IN-SITU MEASUREMENT OF ELECTRODERMAL ACTIVITY DURING OCCUPATIONAL THERAPY

By Elliott B. Hedman

Bachelor of Science, Electrical Computer Engineering,
University of Colorado, 2008

Submitted to the Program in Media Arts and Sciences,
School of Architecture and Planning,
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Signature of Author: ____
Program in Media Arts and Sciences
September, 2010

Certified by: ____
Rosalind W. Picard, Sc.D.
Professor of Media Arts and Sciences
Thesis Supervisor

Accepted by: ____
Professor Pattie Maes
Associate Academic Head
Program in Media Arts and Sciences

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Abstract

Physiological arousal is an important part of occupational therapy for children with Sensory Processing Disorder (SPD) but therapists do not have a way to objectively measure how therapy affects arousal. We hypothesized that when children with SPD participate in guided activities within an occupational therapy setting, informative changes in electrodermal activity (EDA) can be detected using iCalm. iCalm is a small, wireless sensor developed at MIT that measures EDA and motion, worn on the wrist or above the ankle. Twenty-two children (ages 3-10) with a clinical diagnosis of SPD participated. EDA was measured from the backs of the children's ankles. Concurrent video recordings allowed for comparison of therapeutic activities and children's EDA. Overall, we measured 77 therapy sessions. All measurements were in-situ, during regularly scheduled therapy sessions. Statistical analysis describing how equipment affects EDA was inconclusive, suggesting that many factors play a role in how a child's EDA changes. Case studies provided examples of how occupational therapy affected children's EDA. This is the first study of the effects of occupational therapy's in-situ activities using continuous physiologic measures. The results suggest that careful case-study analyses of the relation between therapeutic activities and physiological arousal may inform clinical practice.

Thesis Supervisor: Rosalind W. Picard, Sc.D.
Title: Professor in the Program in Media Arts and Sciences

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Read by: ____

Mary Cummings, Ph.D. Associate Professor, Department of Aeronautics and Astronautics
Thesis Reader

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Read by: ____________________

Lucy Miller, Ph.D. Associate Clinical Professor, University of CO Denver, School of Medicine
Thesis Reader

Contents

1 Acknowledgements

While this paper is my master's thesis, it is more a collaboration between many passionate, hard-working, and creative individuals. I would like to acknowledge them, as this thesis is as much their work as it is mine.

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My mother has been there for me throughout my life's journey, for this project she helped design and sew the sweatbands that were crucial in achieving accurate EDA readings.

2 Introduction

How could knowing a child's electrodermal activity (EDA) during therapy change occupational therapy practices? As a joint project between the MIT Media Lab and the Sensory Processing Disorder Foundation, we measured the EDA responses of 22 children participating in occupational therapy for 77 hours. We saw children lying in a ball pit and their EDA correspondingly decreasing; we saw children's EDA rapidly increase while they were swinging; and we saw many other patterns of responses from different therapeutic activities. Could we show how different guided activities changed children's arousal with a statistical test? Analysis suggests that many factors play a role in changing children's EDA, and these factors could not all be taken into account with our low sample size – making any statistical analysis inconclusive. As more tools begin to measure physiological data over longer periods of time, in less controlled settings, we should not forget to build a base understanding at the individual case level.

3 Background

Occupational therapy aims to help people with a range of disabilities build skills to better their lives. One concept occupational therapists (OTs) focus on is sensory integration. Dr. A. Jean Ayres, a founder of sensory integration thought in occupational therapy, explains:

> "Sensory integration is the neurological process that organizes sensation from one's own body and from the environment and makes it possible to use the body effectively with the environment. The spatial and temporal aspects of inputs from different sensory modalities are interpreted, associated, and unified. Sensory integration is information processing. The brain must select, enhance, inhibit, compare, and associate the sensory information in a flexible, constantly changing pattern; in other words the brain must integrate it (Bundy, Lane & Murray, 2002, p. 11)."

Children who have challenges with sensory integration are classified as having Sensory Processing Disorder (SPD). Approximately 1 in 20 children have Sensory Processing Disorder (Ahn & Miller, 2004). Two main categories of Sensory Processing Disorder are over-responsive and under-responsive (Bundy, Lane & Murray, 2002, pg. 9-10). Over-responsive individuals tend to overreact to a sensation. For example a child may be extremely bothered by the noise of a vacuum cleaner. Under-responsive individuals have small responses to sensory stimuli: a child may burn her hand on a light bulb, not perceiving its real temperature. Children in both of these categories can have additional challenges with emotional regulation.

Children with SPD can struggle with executive functioning (Lane, 2001). Executive functioning consists of a child's self-awareness and the ability to plan, self-evaluate, and self-monitor (Stuss, 2002). Children with either Autism Spectrum Disorder (ASD) (Cohn, 2000) or Attention Deficit Hyperactivity Disorder (ADHD) (Brown, 2000) tend to have poor executive functioning. Correspondingly, children with ASD appear to often have sensory challenges (Adrien, 1993; Dahlgren & Gillberg, 1989; Kientz & Dunn, 1997;

Ornitz, Guthrie, & Farley, 1977; Talay-Ongan & Wood, 2000). A high correlation was also found for children with SPD and a comorbid diagnosis of ADHD (Mangeot, 2001; Ognibene, McIntosh, Miller, & Rand, 2003).

One possible way to measure a child's ability to regulate his or her emotional state is by measuring electrodermal activity (EDA). EDA increases when eccrine sweat glands open; eccrine sweat gland activity is correlated with sympathetic nervous system activation (Dawson, Schell, & Filion, 1990). The sympathetic nervous system is activated during a person's "fight or flight" response (Andreassi, 2000, p. 7). Boucsein (1992) proposes that EDA is controlled by not only arousal, but emotion and locomotion as well. Children who are diagnosed with SPD and who are over-responsive have been found to have higher EDA responses to sensory stimuli (McIntosh and Miller,1999).

Additional research has looked at the relationship between EDA and clinical diagnoses of ASD and ADHD. Children with ASD may have higher EDA responses (Palkowitz & Wiesenfeld, 1980; Stevens & Gruzelier, 1984), however, other studies found EDA responses for children with ASD were no higher than EDA responses for typical children (Van Engeland, et al., 1991; Bernal & Miller, 1970; Palkowitz & Wiesenfeld, 1980; Stevens & Gruzelier, 1984). Children with autism have also shown difficulty habituating (James and Barry 1984 & James and Barry, 1988). Acclimatization to equipment is suggested as one factor controlling the difference in EDA, as participants with ASD had normal heart rate after being acclimatized (Bernal & Miller, 1970; Palkowitz & Wiesenfeld, 1980).

Diminished EDA responsiveness sometimes has been reported for children with ADHD (Spring, Greenberg, Scott, & Hopwood, 1974) but there are also null findings as well (Cohen & Douglas, 1972; Zahn & Kruesi, 1993). One suggestion for the difference in research findings is that a lower EDA could be caused by the additional trait of oppositional defiant disorder, which is often comorbid with ADHD (Herpertz, et al., 2003; Crowell, et. al, 2006).

A few studies have looked at how EDA and emotion interact. In one example, Zimny and Weidenfeller (1963) saw that 59 students had statistically higher EDA responses to exciting music compared to neutral and calming music, though it is unclear whether the EDA response was due to increased arousal or negative affect. In another example, Lanzetta (1976) found that EDA responses were higher when violent words were used to describe a boxing match to male undergraduates.

To better understand the role of arousal and the sympathetic nervous system during occupational therapy sessions, this study builds on findings by McIntosh and Miller (1999) and looks at EDA in children with SPD in-situ, in other words, in a non-lab, clinical direct service therapeutic setting. As will be shown, there were many factors that could influence EDA which need to be examined in future studies.

4 List of Terms

The terms defined below will be used throughout the paper.

Therapy Session: During a therapy session, an OT helps a child achieve his or her parents' therapeutic goals. These sessions last approximately 1 hour. During the session, a child will participate in 3-8 guided activities.

Guided Activity: Within each therapy session, the child chooses the activity and the OT guides the activity to accomplish pre-established goals. Examples of guided activities include: a child choosing a bolster swing, and the OT having the child use their forearms to move themselves faster and faster. Another guided activity could include a child choosing a bolster swing and the OT suggesting they both lay as still as possible, to see which one of them can win the quiet game. There are multiple dimensions to a single guided activity. Two dimensions we pay particular attention to are:

Equipment: Activities usually involve a piece of equipment: the bolster swing, ball pit, bubbles, pillows, etc. The analysis in this paper focuses heavily on the equipment used for the activity, but equipment is only one dimension of a guided activity.

Therapist's Intent: Therapists create guided activities for specific reasons. There are many reasons why a therapist may choose to have a child use the ball pit. The therapist's intent shapes what the child will be exposed to during the guided activity. Many times modifying the child's arousal is not the main intent of a guided activity.

Epoch: An epoch is a single occurrence of a guided activity for one child. For example, the guided activity may be lying in the ball pit, and an epoch would be when Child 12 lay in the ball pit on June 7th. Lying in the ball pit is a guided activity, but the specific instance on June 7th is an epoch. This nomenclature helps us identify when we are talking about general phenomena or a specific example.

Pre and Post Epoch: We will be analyzing the effects of epochs by looking at a child's arousal before (pre) and after (post) the specified guided activity occurred. The pre epoch consists of the 45 seconds before a child begins an epoch. The post epoch consists of the 45 seconds after a child ends an epoch.

"Child X's" EDA Response to an Epoch: During an epoch, "Child X's" EDA will change. The EDA values during the epoch, pre epoch, and post epoch, are referenced as the child's EDA response.

EDA Change during Epoch: By taking the average EDA value in the pre epoch and subtracting that value from the average EDA value in the post epoch, we quantify the direction and magnitude of the Epoch's EDA response.

Epochs for "Equipment X": For analysis children's EDA changes will be grouped together by what piece of equipment was used. For example "Ball Pit Epochs" consists of every time an epoch occurred that had the ball pit as a piece of equipment. This grouping by equipment is only one method of analysis. In future analysis we could group responses by body position, cognitive challenge, number of participants, intention of therapist, etc.

5 Description of Setting

Children's EDA responses were measured during a natural, direct service, occupational therapy session. Children typically attend occupational therapy 3 to 5 times a week with sessions lasting 1 hour. Clients are paired with one OT. Before a therapeutic session the OT lists out intentions for the session –to help the child regulate arousal, develop better tolerance to sensory stimuli, better control his or her body, or other goals. The therapist works on these goals through guided activities. The child and therapist work together to decide what equipment to use for the guided activity – what will help the child achieve his or her goals and what will be fun for the child. Then the OT guides the use of the equipment to accomplish a specific goal.

The therapist and child participate in typically 3 to 8 guided activities during the hour. The child can participate in various guided activities while using one piece of equipment: the child may start by finding animals in a ball pit, then lie in the ball pit, and then toss balls from the ball pit into a basket. In between guided activities, transitions exist: the therapist and child may clean up, move to a new piece of equipment, or set up new equipment.

For our study, we tried to detect whether specific guided activities raised or lowered a child's EDA, which could provide insights into how therapists' guided activities affect children's emotional regulation and arousal. This paper is not an analysis of occupational therapy effectiveness, but rather an exploration into whether changes in children's EDA during therapy might provide a method of obtaining useful information for future studies.

6 Interpreting the Graphs

Graphs of the child's EDA response during OT will be used throughout this paper. This section explains how to interpret these graphs. **Figure 4.1** shows the child's EDA response during an OT session. The title of the graph has the child's identity number and the date of therapy. The X-axis displays the time during the session. The Y-axis is the child's EDA response, ranging from 0 to the maximum peak of the two EDA signals. The maximum EDA value changes across graphs, so the Y-axis scale will differ across graphs. The orange and purple lines represent the child's EDA response from the back of his or her left and right ankle. The green boxes on the bottom represent epochs of guided activities. We label these epochs by the activity's equipment, the dimension focused on in this study, which, as explained above, is only one dimension that describes a guided activity. In **Appendix A**, the pieces of equipment are identified with their full title and picture. Epoch starting points should not be taken as strict boundaries because deciding the exact time when an activity starts is subjective and may be difficult to judge. Labelers, blind to the child's diagnosis, determined boundaries by watching OT session videos and were not allowed to see the child's EDA.

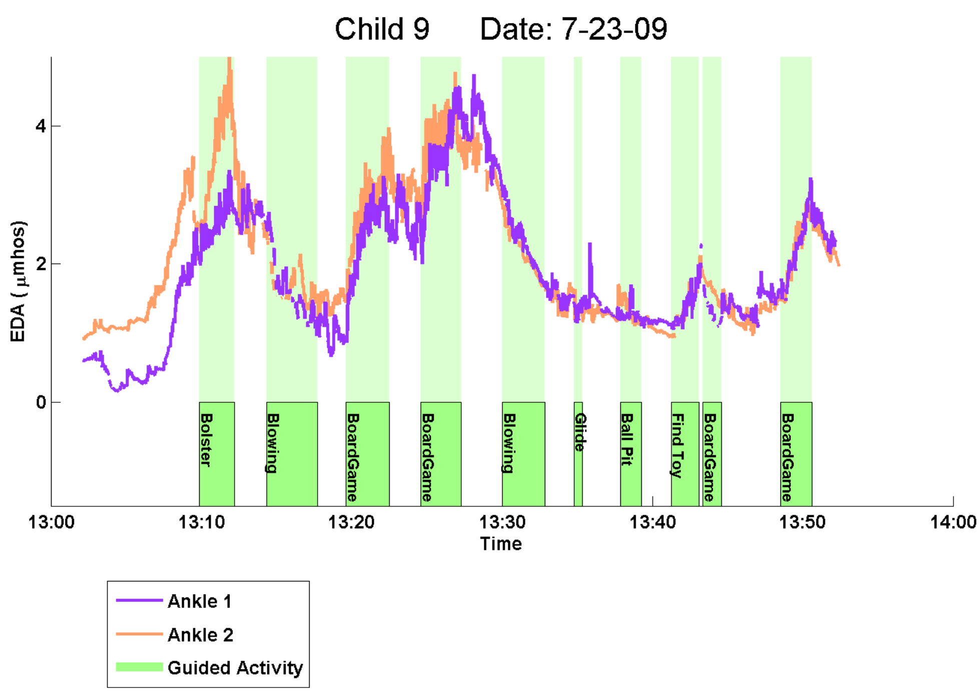

Figure 6.1: **EDA Measured During Occupational Therapy**
The child's EDA response is graphed for an OT session. The green boxes represent different epochs that occurred during the session.

