable device will be equipped with a number of biofeedback sensors, which detects real-time biofeedback activity data from users.

The device will be used to help the diagnosis of ADHD based on physical behavior in the potential subject collecting data from the body. This will require an unified testing standard for ADHD diagnosis, as well as a reference data to set the standard which later will be used to compare the behavior of the potential patients. We are considering if a subject is having lectures from the sensors considered as unusual from the comparison of the reference data, we would like to think that the subject might be a candidate for further testing to diagnose ADHD. In the case where the subject’s records are within the standards we are proposing that the subject is not a potential ADHD patient. We will cover the design of the reference data collection process in the methodology and research design aspect.

2.4 Children weight

According to our approach, the design is contemplating kids in the ages from 5 to 8 years old and in order to standardize the measurement we are using calories burned to measure the activity. Because this measure is relative to the weight and age of the kids, we are considering a healthy kid, within the 55% percentile of body mass index (BMI) meaning that 54% of the people of the same age and gender have a lower BMI [9-10].

Figure 1. The spectrum showing the percentage of individuals with a healthy weight

<table>
<thead>
<tr>
<th>Age</th>
<th>Height</th>
<th>Weight</th>
<th>BMI</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 Year old</td>
<td>110cm</td>
<td>19kg</td>
<td>15.6</td>
</tr>
<tr>
<td>6 Year old</td>
<td>116cm</td>
<td>21kg</td>
<td>15.6</td>
</tr>
<tr>
<td>7 Year old</td>
<td>122cm</td>
<td>23kg</td>
<td>15.6</td>
</tr>
<tr>
<td>8 Year old</td>
<td>128cm</td>
<td>26kg</td>
<td>16</td>
</tr>
</tbody>
</table>

Figure 2. The BMI distribution related within the age range.

Table 1. Relationship between BMI and age, height and weight.

This table is calculated for male kids having a slight difference in the BMI between males and females. This discrepancy in the values does not affect in our data ranges for healthy BMI.

According to the weight, each person can burn different number of calories. The following table shows an average calorie burn per person per hour based on different activity intensity from low to high. We define low as an activity that does not involve displacing like reading, playing cards or video games. Mid intensity activity is defined as light walking and non-cardio activities. The high intensity activities are those involving cardio exercises like hiking and running. In the table we are calculating the calorie
consumption during one hour. The low intensity is defined specifically as “playing board games”, the mid intensity as “walking at 4.5 km/h” and high intensity is “casual soccer”[11]. We will be using the Metabolic Equivalent (MET’s), which is defined by the Compendium Of Physical Activities as:

“The ratio of the work metabolic rate to the resting metabolic rate. One MET is defined as 1 kcal/kg/hour and is roughly equivalent to the energy cost of sitting quietly. A MET also is defined as oxygen uptake in ml/kg/min with one MET equal to the oxygen cost of sitting quietly, equivalent to 3.5 ml/kg/min”[12]

The MET relates an activity with the person’s RMR (Resting Metabolic Rate), which they would burn calories resting and is based on their weight. Other activities are assigned MET values to indicate their intensity level relative to RMR. [13]

<table>
<thead>
<tr>
<th>Age / Weight</th>
<th>Low Intensity</th>
<th>Mid Intensity</th>
<th>High Intensity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Less than 3 MET’s</td>
<td>3-6 MET’s</td>
<td>6+ MET’s</td>
</tr>
<tr>
<td>5 year old / 41 lbs</td>
<td>28 calories</td>
<td>61 calories</td>
<td>130 calories</td>
</tr>
<tr>
<td>6 year old / 47 lbs</td>
<td>32 calories</td>
<td>70 calories</td>
<td>149 calories</td>
</tr>
<tr>
<td>7 year old / 51 lbs</td>
<td>37 calories</td>
<td>76 calories</td>
<td>162 calories</td>
</tr>
<tr>
<td>8 year old / 57 lbs</td>
<td>39 calories</td>
<td>85 calories</td>
<td>181 calories</td>
</tr>
</tbody>
</table>

Table 2. The relationship between intensity of METS and age/weight.

This data will be used for reference when we collect the data from the tests and following the same principle; adults have a proportional calorie burn based on their weight. This data will be used to map and relate the calories burned by an adult and the calories burned by a child assuming that the adults are within the same BMI. [14]

2.5 Extra calories burned by ADHD patients.

We are making the assumption that all ADHD patients manifest a certain degree of fidgeting as a symptom of the hyperactivity and according to the study "Energy expenditure of non-exercise activity" [15] subjects showed an energetic expenditure increased while fidgeting while seated by 54 ± 29% (P < 0.0001) and while walking at 3.2 km/h by 202 ± 45% (P < 0.0001). To prove that the energy drink is inducing an ADHD state in the subjects we are considering this data to validate the calories burned during the experiment after 10 minutes of drinking the energy drink.