7 Method

Four sections comprise the method section. The first section, "Subjects," describes participants included in the study. "Apparatus" describes the tool used to measure EDA. "Procedure" explains the methodology for observing children during a normal therapy session, and "Measuring Guided Activities" describes how videos were labeled.

7.1 Subjects

Subjects were enrolled in occupational therapy at the STAR (Sensory Therapies And Research) Center in Greenwood Village, Colorado. The child's therapist recommended him or her for the study based on who they believed had challenges regulating their behavior and who appeared to be either under-responsive or over-responsive to sensory input. Based on the therapist's opinion, a child was excluded if wearing sweatbands or being videotaped would negatively impact his therapy. Parents and children over the age of 7 signed an IRB-approved consent form before the child's first observed session (Appendix C).

Overall, 22 children participated in the study. Fifteen out of the 22 children provided their demographic information which the following description is based on. Children's ages varied from 3 to 10 with a mean age of 6.5. All children had at least one parent with a college education. Of the 15 children, 7 of the children were female. Fourteen children were Caucasian, and one was Hispanic. According to developmental history forms that 9 parents filled out, 3 children were taking medications: one child was taking advair, najonex, vigtirl, one child was taking abilify, risperdal, cholestyranuil, and one child was taking sulphur 30. These medications could possibly alter the children's EDA in unknown ways. Demographic information was missing because a clear process was not put into place for parents to fill out information at the beginning.

All participating children had a diagnosis of Sensory Processing Disorder, diagnosed by a global clinical impression of an expert OT after a comprehensive evaluation using observations from a standardized test, observations in the clinic, and standardized scores on parent rating scales. The evaluating/treating OT categorized children into SPD subtypes. 9 of the children were over-responsive, 6 under-responsive, 6 sensory-seeking/craving, and 1 sensory discrimination disorder. Children could have multiple secondary diagnoses for their SPD subtypes.

One child was diagnosed with comorbid ADHD and two were diagnosed with comorbid ASD. Not all children had been clinically tested for ADHD or ASD, so some may have qualified for these labels but not received them. One child had an extremely rare, unnamed genetic disorder.

The Sensory Therapies And Research (STAR) Center uses an intensive model of treatment. Children are seen 3 to 5 days a week over a short time period (usually about 30 sessions) and afterwards activities in natural settings are recommended. Some children return for "boosters" 6, 12, or 24 months later. The number of sessions the child previously had in this pilot study with his or her therapist varied. All children were seen for at least 3 sessions before being recommended for this study by their therapist.

Each child was paired with a specific occupational therapist. Across the 22 children, 8 occupational therapists worked with the children. All occupational therapists had a master's degree, advanced training, and intensive mentorship by Dr. Lucy Jane Miller before participating in this study. Children were assigned to OTs by the Clinical Director of OT and the Assistant Director of the STAR center on what they believed would be the best fit between therapist's and child's/family's temperament characteristics.

One child left the study after two recorded OT sessions. Their therapist was concerned that the filming by research assistants was making the child anxious. No other concerns were expressed from parents or therapists about the other participating children. None of the 22 children had problems wearing the iCalm sensors. Six of the 77 observed sessions were not used in analysis as the corresponding videos were saved incorrectly and were not useable. Approximately 20 additional sessions were not considered as part of the 77 observed sessions as hardware malfunctioned and EDA data was not properly recorded.

7.2 Apparatus

Each child's EDA was measured using iCalm – a wireless, comfortable EDA sensor (Fletcher, et. al, 2010). iCalm provided a new opportunity to measure guided activities in natural settings: the children could participate in their regular therapy routine while wearing the device which provides immediate continuous information, rather than obtaining EDA in an artificial, controlled lab experiment. The sensor is battery-powered and transmits wirelessly through a Zigbee antenna. For information on circuit design, refer to Eydgahi (2008).

Traditional measurements of EDA are taken on the palm or finger tips (Fowels, 1981). Previous research, using iCalm, measured EDA from the wrists (Fletcher, et. al, 2010; Poh, 2010) Initial trials with iCalm worn both on the wrist and on the ankles suggested that ankles would be more suitable for this experiment because children were often observed to moving their wrists and applying pressure to their fingers and wrists. In pre-trials, this varying pressure and movement was not observed when iCalm was placed on the ankles. Children appeared less distracted by the sweatband being on their legs compared to on their wrists or fingers.

The EDA literature does not describe how EDA responses differ on the back of the ankles compared to EDA responses on the palms and fingers. Thus a small study comparing EDA responses on the back of the ankle with traditional palm sensors and wrist sensors was conducted as explained in 7.2.1 below.

7.2.1 Comparing the EDA response on the ankle to the response on the palm and wrists

To compare EDA responses on the ankle and palm (Venables & Christie, 1980) a small experiment was conducted. An adult female (Caucasian, age 50-60) participated in the Space Lab Experiment (McIntosh and Miller, 1999), where she was repeatedly exposed to the same sensory stimuli in five sensory domains. She was asked not to move her body during the experiment. The adult's back ankle was measured and her palm was measured as well. Both sensors were on her 10 minutes prior to the experiment. Dry electrodes were used on the ankle where a gelled electrode was used on the palm. The sensor on the palm was down sampled from 1000 hz to 8 hz, and the two sensors samples were aligned by internal clocks. Below is a graph describing her EDA response (**Figure 7.1**).

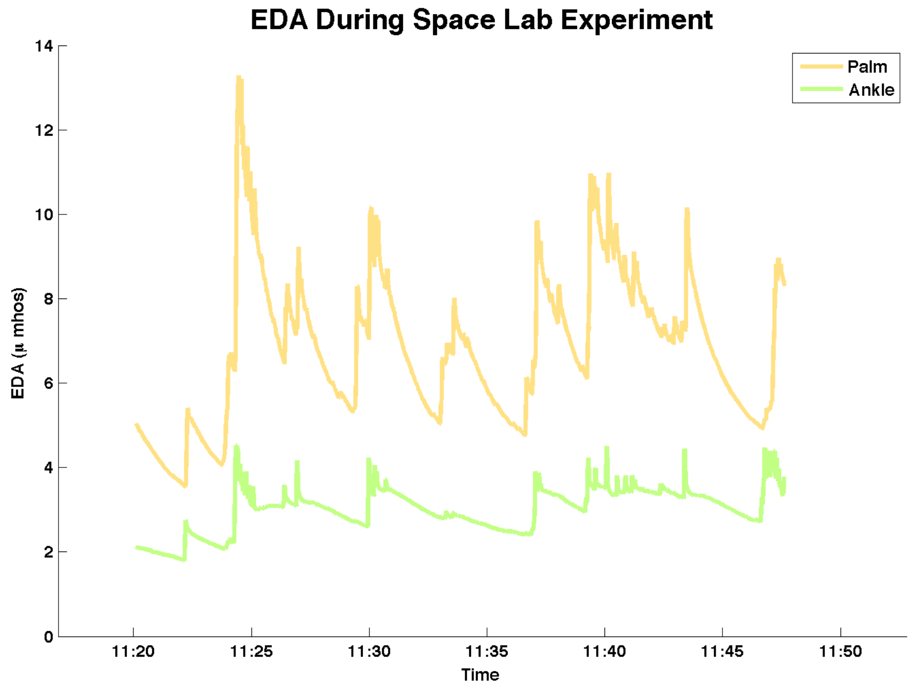

Figure 7.1**: A Comparison Between Palm and Ankle EDA Responses**
The orange line shows the traditional measurement of EDA on the palm of the adult. The green line shows the EDA response on the ankle of the adult.

The graph shows that orienting responses happen at the same time but the ankle response has less amplitude. Additionally, the two signals are correlated (r=0.75). This correlation suggests that the EDA responses measured on the back of the ankle are similar to EDA responses on palm, with regards to sensory stimuli.

As an additional test, we looked at how EDA responses compare across a 24-hour period. The author (Caucasian, male, age 24) wore two sweatbands on his ankles, a sweatband on the left vistral distal forearm, and a sweatband on the right ventral distal forearm. His EDA responses for the 24-hour period are shown in **Figure 7.2**.

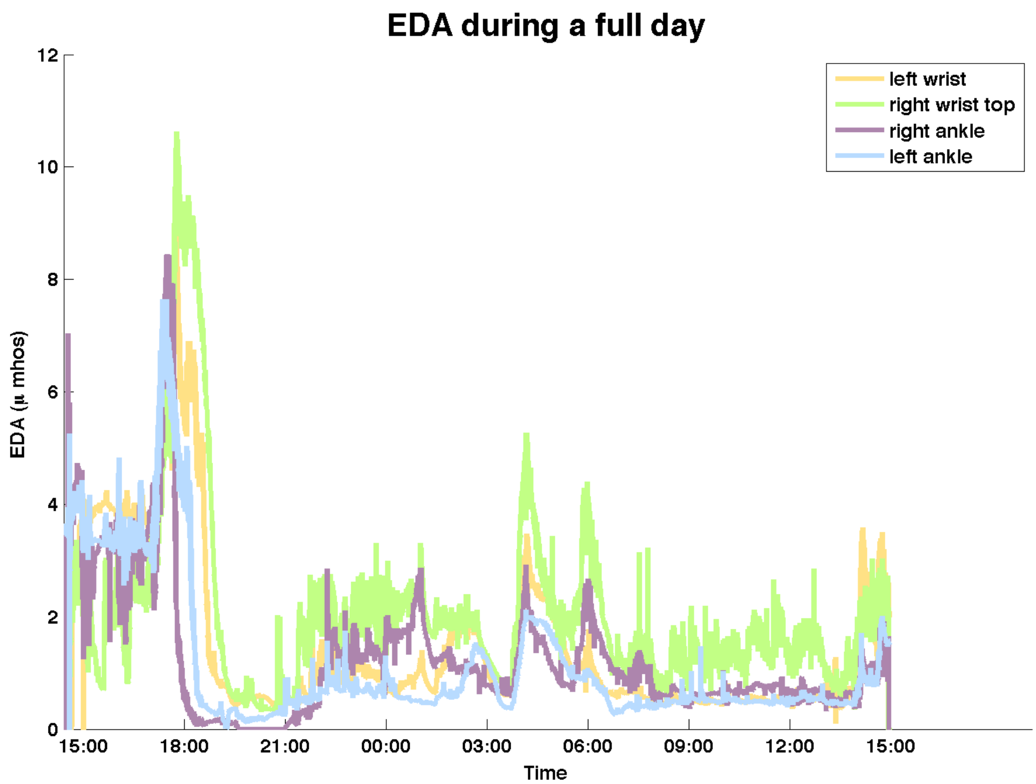

***Figure 7.2*: Comparison of EDA Locations during a Full Day**
During the day the author worked on his computer (15:00), played soccer (16:00), ate dinner (17:00), talked on the phone (18:00), saw a bike theft (00:00) and went to sleep shortly after. The four lines represent EDA measurements from 4 different body locations.

While wrists (distal forearms) are not a standard location to measure EDA, Poh (2010) found a high correlation between the wrists and ipsilateral fingers ($0.76 \leq r \leq 0.96$). Correlations between the left wrist, top of the right wrist, right ankle, and left ankle are described in Table 7.1.

Wristband Location	Left Wrist	Right Wrist Top	Right Ankle	Left Ankle
Left Wrist	1.00	0.79	0.63	0.87
Right Wrist Top		1.00	0.34	0.38
Right Ankle			1.00	0.56
Left Ankle				1.00

Table 7.1: Correlation Coefficients for Measuring EDA in Different Locations

Assuming the EDA measurements on the left wrist correlate with EDA measurements on the ipsilateral fingers, we conclude that the right and left ankles are likely to be correlated with the ipsilateral fingers. These correlations are only one way of comparing two signals; further analysis should look at how SCR's and orienting responses differ. No children with SPD were available for this test so the two tests were conducted on adults, and children might have different EDA response characteristics. As a caveat, both tests only represent one person on one day. We have seen variation within a person and across days, suggesting a larger sample size would be needed to fully describe the relationship between EDA measured on the back of the ankles and more traditional locations.

7.2.2 Sensor Casing

In addition to a change in positioning, we designed specific casing specialized for the children in this study building off of the previous work of Fletcher, et al. (2010). The casing design maximized pressure on the electrode, limited movement of the sweatband, and increased comfort. To increase pressure, an additional layer was sewn into the interior of the sweatband, providing more pressure to the electrodes towards the skin. To limit sweatband movement and further increase pressure, double-sized, fold-over sweatbands were utilized to grip the children's legs tightly. We used dry electrodes, so children would not be bothered. Children appeared to habituate to the presence of the sweatband, none of the children asked for the sensors to be removed. For a visual description of the sensor casing see **Figure 7.3**, **Figure 7.4**, and **Figure 7.5**.

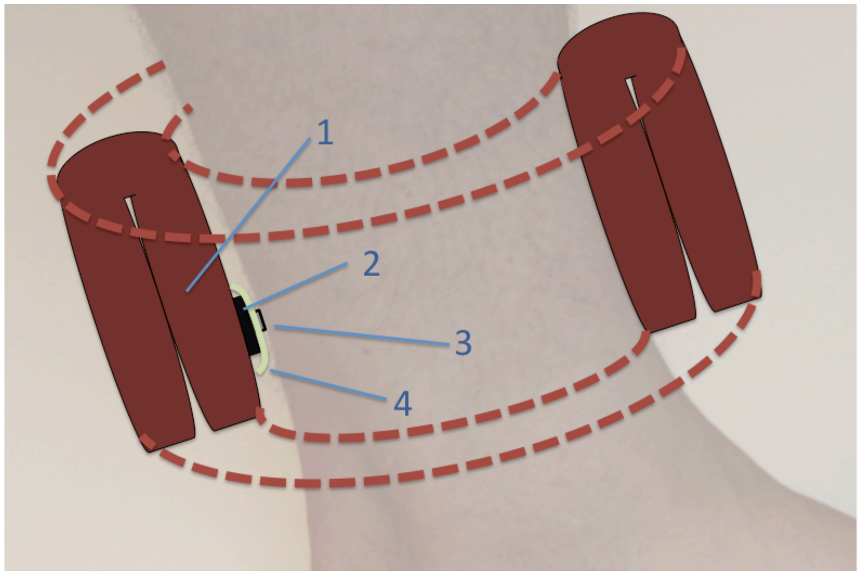

***Figure 7.3*: Diagram of Electrode Setup**
Electrodes were placed in a sweatband (1) that double folded over. A piece of Velcro (2) was added to the inside and two dry electrodes (3) were placed on top of the Velcro. A water proof sheet (4) was sewn on top of the Velcro.