3. METHODOLOGY AND STUDY DESIGN

3.1 Research Questions and Hypothesis

Our research tries to answer the following research questions:

- Q1: Does biofeedback wearable system accurately diagnose ADHD behavior based on our research design?
- Q2, How can the wearable system be designed to provide minimum level of negative invasion and intervention to the users?

We have the following hypothesis of our research questions:

- H1. The biofeedback wearable system will provide high accuracy of ADHD diagnosis based on our research design and reference data collection.
- H2. The wearable system can be designed to provide minimum level of negative intervention and invasion to the users.

Our study design and prototype aims to validate our hypotheses and reject the null hypotheses.

3.2 Prototype design

Figure 3 shows an image of a sensor used. The proposed system will include hardware and software components. Each component will have its minimum system specifications to maintain the proper system operation. The system specification explained in this section will act as the development guideline.

Figure 3. BodyMedia FIT’s hardware architecture.

3.2.1 Proposed Hardware

BodyMedia FIT is an on-body monitoring system that uses biofeedback sensors technology to measure, analyze and record the bio medical data from users on a daily life basis. The device is designed as armband which automatically track the calories burned during user’s daily activities. It takes the user’s weight, height and age to calculate the data. The information tracked can easily be
managed with BodyMedia’s online Activity Manager accessing the data through HTTP GET methods of the API.

As a system that captures intensive bio-feedback related data, BodyMedia FIT captures over 5,000 data points per minute, from heat and sweat to steps and calories burned every minute of every day. [16]

BodyMedia FIT System uses multiple sensors, as illustrated in Figure 3, in which differentiates the system from other products in the market. For example, the heat flux sensor measures the amount of heat given off by the body. This is energy that accelerometer-only products miss when calculating energy burn based solely on motion.

Precisely, BodyMedia FIT uses four sensors to achieve the proven accuracy.

- 3-axis accelerometer, which will measure the motion related data such as steps.
- Calibrated range is +/- 1.0g
- The minimum resolution is 0.01g
- Two-standard-deviation error of +/- 0.08g on all axes
- Heat flux sensor, which measures the rate at which heat is dissipating from user’s body.
- Calibrated range is 0.0 W/m2 to 300.0W/m2
- A minimum resolution of 1.0W/m2
- Two-standard-deviation error of +/- 10.0W/m2 to 30W/m2
- Two-standard-deviation error of +/- 35.0% otherwise
- Galvanic skin response sensor, which measures how active the electrical conductivity is when the users are sweating.
- Calibrated range is 56k Ohms to 20M Ohms (50.0 nSiemens – 17.0 µSiemens)
- Two-standard-deviation error of +/- 9.0 nSiemens. 50 to 255 nSiemens
- Two-standard-deviation error of +/- 4.0% otherwise
- Temperature sensor, which measures surface temperature of the user’s body
- Calibrated range is 20.0°C to 40.0°C
- A minimum resolution of 0.05°C
- Two standard deviation error of +/- 0.8°C [18]

Our research project chose the BodyMedia FIT system as a primary set of sensors for our research over a few reasons:

- The BodyMedia FIT system provides personal bio-medical data of high accuracy and precision, which are highly related to the metrics for ADHD diagnosis analysis.
- The device are able to measure the caloric differences reliably, since it contains sensors that measure caloric difference based on a default time interval, the calories value measured for a single subjects reflects his own bio medical data.
- The difference in calories related to ADHD reliably mainly because the calories consumption for an ADHD patients is increased due to the hyper behavior experienced by the them, hence the correlated increase in caloric consumption measured by the BodyMedia fit system can reliably indicates that the subjects with higher caloric consumption can be diagnosed for ADHD.
- The API provided by BodyMedia FIT is instrumental for our research purpose in terms of data analysis.
- The design of the BodyMedia FIT is highly ubiquitous, which eliminates the constraints of the system when the user testing is being conducted.

3.2.2 Software

The requirements needed for the software design are based on the need of visualizing; collecting user’s behavior data based on the result of the reference data. To achieve this, the proposed system needs the following:

a. Data storage.

The data will be stored in the BodyMedia FIT system and will be transmitted to the web-based platform interfaced with the USB port of the computer. BodyMedia website is taking care of the calculation and the data processing providing only certain methods in the API restricted by proprietary software but enough to suffice our needs.

b. Sampling rate

Since we are using BodyMedia’s sensor as the sampling mechanism we are subject to a fixed sampling rate of the BodyMedia FIT system, which was provided in the specifications of the product as 83Hz.

c. BodyMedia API:

We will be using the BodyMedia API for the collection of the calories data. The BodyMedia API provides a set of real time biomedical data that will be used for quantitative analysis of our research questions. We will be using the data provided by the API alongside our research process using BodyMedia FIT systems.