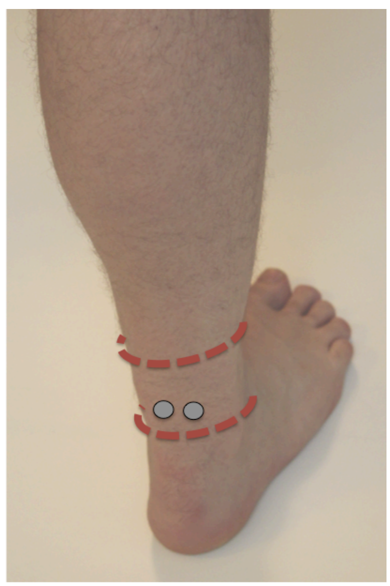

***Figure 7.4*: Diagram of Electrode Placement**
Electrodes were placed just above the back of the ankles. The red line shows where the sweatband was located.

***Figure 7.5*: Child Wearing Two iCalm Sensors**
A child wears two iCalm sensors with the double folded over sweatbands. The OT to the left is also wearing sweatbands. Notice how the child can play on a balance board while wearing sensors.

7.3 Procedure

This study was an observational study during which the therapist and child were asked to perform therapy as usual. Because this study was observational, many uncontrolled factors existed.

The procedure for observing OT sessions is detailed below; **Figure 7.6** displays this procedure on a sample timeline. The study was administered at the STAR (Sensory Therapies And Research Center) in Greenwood Village, Colorado. Participating families were asked to arrive 15 minutes early to their therapy session to allow time to place the iCalm sweatbands on the children and allow additional time for the sensors to acclimate to the skin. Typically, children arrived 5 to 10 minutes early.

When the child arrived, a research assistant placed iCalm sweatbands on the child's ankles. At times, only one sensor was available because of occasional sensor breakage (these sensors were made by students at MIT and were not a commercialized product). In this case, the child wore the one available sensor on the ankle of his or her choosing. After the child felt comfortable with the sweatband, the child was allowed to play freely, which typically consisted of playing with toys in the waiting room, playing with the parent, or playing with another child.

When the OT was finished with their previous clinic session, the therapist also put on iCalm sensors (We do not use the EDA measured from the OT in this analysis, but recording the therapists' EDA may have altered her behavior during therapy). When the OT and child both left the waiting room, the research assistants began videotaping the session. The cameraperson attempted to include the child's entire body in the shot, but occasionally the child sat or stood in a spot that was difficult to film. The child was videotaped and EDA was measured for the entire therapy session, usually about 50 minutes, until the child returned to the waiting room where he or she reunited with his parents.

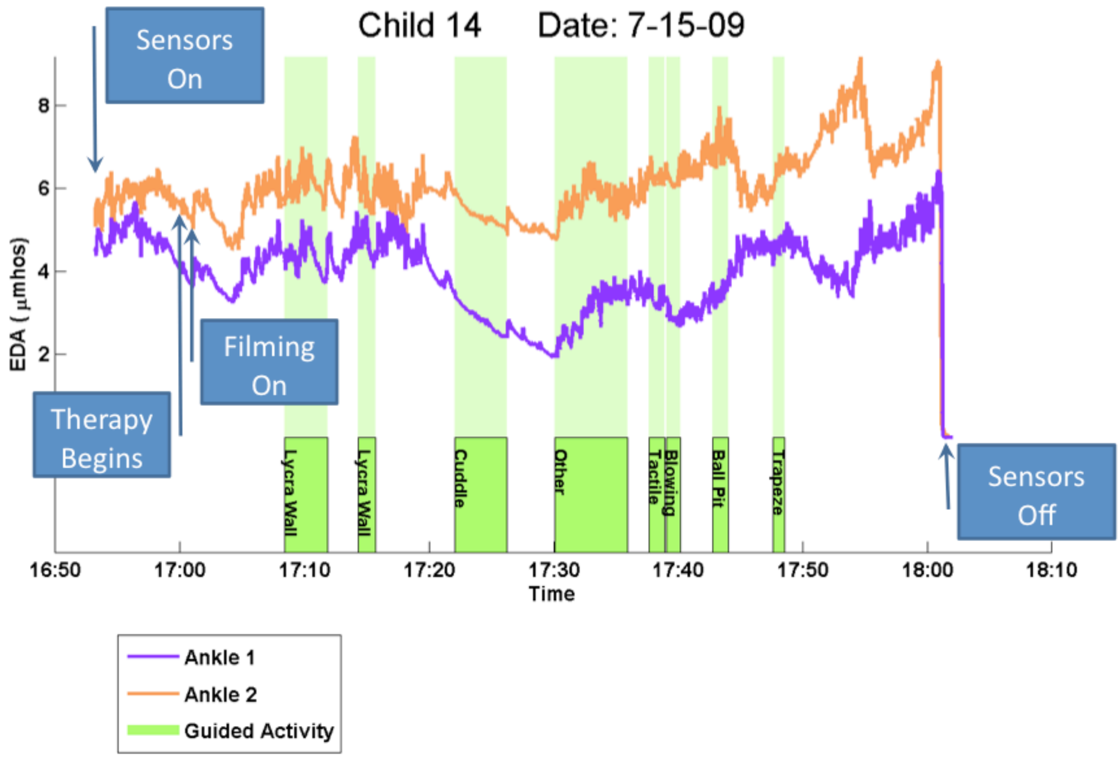

***Figure 7.6*: Procedures During A Therapy Session**
The above graph shows the child's arousal during a full session. The blue markers show steps in the research procedure.

OTs conducted therapy as usual. Children participated in numerous guided activities with a variety of equipment. In a one-hour session, the child typically participated in 3 to 8 different epochs. Epochs were designed based on child's individual developmental, behavioral, and sensory needs. During these epochs, the therapist could attempt to calm the child, or excite the child, or excite the child a little bit and then have the child regulate him or herself. Other times, the therapist's planned epoch had intentions that were separate from regulating the child's arousal: teach a new social skill, raise cognitive processing, increase engagement, practice a physical task, etc. Usually, multiple intentions existed for a single epoch, and arousal regulation made up only one dimension. After each session, we asked therapists to reflect on how they had intended to change arousal during guided activities. They could select "increase arousal," "decrease arousal," or "neither."

Each child participated in at least 2 therapy sessions. The maximum number of recorded sessions for an individual was 7 and the mean number of sessions was 3.5. All recordings were conducted from June 11 to August 14, 2009. We intentionally did not record successive sessions e.g., a fourth session, seventh session, and eighth session might be recorded.

7.4 Measuring Guided Activities

We videotaped each therapy session and simultaneously recorded the child's EDA. From initial viewing of a few children's EDA with video, changes in EDA appeared to correspond with different guided activities. To better understand the relationship between guided activities and the child's EDA, blinded labelers marked the time of the guided activities. While many factors describe a guided activity (physical challenge, OT's intent, body position, etc.) we found that the equipment used in the activity was an easy way to identify an epoch – it was easy to note whether a child was using a piece of equipment or not.

To mark guided activities, four research assistants independently labeled the videotaped therapy sessions. Labelers practiced on a few videos, comparing their results to the author's labels. The labels were not ratings of behavior and were only used as markers for where data should be used for statistical tests. The labelers were blinded to the child's EDA and the intent of the labeling. The labelers labeled the following epoch characteristics.

1) When was the epoch mentioned?

2) When did the epoch take place?

3) When did the epoch end?

4) What equipment was used during the epoch?

5) What body position was the child in?

6) Was any additional equipment used?

7) Who was the child interacting with (besides the OT)?

Labelers noted how listed factors changed through an epoch as well.

See Appendix B for a full description of labeling instructions given to the video labelers.

8 Interpreting EDA

As we were measuring EDA in a non-controlled setting, many decisions had to be made about how EDA measurements should be interpreted. We attempted to follow the suggested methods outlined in Andreassi (2000), but many factors were new and different. Below we detail how we handled movement of the sweatband, signal dropouts, acclimation time, and the measuring of two signals.

8.1 Sweatband Movement and Wire Disconnects

At times, the sensors used in the experiment would not work: wires would break, battery power levels changed, and sometimes the circuit delivered incorrect values. To ensure reliable data, we often measured a 1 ohm resistor with the sensors prior to each use and verified the output was 1 µ mho. Loose wires, wire shorts, and battery disconnects all created artifacts (Figure 7.1). Because the sweatbands were not taped to the child and the child was often moving, there were times when the child's movement would cause the sweatband to change location, placing the electrodes on a new area of skin, and creating an artificial drop in the data.

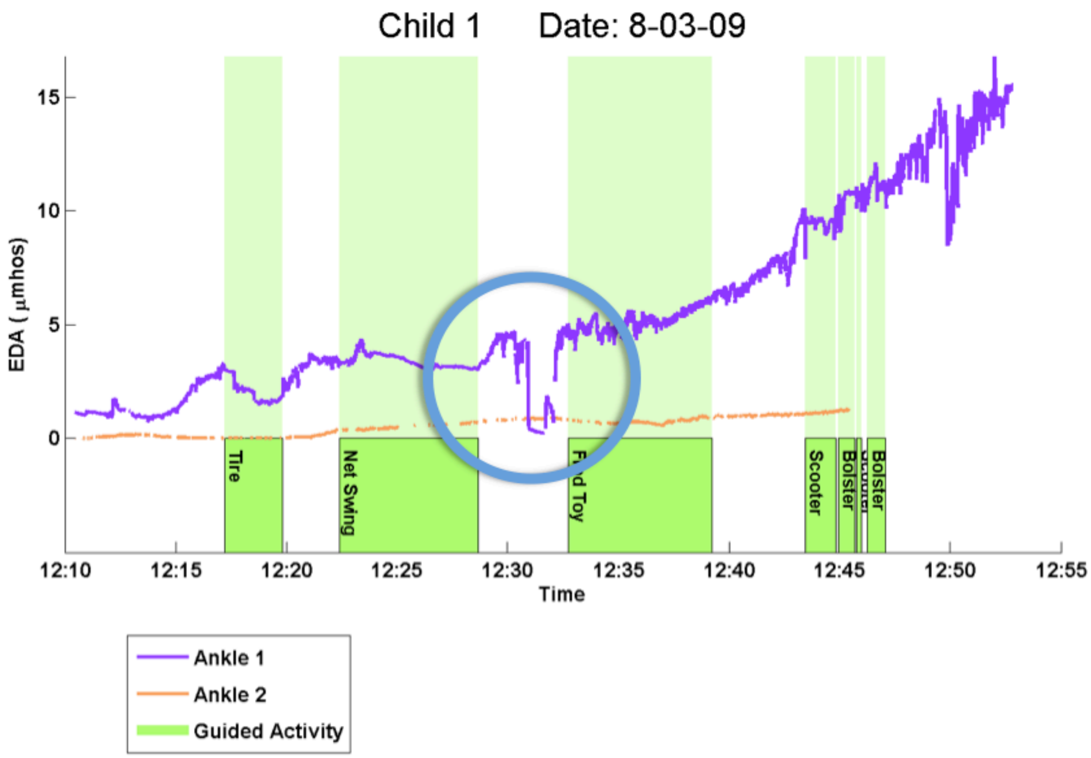

***Figure 7.1*: Signal Dropouts and Low Measurements**
The highlighted purple line drops to 0, probably due to a wire disconnect or a movement in the sweatband. When the wire becomes reconnected or the sweatband moved back in place, we can see the EDA return to the predicted value.

Identifying these dropouts can be challenging as EDA naturally decreases and increases. For case study purposes, a drop out was classified as an event where the EDA signal decreased almost instantaneously. If the signal quickly returns back to the same value this was further evidence that a movement artifact existed. Movement artifacts existed in almost every session but were small in time and magnitude compared to this example.

These technical artifacts and movement artifacts motivated us to include two independent sensors for measuring data. If we observed one signal that was abnormally low, we assumed the sensor was broken. If we observed a rapid increase and decrease in only one sensor, we assumed this was an artifact movement. For statistical analysis, we observed the signal with higher average EDA value during the epoch of interest.

8.2 Lost Data Signals

EDA data was sampled every half-second. The wireless sensor sometimes could not send recorded data back to the computer when iCalm was covered by an object. Only data collected with 80% or more received data was considered for statistical and qualitative analysis. By recording EDA from the right and left ankles, we were able to look at most EDA changes, even if one signal dropped out. **Figure 7.*2*** gives an example where one foot's data was not considered.

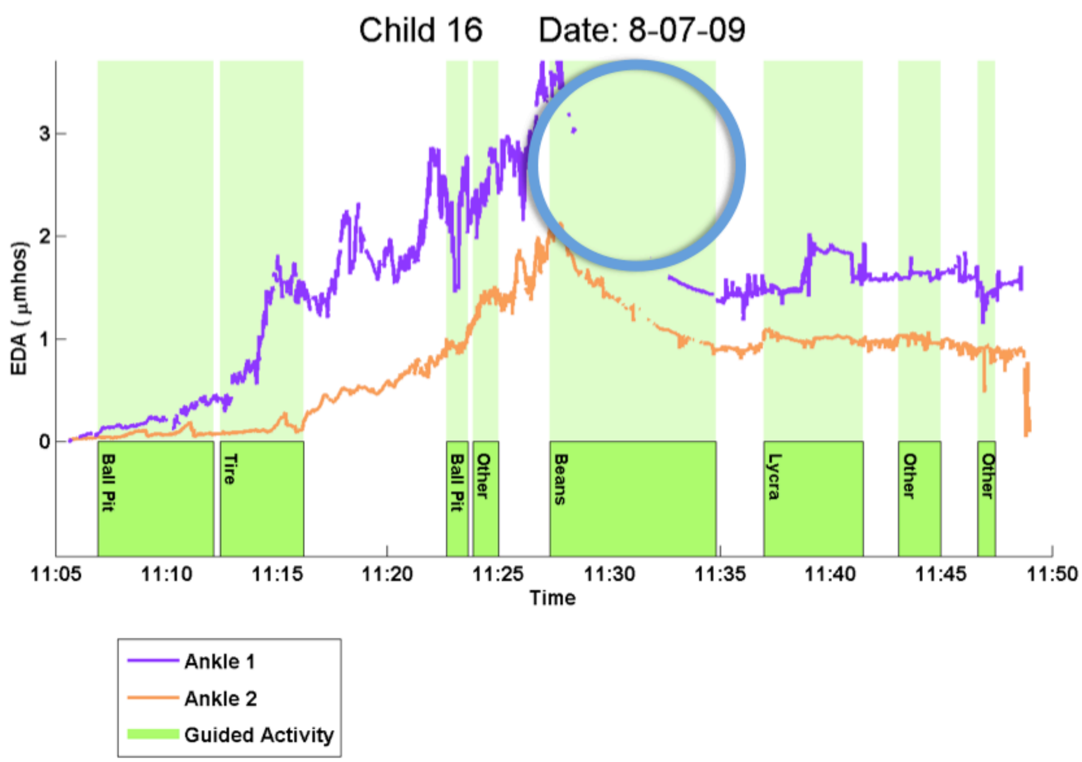

Figure 7.2: Missing Data from Foot 1 While Playing with Beans
At times a sensor could not send a wireless signal to the computer collecting data. In this case, Ankle 1's data was missing, so the other leg was used for analysis during the guided activity with beans.

8.3 Selecting Data Signal for Analysis

Sometimes both signals measured would be clean with no dropouts or movement artifacts. In this case, for each epoch, we considered the signal with a higher average EDA value during that epoch (**Figure 7.*3***). The higher value tended to provide clearer information – more peaks, and the observed peaks had a larger magnitude. By only analyzing the larger signal, children with two measured signals will likely have a higher average EDA value across the session compared to children with only one useable signal.

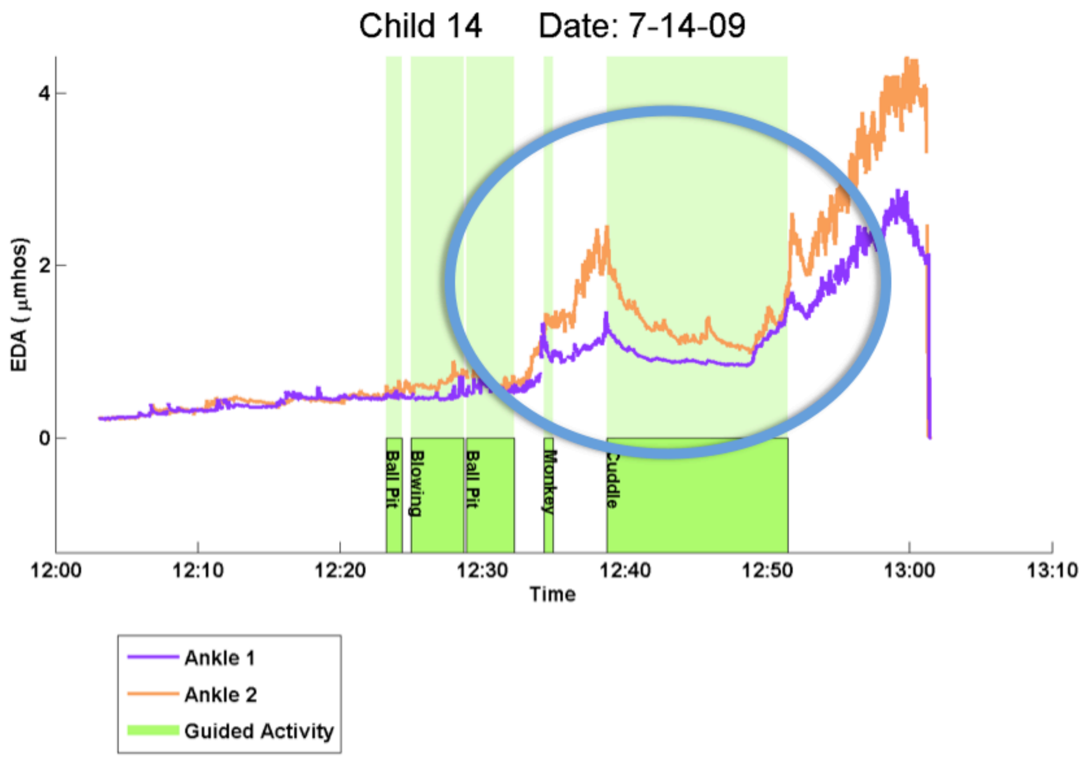

Figure 7.3: Higher EDA Providing Clearer Changes in EDA for Foot 2
The sensor with the higher average value was used for data analysis. The orange line above has clearer peaks and changes during the guided activity with the cuddle swing.

8.4 Acclimation

At the beginning of most sessions, a child's EDA was not acclimated with the sensors- a small, non-zero value was being read but that value was not dynamic- the value remained flat and did not change with environmental influences. Eventually the child's EDA would increase past 0.5 µ mhos and the value began dynamically changing, having much more variability (**Figure 7.*4***). To account for these flat readings, we only evaluated EDA responses when the read signal was above 0.5 µ mhos at some point during an epoch. The threshold of 0.5 µ mhos was used since most flat signals we observed were around 0.2 µ mhos. Because we removed low EDA responses, the effectiveness of guided activities can only be understood for times when a child's EDA is high enough to be read in the first place.

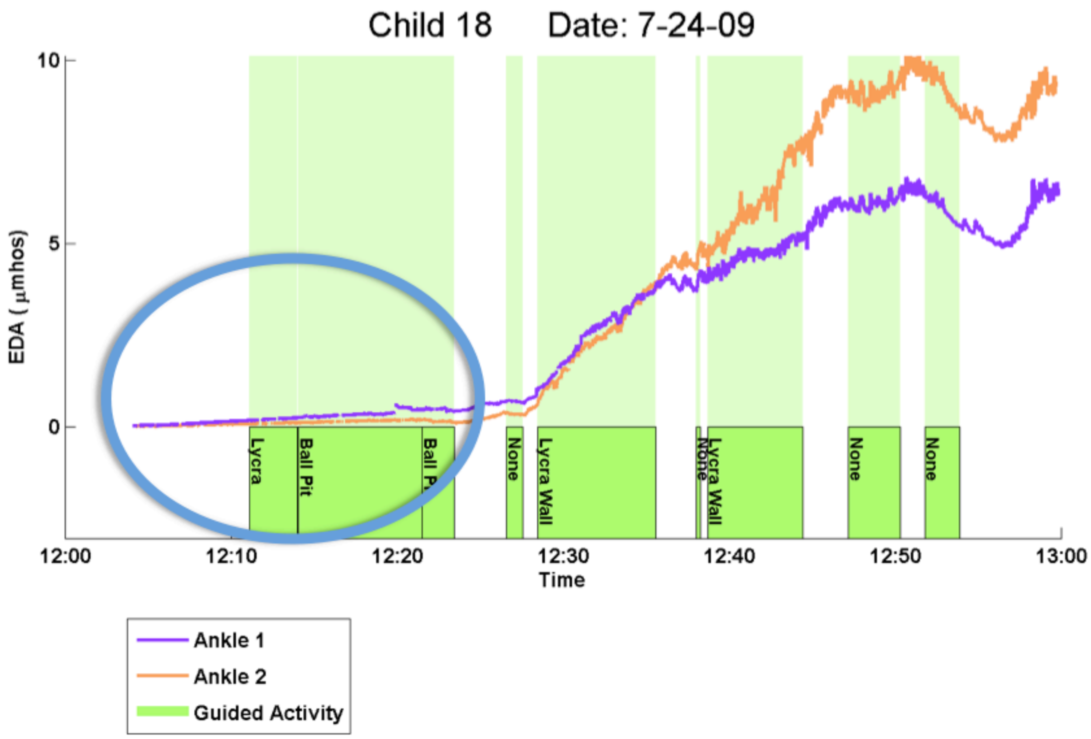

Figure 7.4: A Delay before the Child's EDA Becomes Acclimated
The EDA for Child 18 did not change for the first quarter of the therapy session. Since no EDA changes were observed for the epochs that included the lycra swing and ball pit, we cannot conclude how the child's arousal changed at these points.

Two children's EDA values were always observed to be below 0.5 µ mhos. One of these children had a diagnosis of ADHD and was not taking medication; we observed 4 of his sessions. The second child had an extremely rare, unnamed genetic disorder. We recorded 5 of her sessions. These two children wore the same sensors that gave non-zero readings for other children, so we believe that the two participants probably had nonresponsive EDA.

9 Statistical Analysis

From the observed therapy sessions, such as the ones presented in Section 10, we noticed that EDA often changed with the guided activities. For example, we can see that swinging on the bolster swing for Child 15 corresponded with the lowering of the child's EDA (**Figure *10.1***). We wanted to test whether these changes in EDA were similar across children. For example, can we build on our finding from Child 15 with the bolster swing and test the more general idea that guided activities with the bolster swing reduce EDA on a statistically significant level. The statistical analysis we show is inconclusive, in part due to low power, and also due to many uncontrolled factors, which the discussion section covers. A list of the many uncontrolled factors can be found in **Section 12.2**. In addition, **Section 12.5** lists the many confounds discussed throughout the paper. These uncontrolled factors and confounds should be considered before making any conclusions about the relationship between EDA and guided activities within occupational therapy.

9.1 Comparing Independent Epochs of Guided Activities

To answer the question of whether therapeutic equipment increases or decreases EDA, we analyzed children's EDA responses during the epochs that the labelers, blind to EDA responses, had identified. We observed children across multiple days – allowing us to record them participating in a variety of guided activities with different pieces of equipment. Sometimes, a child would use the same piece of equipment during different epochs. We only considered the epoch where the child was first observed using the specified equipment. For example, we observed Child 14 participating in 4 epochs that included the ball pit but we only considered the first observed epoch for statistical analysis. Including only the initial epoch allowed for the analyzed data to be independent, and no child's EDA would unfairly bias the average response.

9.2 Separating Equipment use into pre-epoch, epoch, and post-epoch sections

For analysis each epoch event was divided into 3 sections: pre-epoch, epoch, and post-epoch. **Figure *9.1*** shows this division.

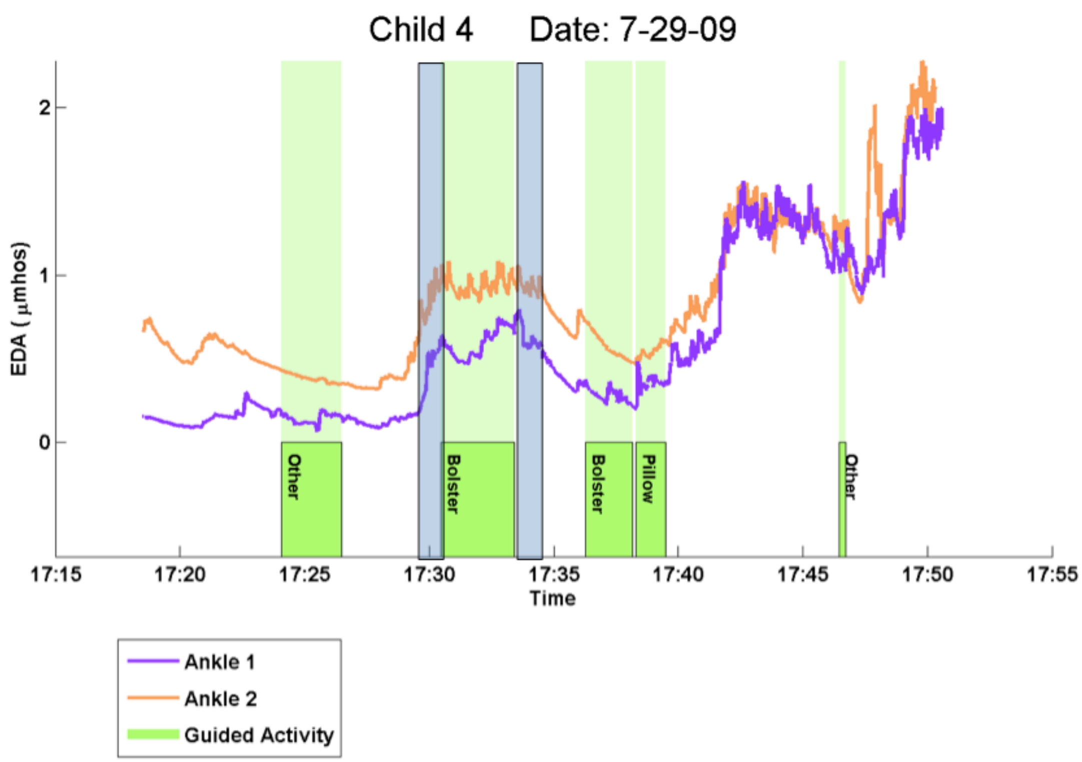

Figure 9.1: Extended Time for Evaluating the Bolster Swing
The blue bars represent the pre and post epoch. The green bar with the title Bolster represents the epoch that the pre and post epoch relate to. The blue bars are 45 seconds long.

The epoch included the entire length of time a specific piece of equipment was used. The epoch was excluded if it lasted less than one minute. Many factors might change during an epoch: body position, therapist's intent, music the child was listening to, external sounds, etc. The only factor that was guaranteed to stay the same was therapeutic equipment. Ideally these other effects would be controlled for, but the sample size was too small for blocked effects and we were unsure what factors would play a role in changing a child's EDA.

The pre epoch consisted of the 45 seconds before the onset of the epoch. What happened during these 45 seconds was not controlled for: the child may be anticipating the guided activity, participating in another guided activity, or physically moving to the new guided activity. Similarly, the post-epoch consisted of the 45 seconds after the epoch. During this time, the child could be cleaning up, transitioning to a new guided activity, or already participating in a new guided activity.

To determine the length of these pre and post epoch intervals, we considered two confounds. If the pre or post epoch's interval was too long, the previous epoch may still be going on and affecting the child's EDA. If the length is too short, then the child's anticipation and movement for preparing for the activity will define the EDA measurement. Most transitions appeared to last 1 minute, making 45 seconds a conservative estimate of how long we could measure a child's baseline without other epochs interfering.

The pre- and post-epochs probably serve as a weak measurement of a baseline. Many times children were excited or nervous during the transitions when a piece of equipment began to be set up.

9.3 Calculating Change in EDA

We calculated changes in EDA by subtracting the pre-epoch from the post-epoch. Each epoch was now associated with a value - EDA change. **Figure *9.2*** shows EDA changes for each epoch across children and equipment. Only equipment that had 5 or more children for analysis was considered for statistical analysis. By not considering equipment where fewer than 5 children participating, the chance for a Type I error was reduced.