3.3 Sampling for reference data

3.3.1 Sampling for BodyMedia FIT

The break down of the sampling experiments we conducted is as following:

- Divided the subjects into two test experiments:
  - a. The Non-ADHD test
  - b. Simulated-ADHD test.
Based on the samples we collected from the 8 subjects involved in the test that follows different testing scenarios with regards to non-ADHD subjects and simulated ADHD subjects, we will extract the crucial data we need from the BodyMedia API and generate two sets of average data for comparison. Our theory contemplates that if the average obtained from the subject after the one-hour analysis period is consistent with an ADHD behavior, we would like to consider the subject as a potential ADHD diagnosis suitable for further tests. On the other hand, if the results from the test subject are consistent with the average from the reference data, this subject can be considered as a non-ADHD patient.

3.4 Study Design

We designed a set of experiments to evaluate and validate the research questions and hypotheses we proposed which are explained later in this section. We aim to adopt controlled experiment methods for most of the experiments due to the high accuracy the research methods provide for quantitative analysis. The controlled methods include similar activities for all the subjects.

3.4.1 Group based test for ADHD biomedical data collection using BodyMedia FIT.

To evaluate and answer research question H1, we will use the BodyMedia FIT to conduct a group based reference data recording process to retrieve the standardized values that will be used to the ADHD diagnosis process.

We collected data from 8 randomly selected participants aged from 18-55, making sure the participants have no indication of ADHD based on a pre-test questionnaires which examines if subject has ADHD related behaviors.

The group of participants will be taking part in both parts of the experiment. First the biofeedback information was recorded in a normal situation. For the second part of the experiment the same subjects were given an energy drink to induce an ADHD state and their biofeedback information was measured.

3.4.2. The induced ADHD state.

To achieve a simulated ADHD state we used energy drinks to develop periods of increased mental and physical exertion. The product used was a “Monster Energy - Absolutely Zero” in the 473ml presentation.

The product was consumed 10 minutes prior the test.

The features of the product are:

| Zero calories | 10mg d-glucuronolactone |
| Zero sugar    | 10mg Guarana            |
| 2000mg Taurine| 10mg Inositol           |

Table 3: Ingredients on the energy drink

3.4.3 Avoiding the anxiety and irrelevant reference data.

To evaluate and answer the research question R2 (How can the wearable system be designed to provide minimum level of negative invasion and intervention to the users?), we will be re-arranging the experiment procedure and settings. There are key observations we want to point out regarding the relationship between data validity and the use of the interface:

If external interference occurs from anxiety or stress when using the wearable interface for the purpose of gathering reference data of ADHD, there is a possibility of having invalid or irrelevant data coming from the reference subjects experiencing anxiety. To evaluate this, the participants were asked to rate the comfort wearing the device and interpret the level of comfort as interference with the experiment.

3.4.4 Ethical issues.

Participants of a relatively young age range will be involved in the experiment, thus research ethics will be an important issue that need to be addressed carefully. We have completed an ethics tutorial certificate and have read through the related ethical codes set by UBC’s Behavioural Research Ethics Board to guarantee the adequate data management.

4 THE EXPERIMENT

The experiment were conducted in the following manner:

8 randomly selected participants were chosen for this experiment aging from 18 to 55, making sure the participants have no indication of ADHD. We asked all subjects to participate in two one-hour experiments where they are required to put on the BodyMedia FIT armband to conduct a series of physical activities, which were previously explained as: Sitting down activities (Reading 15 min. Web browsing 15 min. Playing cards 20 min) and standing up activities (Walking lightly 10 min). Before each experiment the BodyMedia FIT is updated with the subject’s personal information. The activities were designed to ensure the MET’s value is lower than 6.

During the test, their skin galvanic response, temperature, heat flux and acceleration of the body was recorded and all will be measured by the BodyMedia FIT sensors calculating the calories burned. We will collect the subject’s calories output using the BodyMedia API as a data source.

5 THE RESULTS

After recording the calories burned every minute during the experiment we calculated the increase of calorie burned based suggested by the “Energy expenditure of non-exercise activity” research and compare the differences between the first recorded set of data and the ADHD induced data. In average we
expected an increase of 31% of the calories burned based on 50 minutes at a rate of 29% and 10 minutes at a rate of 45% increase.