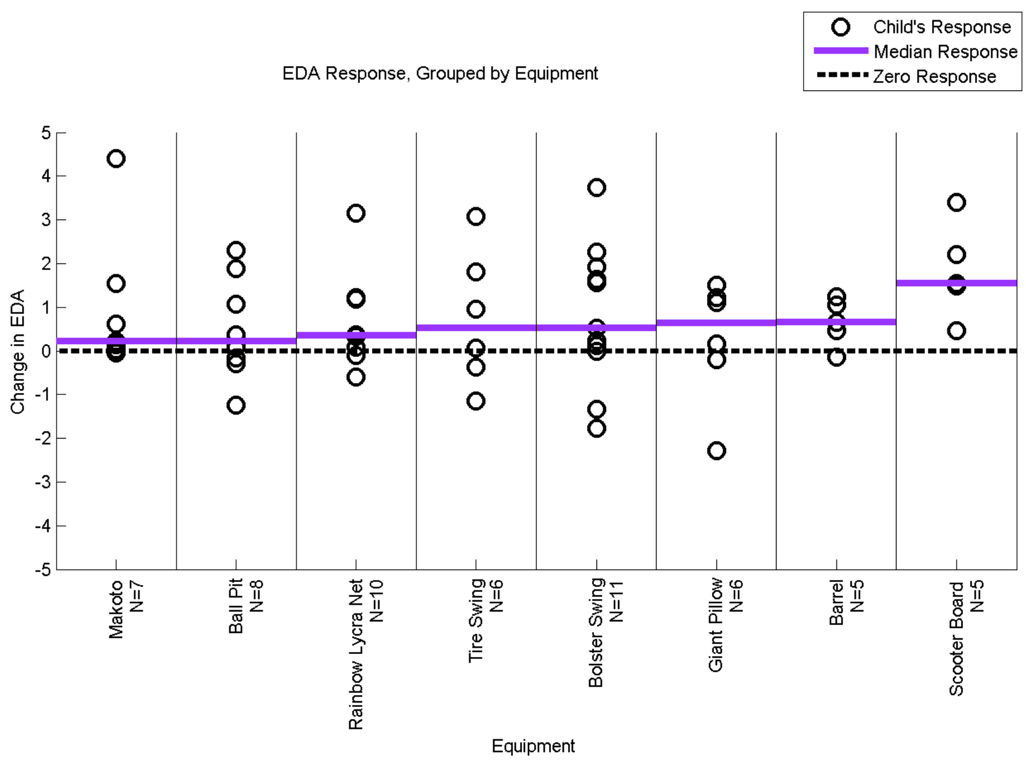

Figure 9.2: Compilation of EDA Responses for Different Epochs
*Each circle represents one child's EDA change for a specific epoch. Epochs are grouped together by equipment. The dotted line represents a 0 μ mho change, which means the EDA level at the post-epoch was the same as the pre-epoch. The purple bar represents the median value change in EDA for epochs with the column's equipment. All EDA changes were included that met the requirements from **Sections 7, 9.1, and 9.2**.*

9.4 Comparing EDA Change

We used a Wilcoxon Rank-Sign Test to determine whether specific equipment, created a consistent change in children's arousal, as indicated by their EDA. The Wilcoxon Rank-Sign Test looks at ordinal values (increasing or decreasing) instead of comparing numerical changes like traditional parametric tests. The following case shows how two children's numerical EDA values relate differently with the child's arousal.

We compare two children's EDA changes from an epoch that included being in the ball pit. Child 16's change in EDA during the ball pit (9:20) was 2.2 µ mhos for Ankle 1 (

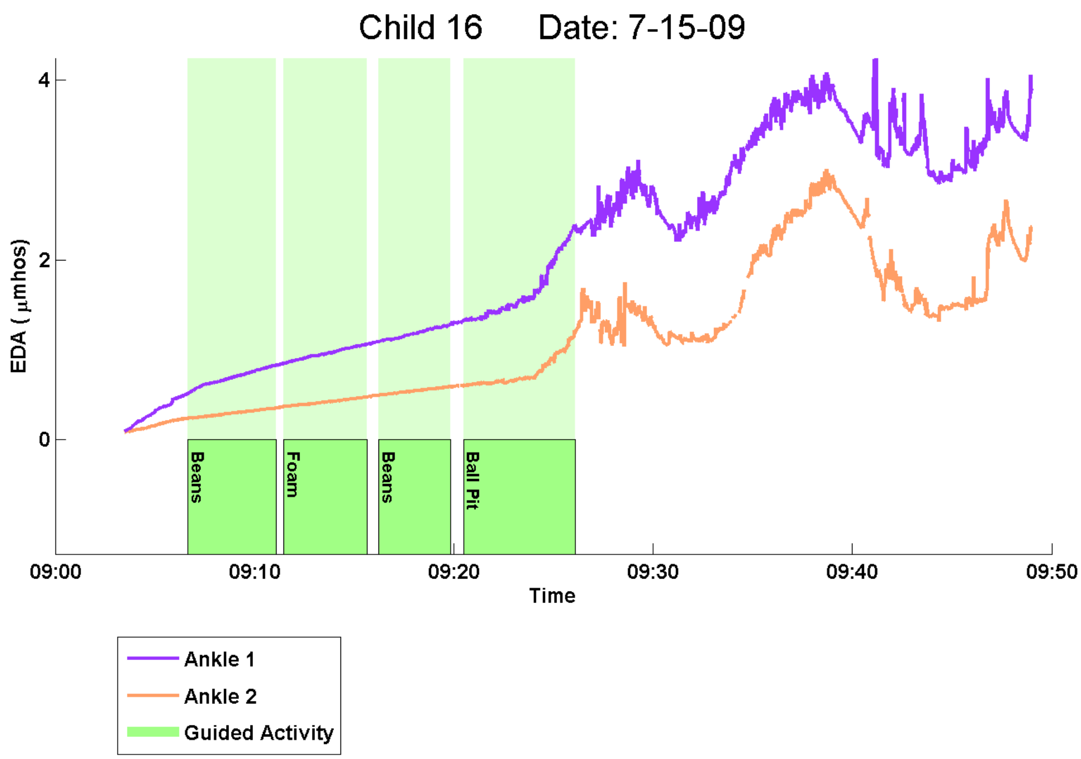

Figure *9.3*). Child 16's EDA started at 1 µ mho. He appeared calm. The therapist explained to us that afterwards, the child had become over aroused: he accidently hit the therapist, would not listen to her, and moved around without stopping.

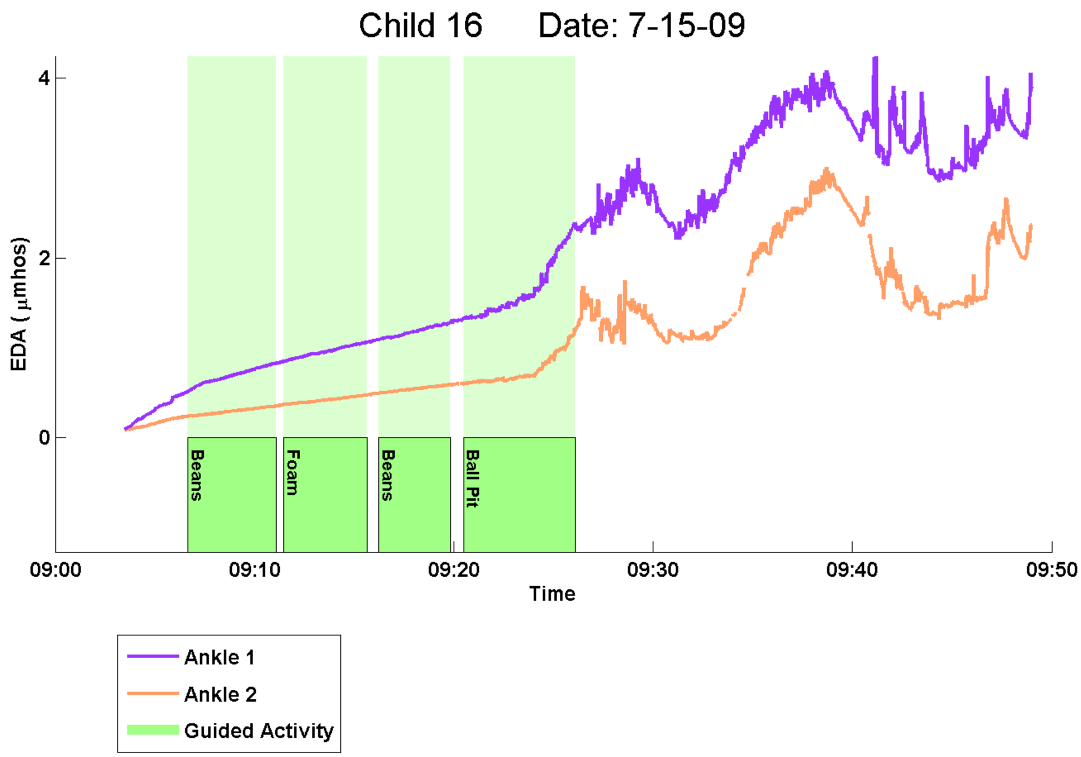

Figure 9.3: Child 16's EDA response to being in the ball pit
EDA response of Child 16 as he become excited entering into the ball pit.

In contrast, Child 2 also went into the ball pit (**Figure *9.4***). For the epoch at 15:20, Child 2 fell into the ball pit from the zip line. He used the therapist for support as he got up. He was able to plan on moving the "red pizza" after leaving the ball pit. Child 2 appeared to be aroused, but not over aroused. He was still in control. During this guided activity his EDA increased by 3 µ mhos on Ankle 2.

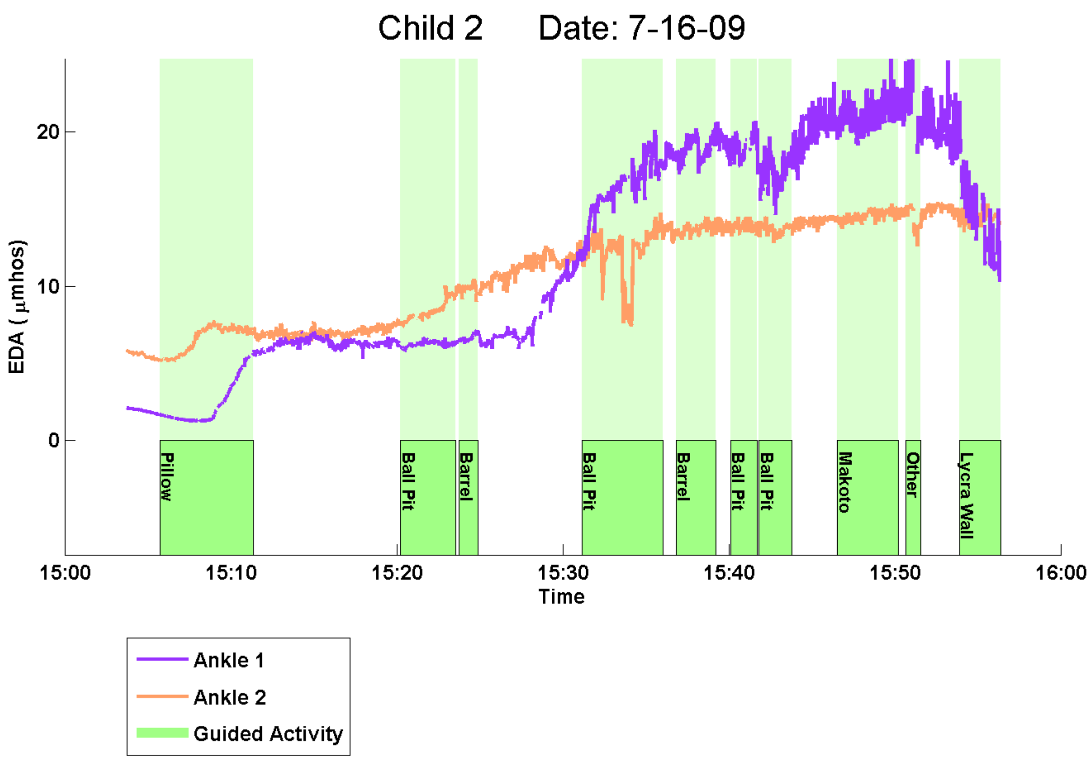

Figure 9.4: Child 2's EDA response to being in the ball pit
EDA response of Child 2 in the ball pit. Notice the large increase in EDA at (14:20) for Ankle 2.

Child 2's EDA increased by 50% more than Child 16's. By their behavior, the first child, Child 16, appeared much more psychologically aroused than Child 2, suggesting that our measured EDA values are not on a homogenous linear scale – an increase of 2 µ mhos may be a high arousing event for one person, but not another. This example suggests that EDA changes differ across children. A child's EDA change being larger (in the above case by 50%) does not mean that a child's arousal increases by that much more. This case example is not enough evidence to conclude that EDA responses are different across individuals, but suggests that considering direction of response may be more informative than magnitude.

9.5 Wilcoxon Signed-Rank Test

Because the obtained EDA responses do not appear to fit an interval test, we instead use an ordinal test: the Wilcoxon Signed-Rank Test. The intensity of an EDA change is not considered by using the Wilcoxon Signed-Rank Test, only the direction. An EDA change of 0.1 µ mhos, and an EDA change of 5 µ mhos are both considered an increase in EDA. By not evaluating intensity, we can more assuredly compare across individuals. On the other hand, we may emphasize changes that do not exist. For example, in **Figure 9.5**, Child 14's EDA does not appear to change by much while on the rainbow lycra wall at 15:08, but since her EDA slightly decreased, this is still considered a decrease in EDA.

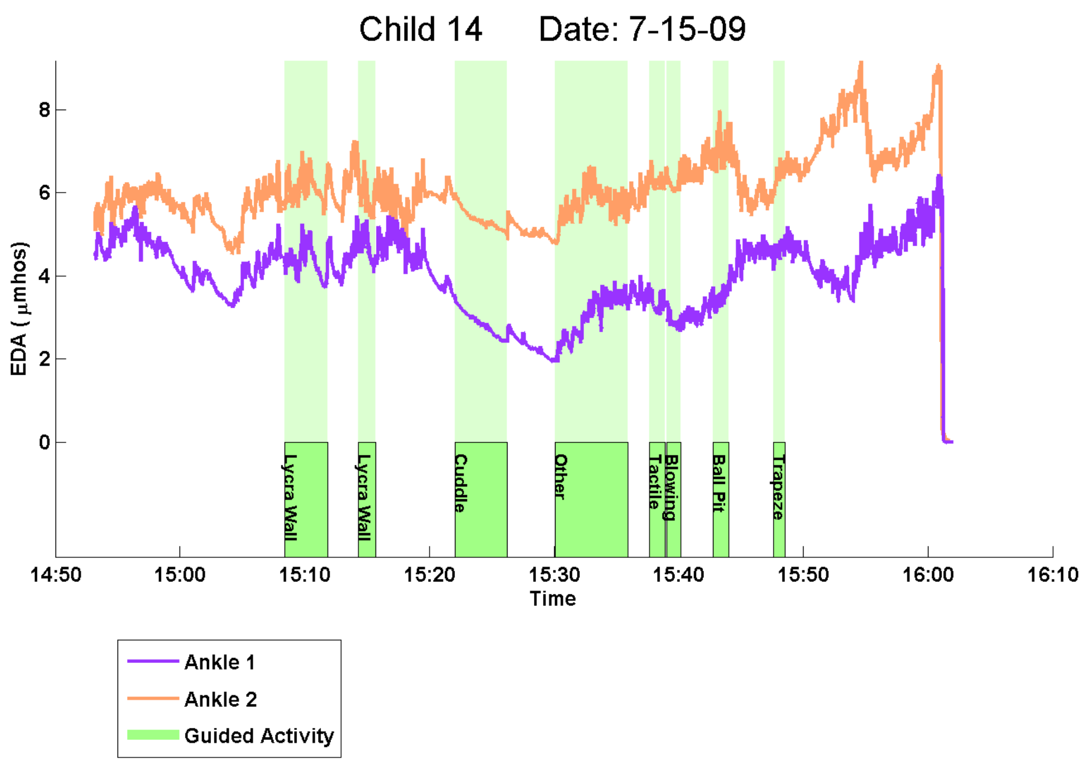

Figure 9.5: Child 14's Small Change in the Lycra Wall

Child 14's EDA only slightly decreases at 15:08 in the lycra wall. With an ordinal test, this change would be considered a decrease.

A more complicated analysis in the future could potentially divide responses into 3 responses: decrease, no change, and increase. This analysis is beyond the scope of the paper. Statistical tests were only run for pieces of equipment where 5 or more children were observed using the equipment during an epoch. The threshold was set at 5 participants, as having fewer than 5 children would be a poor descriptor of the general effect. Below the results are displayed for the Wilcoxon Signed-Rank Test (Gibbons, 1985) for each piece of equipment:

Equipment	N	Median Value (µ mhos)	P Value Two-Tailed, Wilcoxon Signed-rank Test
Makoto	7	0.22	0.047
Ball Pit	8	0.23	0.38
Rainbow Lycra Net	10	0.35	0.065
Tire Swing	6	0.51	0.44
Bolster Swing	11	0.52	0.10
Giant Pillow	6	0.64	0.69
Barrel	5	0.65	0.13
Scooter Board	5	1.54	0.063

Table 9.1: Wilcoxon Signed-rank Test for Epochs Grouped by Equipment

Because eight independent tests were conducted, the alpha value needed to be adjusted to prevent a Type I error. By using the Dunn-Šidák correction method, an adjusted alpha value of 0.0064 was used.

$$1-(1-\alpha)^{1/n} = 1-(1-0.05)^{1/8} = 0.0064$$

Equation 1

To meet this threshold at least 9 samples would need to be measured and all of those samples would need to be in the same direction of change. Because of this restraint, the listed p values can only suggest that not enough epochs were observed to conclude how equipment affects EDA responses. Because of low statistical power, we cannot conclude the inverse- that equipment does not have an effect on EDA.

A larger sample size and fewer tests could bring some of these results to a statistically significant level. The discussion section suggests other factors that should be accounted for in future statistical tests, regardless of statistical power.

10 Case Studies

Despite no statistical significance, therapists, research assistants, and research advisers observed many notable interactions between the child's EDA and guided activities. These studies are not a full list of findings, but a short example of some of the interesting measurements that iCalm recorded. These observations may be coincidental or misinterpreted. A more thorough qualitative analysis across all of the recorded sessions could help support some of the conclusions.

Figure 7.1 shows the EDA of a young girl with ASD. The child's EDA increases while she finds toys in a large room (11:06). Her EDA decreases when she is in the ball pit (11:20), until she starts looking for animals in the ball pit (11:26). She then lies down in the ball pit (11:32), which corresponds with a decrease in her EDA. When she leaves the ball pit (11:34) her EDA increases as she anticipates riding on an elevated bolster swing. When the child is rocking on the swing (11:37), her EDA decreases.

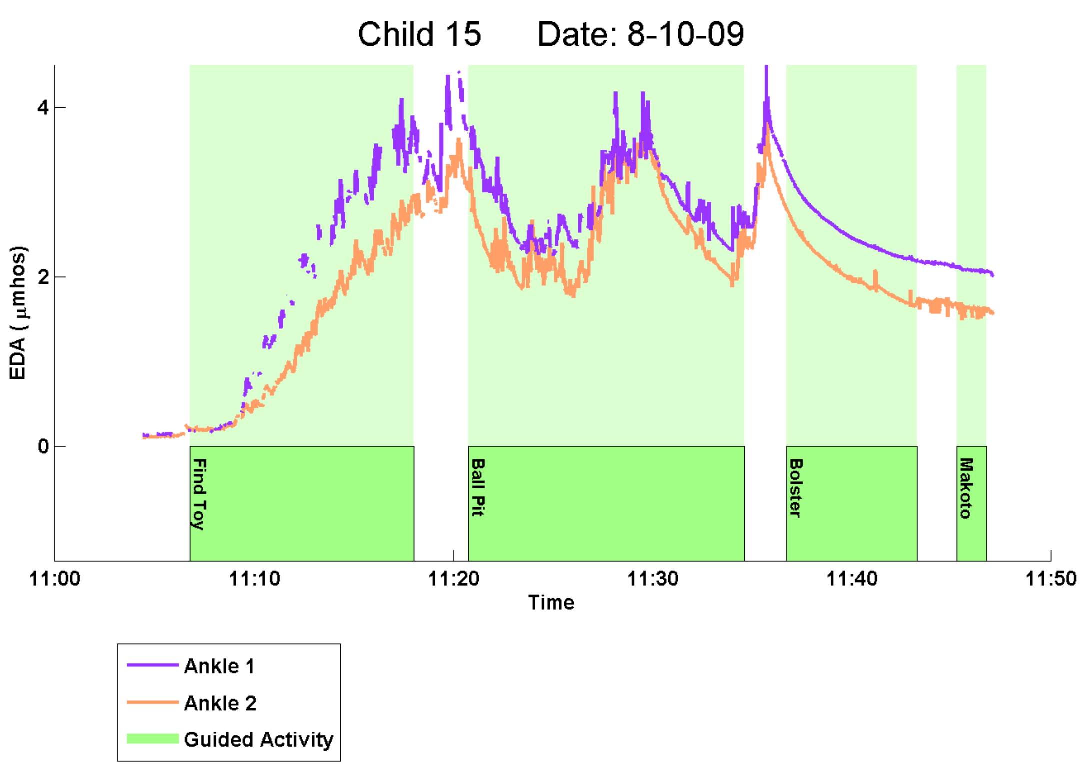

Figure 10.1: Child 15's EDA Response

In **Figure *10.2***, a child with ASD starts therapy early in the morning (8:00). She is lethargic and does not appear aroused when jumping on a trampoline, playing in a ball pit, and running through a tunnel. When

Child 12 is told that she is going to ride in a wagon to her listening exercise (8:40), her EDA increases. When the child begins the listening activity (8:47) her EDA decreases.

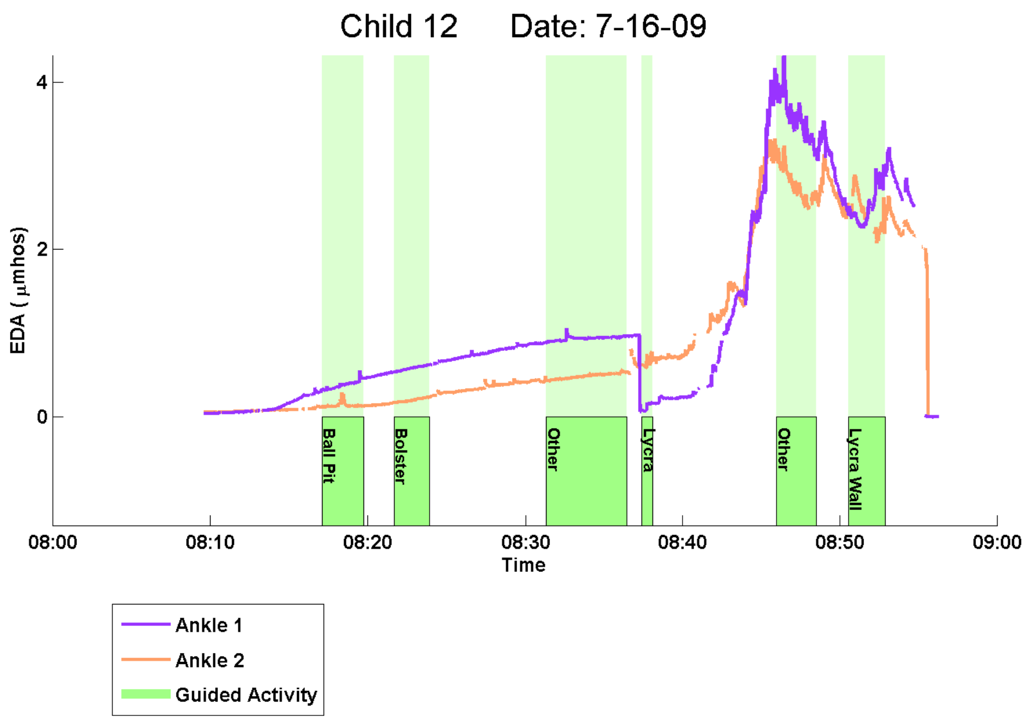

Figure 10.2: Child 12's EDA Response

In **Figure *10.3***, Child 14 sits in the different levels of the rainbow lycra wall (15:09). She talks with the therapist about having to face a robot Mr. Bucket. Child 14 dislikes the loud noises that Mr. Bucket creates. The child and therapist plan together how she is going to ask to turn Mr. Bucket off, "We can say turn him off". She walks on all fours to a small room. The child gently rocks in the cuddle swing and discusses why she should not be afraid of Mr. Bucket – "He's just a bucket." At 15:30 Mr. Bucket is brought to her while she sits in a chair. She is unable to say complete phrases to the therapist or her mom – only saying one-word sentences. The therapist never turned on the robotic bucket during the session.

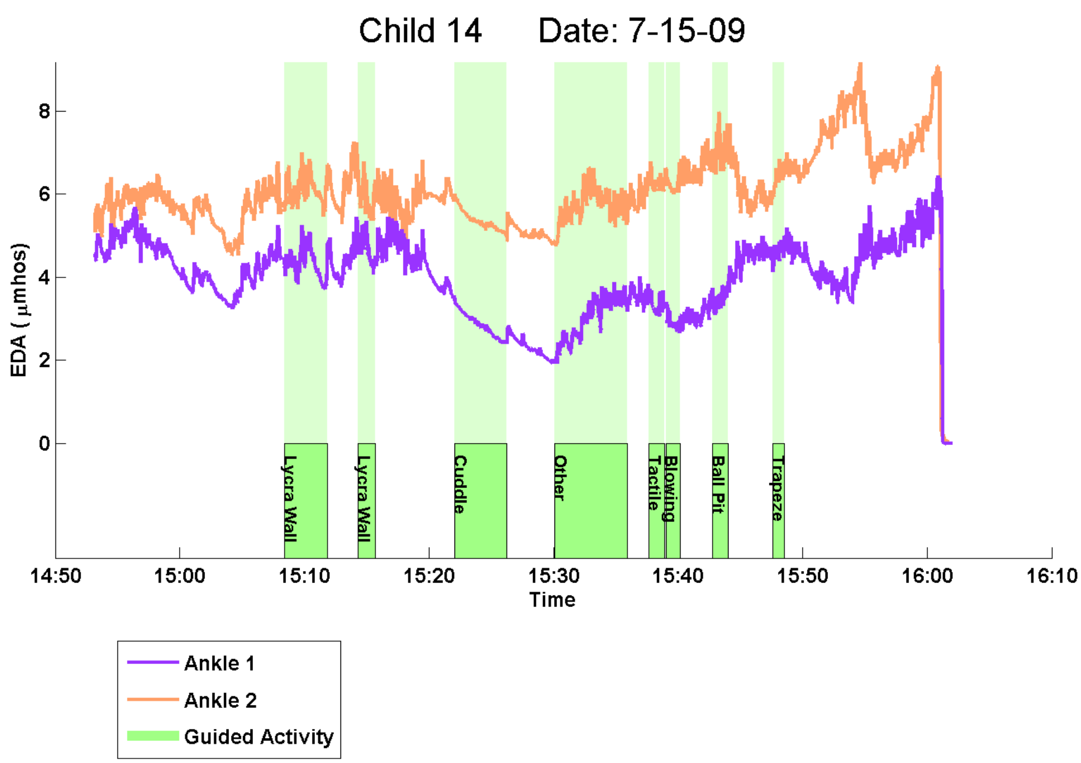

Figure 10.3: Child 14's EDA Response

In ***Figure 10.4***, Child 14, who is easily over stimulated, has her EDA decrease while painting at 16:18. Her EDA increases when she rides a bike to the zip line and falls into the ball pit (16:27). She becomes agitated when the therapist asks her to roll on her g-tube (16:38). At 16:46 she begins painting with scented pudding. As she is sitting down and painting, her EDA begins decreasing again.