<table>
<thead>
<tr>
<th></th>
<th>Non-ADHD Burnt Calories</th>
<th>ADHD Burnt Calories</th>
<th>Expected Calories for ADHD</th>
<th>% Increase</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>79.767</td>
<td>89.347</td>
<td>105.02</td>
<td>12%</td>
</tr>
<tr>
<td>S2</td>
<td>120.512</td>
<td>125.44</td>
<td>158.6741</td>
<td>4%</td>
</tr>
<tr>
<td>S3</td>
<td>131.365</td>
<td>135.676</td>
<td>172.9639</td>
<td>3%</td>
</tr>
<tr>
<td>S4</td>
<td>114.126</td>
<td>135.651</td>
<td>150.26</td>
<td>18%</td>
</tr>
<tr>
<td>S5</td>
<td>120.883</td>
<td>120.971</td>
<td>159.1626</td>
<td>0.07%</td>
</tr>
<tr>
<td>S6</td>
<td>122.3</td>
<td>125.051</td>
<td>161.0283</td>
<td>2%</td>
</tr>
<tr>
<td>S7</td>
<td>80.611</td>
<td>90.659</td>
<td>106.1378</td>
<td>12%</td>
</tr>
<tr>
<td>S8</td>
<td>132.774</td>
<td>137.683</td>
<td>174.8191</td>
<td>3%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>8.75%</td>
</tr>
</tbody>
</table>

Table 4: Comparison of calories burnt between subject’s experiments

<table>
<thead>
<tr>
<th></th>
<th>Non-ADHD MET’s</th>
<th>ADHD MET’s</th>
<th>% Increased</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>1.19</td>
<td>1.39</td>
<td>17%</td>
</tr>
<tr>
<td>S2</td>
<td>1.83</td>
<td>1.96</td>
<td>4%</td>
</tr>
<tr>
<td>S3</td>
<td>1.41</td>
<td>1.45</td>
<td>3%</td>
</tr>
<tr>
<td>S4</td>
<td>1.21</td>
<td>1.45</td>
<td>20%</td>
</tr>
<tr>
<td>S5</td>
<td>1.28</td>
<td>1.3</td>
<td>1%</td>
</tr>
</tbody>
</table>

Table 5: Comparison of MET’s (activity intensity) between subject’s experiments

The trials
We originally suggested 60 subjects for the trials, considering 30 for a non-induced ADHD state and 30 more for the induced-ADHD state to have more consistency in the data. Due to difficulties faced to find volunteers for the tests, our data is only considering 8 subjects.

The questionnaire
Users were asked about the comfort wearing the sensor and sensations experienced drinking the energy drink. Regarding the comfort experienced wearing the device, in a scale of 1 to 5, where 5 was very comfortable users responded with an average of 4.25.

6. DISCUSSIONS

6.1 Threats to validity
By comparing the two set of data collected through the calculation over BodyMedia API, we studied the results in a quantitative manner, and we are reaching the conclusion that the data represents no obvious statistical difference between the measures from the non-ADHD state and the induced ADHD condition. We elaborated several discussions about the result retrieved:

- The energy drink used in the experiment is not sufficient metabolism boost to simulate an ADHD behavior. We used energy drink for participants to mimic the boosted metabolism, hoping that the participants will experience behavior biologically similar to ADHD patients, yet the results of the subjects in this testing condition does not reveal a significant difference in calories consumption that can lead to confirm the ADHD behavior. We believe a reason for this to happen is that our initial assumption of using Energy drink as a reliable indicator of metabolism boost is, however, not valid.

- Subjects tend to control the symptoms caused by the energy drink, as they are no ADHD patients. Another possibility that there is no obvious statistical difference between the measures from the non-ADHD state and the induced ADHD condition is the possibility that all of the subjects being tested in the user testing are potentially non-ADHD people. Due to that the nature of our research is exploratory and the diagnosis process is subjective to the participants, there will be possibility that we only accidentally chose non-ADHD people even considering there are questionnaires being used before the test.
7. CONCLUSIONS

By comparing the two set of data collected through the calculation over BodyMedia API, we are reaching the conclusion that during the experiments, the notion of using the energy drink to stimulate ADHD behavior is flawed. We proposed 4 different threats to our validity and we believe those potential threats to validity could be further used and replicated by researchers for further work that has a similar research purpose and aim.

The conclusion is based solely on the research by Levine, et. al. in which the increase of the calories burned by ADHD subjects based on the activities we performed during our experiments require a 31% of increase in the calories burnt. We conclude that the energy drink used for this experiment is not an effective method to induce an ADHD state; therefore further tests are needed.

We also conclude that the device is accurate enough to detect changes in the calories burned because we observed differences in the calories as small as 0.07% assuming that the device will not have problems detecting the necessary 29% increment in an ADHD patient.

8. REFERENCES