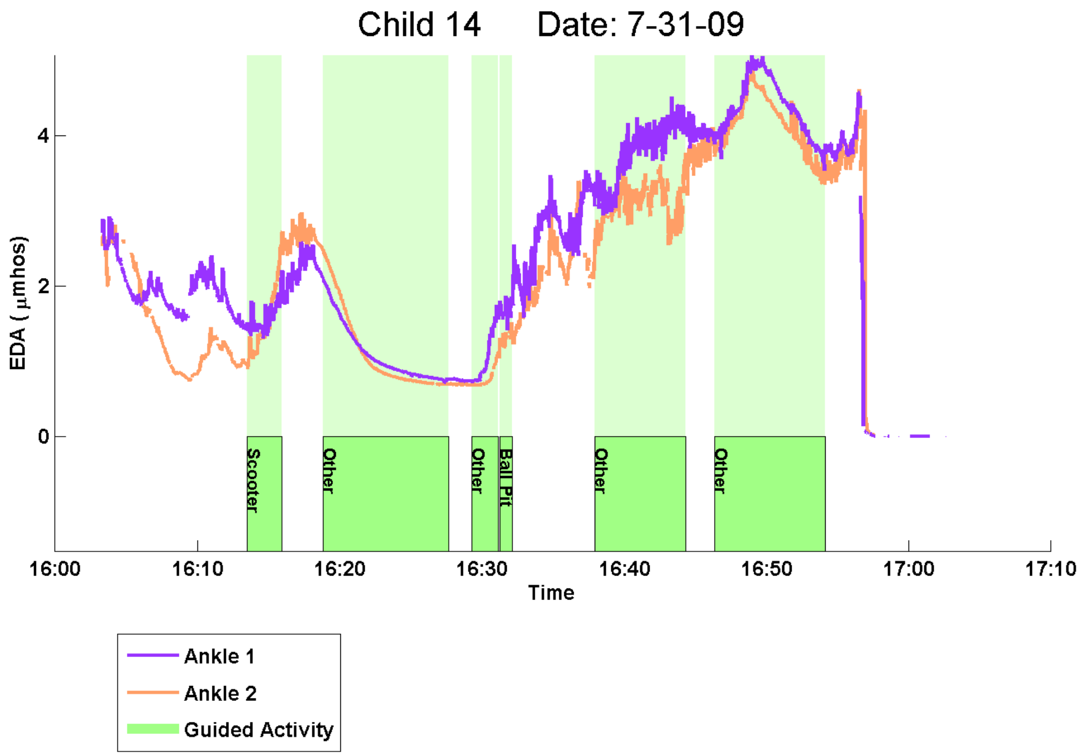

Figure 10.4: Child 14's Second EDA Response

In **Figure *10.5*** A 3 year old child who can only say one-word phrases has his EDA increase extensively while in the ball pit (9:21), his favorite piece of equipment. When in the ball pit, he does not appear to pay attention to the therapist or her commands. The therapist spends the rest of the session trying to help the child calm down.

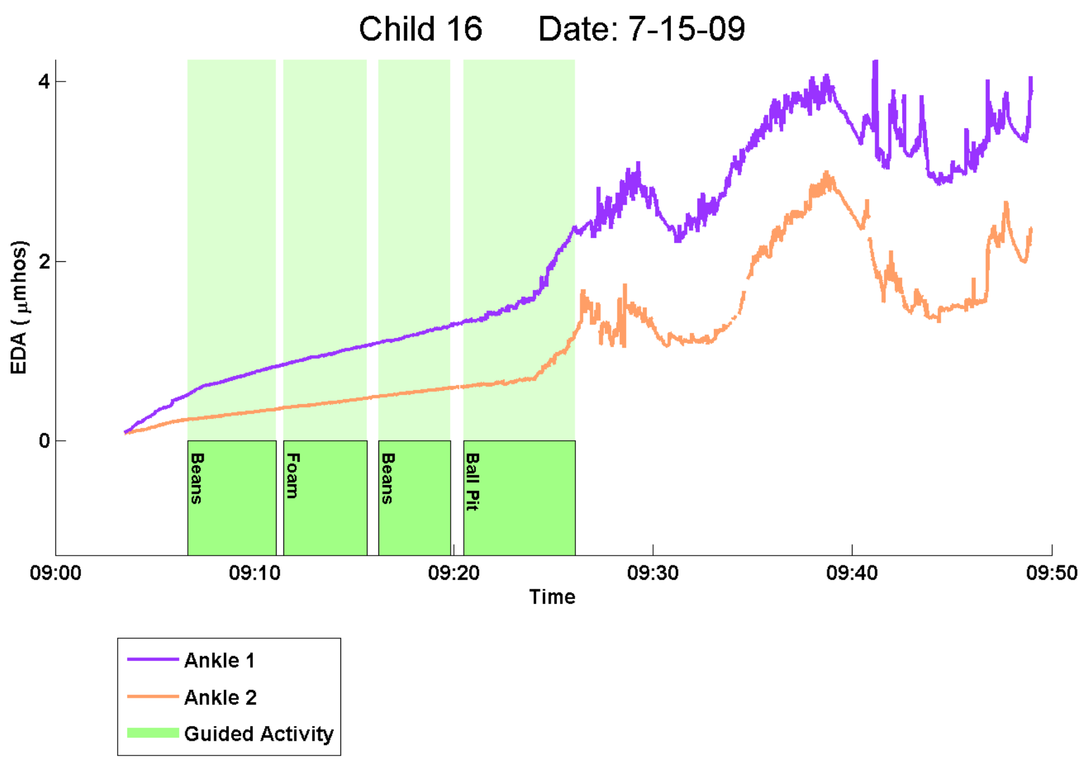

Figure 10.5: Child 16's EDA Response

In **Figure *10.6***, Child 9 is exposed to various different therapeutic activities. When the child swings on the bolster swing his EDA increases. Leaving the swing and blowing (13:12) corresponds with a decrease in EDA. The child's EDA increases (13:20) as he plays a game with his mother where he must slap certain cards before her.

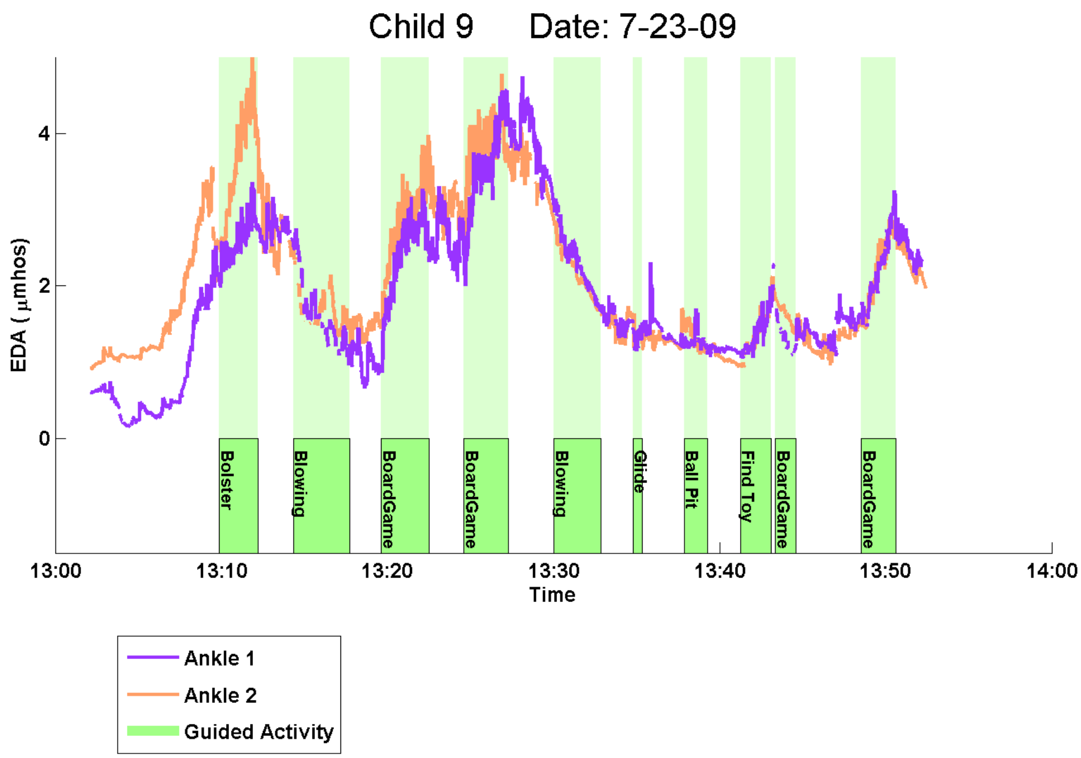

Figure 10.6: Child 9's EDA Response

In **Figure *10.7***, Child 11's EDA increases while he swings in a tire. After the tire task, his EDA further increases as he cleans up. When the child is in the ball pit, his EDA decreases. When the child is pulled on a scooter to begin a listening activity, his arousal increases.

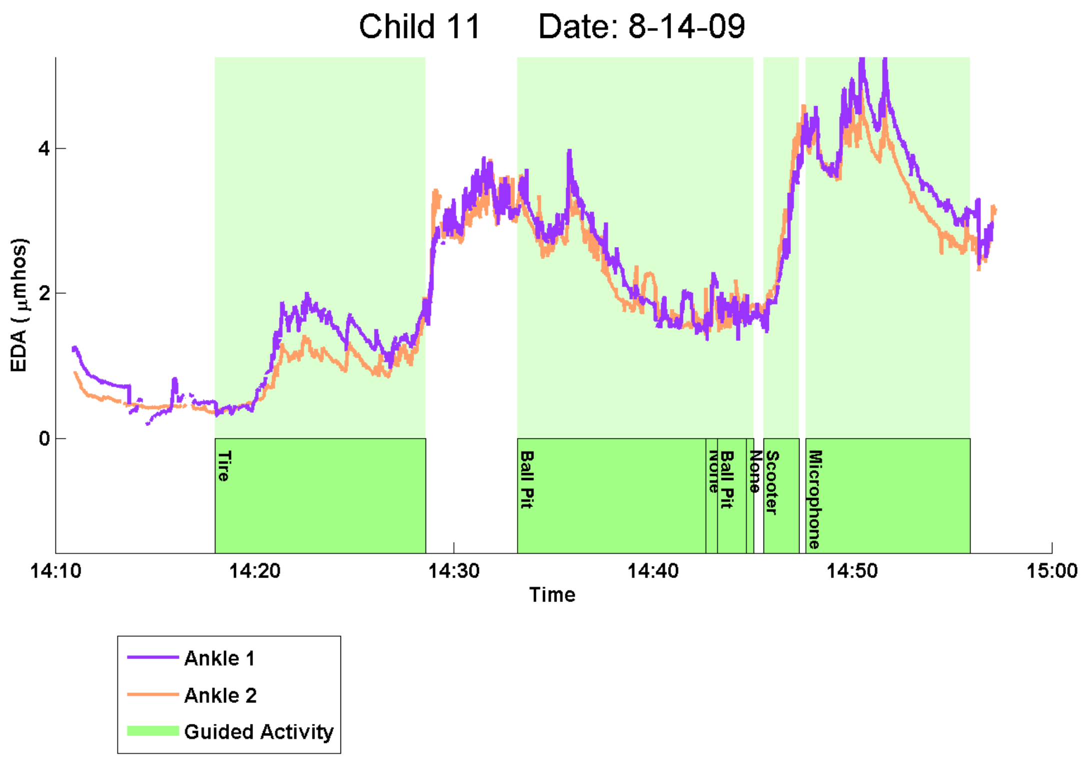

Figure 10.7: Child 11's EDA Response

These stories demonstrate different ways in which iCalm provides new information about how occupational therapy affects a child's sympathetic nervous system and arousal. None of these descriptions have causal conclusions: there are many factors that could influence a child's EDA. If enough observations like these were made though, we could better understand what makes occupational therapy work and what factors should be focused on for describing effective treatment. These case studies are only a few examples of what iCalm can measure and should not be used to make conclusions about how occupational therapy works.

11 Discussion

To see if the use of specific equipment had a consistent effect on children's arousal, across children, we ran a Wilcoxon Signed-Rank Test. These results were not statistically significant, in part due to low power. In the case study section, guided activities and their corresponding EDA response were presented on an individual level. From these case studies we concluded that EDA appeared to change with different guided activities. In the discussion section we suggest other factors that may determine how arousal changes during a guided activity.

We suggest that comparing EDA responses only to specific equipment does not accurately portray a therapeutic session. We highlight the importance of considering epochs on an individual level and taking into account therapeutic intent and external factors.

11.1 Guided Activity Factors and Therapeutic Intent

The following epochs shows how equipment can be used to excite and calm a child, based on the therapist's intent.

Child 19 begins his session by climbing to the top of 5 layers of lycra (**Figure *11.1***). At the top he plays volleyball with his mother while kneeling (8:30). This corresponds to an increase in EDA. This guided activity continues until the child reaches the max value of 6 μ mhos, when the child falls out (8:33). After a small time relaxing on a giant pillow the child then lies on the Rainbow Lycra Net. Here, the child and the therapist talk about calming down. The therapist gives him space and talks slower. He concludes," I have learned to calm myself down thanks to three weeks at the STAR center". During this second time using the rainbow lycra net, we can see the child's EDA decreasing. Within a 15 minute period, we see the child's EDA both increase and decrease using the same equipment but with different intentions from the OT.

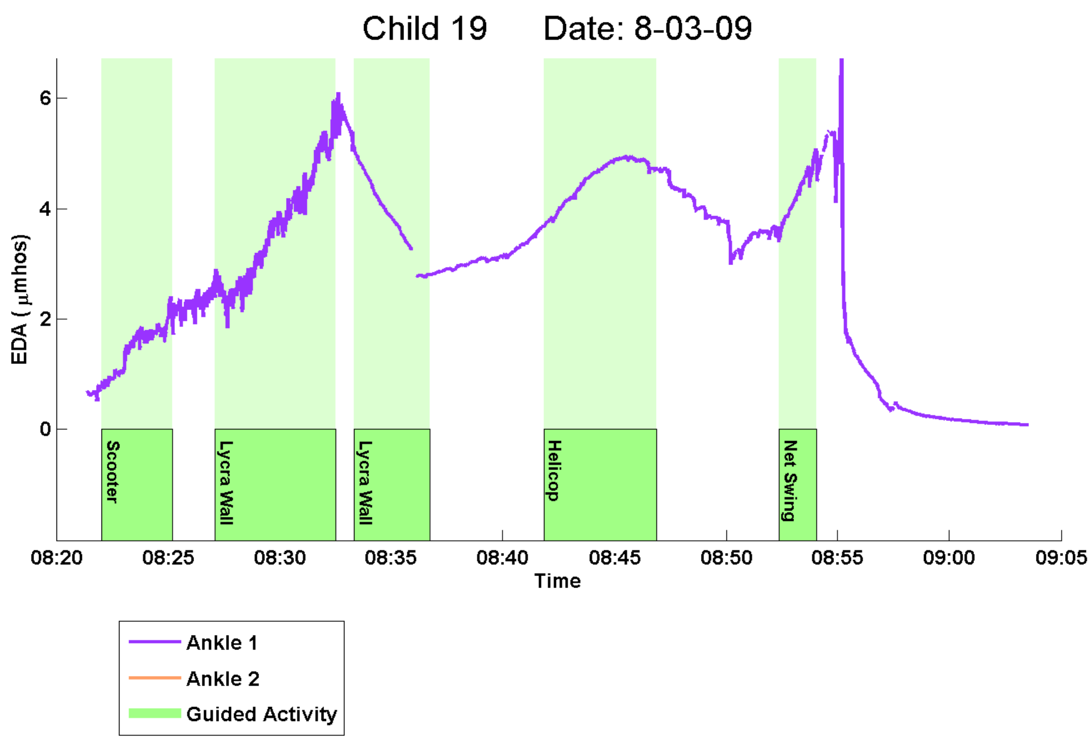

Figure 11.1: the Rainbow Lycra Net Increases and Decreases Arousal
Child 19's EDA increases and then decreases while using the rainbow lycra net.

Multiple factors differed for Child 19 between the two epochs of using the lycra wall: the child's body position, the game he was playing, who he was interacting with, and the cognitive challenges all differed. Many of these factors are controlled by the occupational therapist: therapist's intent controls factors which in turn affects the child's EDA.

11.2 Environmental Influences

The following epoch suggests that environmental factors affect a child's EDA.

Child 14, who is sensory over-responsive to loud sounds, smells, and tastes, calms down while using a hanging cuddle swing (**Figure 11.2**). She gently rocks in the swing that covers her entire body. While the child is still in the swing, the therapist introduces a noisy robot to her. When the robot approaches the child, her EDA increases. The child begins screaming and hiding in the cuddle swing.

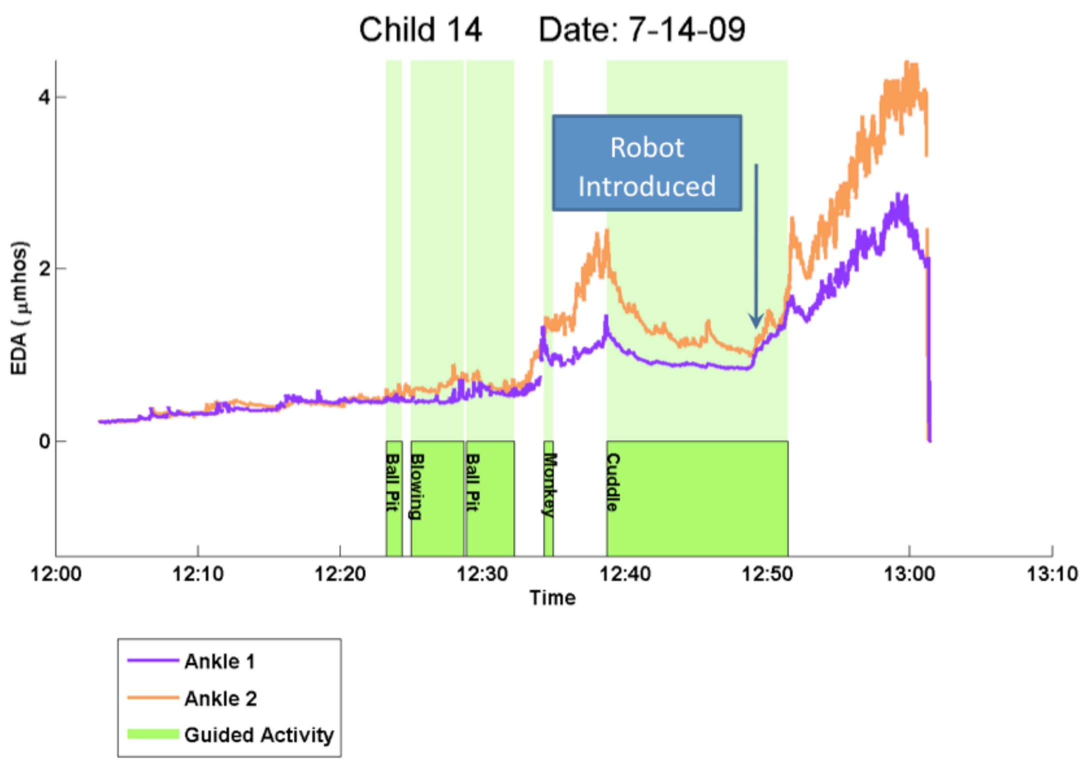

Figure 11.2: Robots Increase Child 14's Arousal
A child's EDA decreases while using the Cuddle Swing but increases when exposed to a loud robot while still in the Cuddle Swing (blue arrow).

The child's EDA increases because of an environmental factor. In this sample, the therapist introduced the sensory stimuli part way through the epoch with the cuddle swing. In other epochs, the therapist may not control these environmental influences: there may be another child in the room, or the child is elevated in the air, or bright lights may distract the child. A more controlled study, situated in a new world setting, may reduce these external stimuli, but many environmental factors may still exist: a new place, a new routine, and new interactions with the research assistant could all affect how a child reacts to a piece of equipment.

11.3 Individual Differences

Children may also have unique EDA responses because of individual differences –guided activities may affect children in different ways. If an epoch was the exact same for two children, there still could be a difference in response depending on the child's internal response. For example, deep pressure from the giant pillow is often used to calm children in therapy. Child 9 in **Figure *11.3*** appears calm when using the giant pillow (12:42) but his arousal spikes up (12:49) after leaving the pillow. This increase afterwards is not how all children respond – his response may be unique.

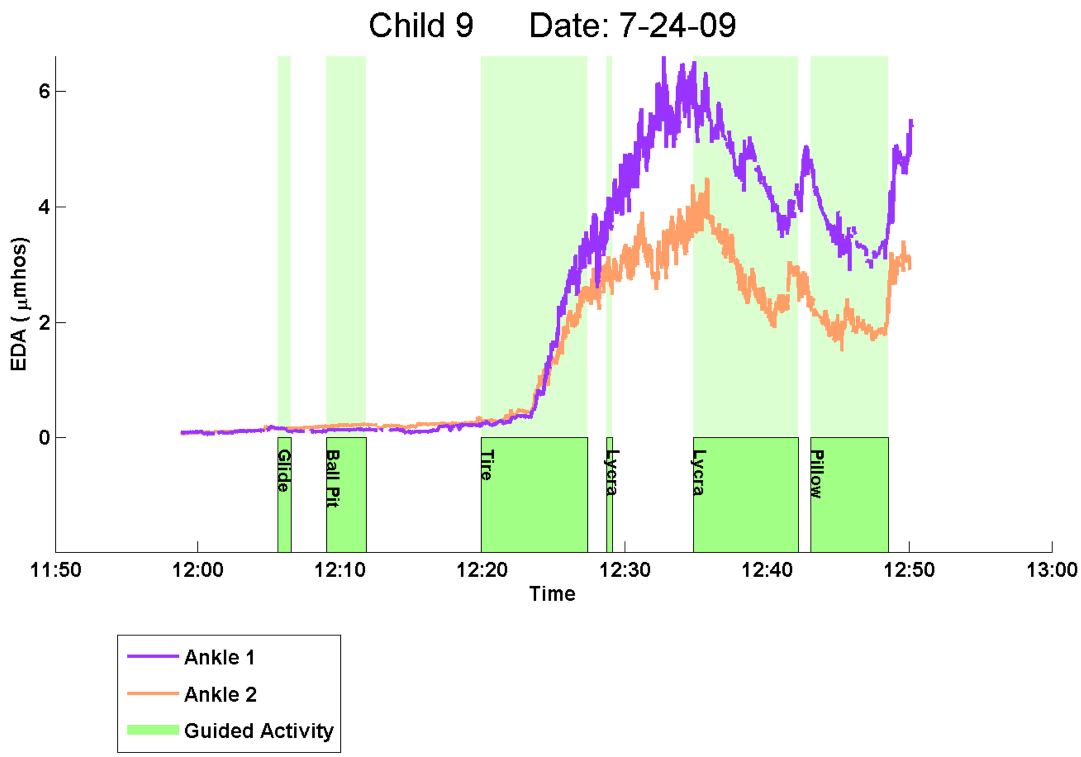

Figure 11.3: Child 9's EDA with Giant Pillow

Child 9's EDA decreases while using the giant pillow, but his EDA increases after the pillow is removed. We cannot conclude if this response is due to his unique physiological responses or whether most children respond in this way.

11.4 Discussion Conclusion

The Wilcoxon Sign-Test tested whether therapeutic equipment tended to increase or decrease arousal within guided activities. The discussion suggested that, in addition to equipment, other factors, both in and out of the therapist's control affect how a child's EDA responds to a guided activity. For further analysis, we suggest shifting from analyzing group effects, to better understanding individual case studies, like the ones listed in the case study section. By combining time series analysis to these case studies, a statistical and descriptive model could be produced, suggesting important factors for guided activities.

12 Additional Limitations

Many confounds were presented in this research study. This section underlines additional limitations that should be taken into consideration when interpreting the results, discussion, and conclusions of this paper. This section concludes with a list of all confounds mentioned and suggestions on how these confounds may be addressed in the future.

12.1 Lack of Prior Research for measuring EDA during a natural hour

This study is one of the first to measure EDA in an observational setting. Lacking the structure of a controlled experiment, there was no "baseline" point. The child did not sit still and relax before an epoch was introduced. The previous epochs and the child's corresponding EDA responses may have interacted with the child's current EDA level. Many of the sessions had a continuous increase of EDA from the beginning to the end. See **Figure *12.1*** for an example.

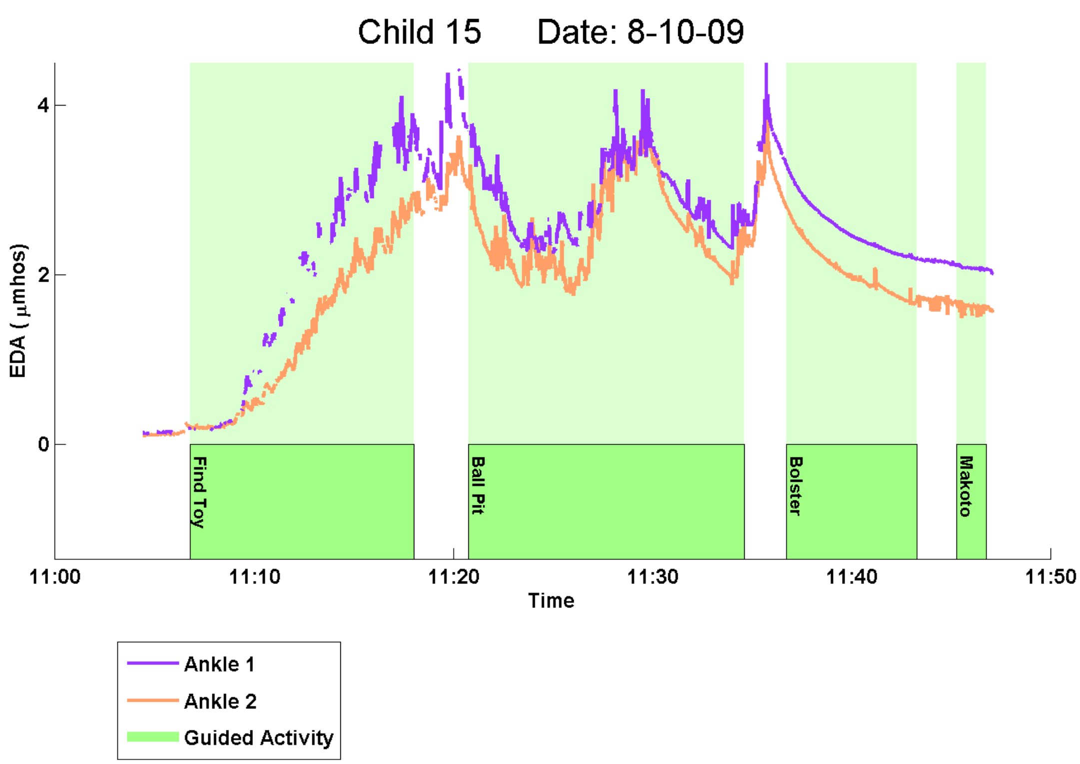

Figure 12.1: Measuring EDA Across Time
In a typical experiment, we may observe how a child's EDA increases while being in a guided activity with the ball pit. How did the "finding a toy" activity affect the EDA of the ball pit? Does the ball pit appear to initially calm the child only because the child has a heightened arousal after entering from the "finding a toy" activity?

12.2 External Factors

As suggested in **Section 11.1** and **Section 11.2**, many different factors appeared to affect EDA. Below is a list of external factors that were not controlled for during the study:

- The music the child is listening to in their earphones varied and switched throughout the session.
- The switching of music every 15 minutes
- The number of children in the room and the excitement and frustration those children showed
- The ambience of the room: the lighting, the equipment setup, who was observing the child, etc.
- The motivation of the child: is a reward being offered? Is there a time limit or competition?
- The cognitive challenge of the activity: the child may have to navigate an obstacle course or solve a puzzle.
- The physical challenge of the task: a child may be balancing on a swing, or carefully squeezing a nerf gun, or having their body in a new position
- The therapist's intent- is the therapist trying to calm or excite the child?
- The child's body position- is the child laying down, sitting, walking, etc.?
- The way equipment was used – is a child pushing the pillow, being rolled into the pillow, dragging the pillow, etc.

Having uncontrolled factors are part of an observational study, and by more closely looking at case studies, we may better understand how these factors appear to change a child's EDA.

12.3 Time Trends in the Data

EDA readings incrementally increased across most therapy sessions as the sensors became more acclimated to the skin. A more thorough statistical analysis should take into account the dependencies the current EDA value has on the previous values. A statistical analysis that uses time series analysis could take into account time trends.

12.4 Controlled EDA levels

This study is an observational study within the confines of an occupational therapy session. The conclusions made, may not apply to a child's home or school setting. During therapy, the therapist intentionally tries to keep the child's arousal at an optimum level. We observed very few times when the child was exceedingly overwhelmed: crying, throwing a temper tantrum or having self-injurious behavior. Our observations about guided activities are restricted to therapeutic settings for children with Sensory Processing Disorder.

12.5 List of Confounds

Throughout this study we mentioned confounds that could affect results – both in case studies and statistical studies. This section lists these confounds in one location and mentions which section these confounds were discussed.

1. EDA may be a reaction to metabolism or sweating, not just arousal (Section 3).
2. Some children took medication that may affect their EDA responses (Section 7.1).
3. Some children had been working with occupational therapists for a longer time (Section 7.1).
4. Children worked with different occupational therapists (Section 7.1).
5. Only children who were comfortable being videotaped were observed (Section 7.1).
6. EDA was measured on the back of the ankles as opposed to fingers and palms (Section 7.2)
7. At times only one sensor was available (Section 7.3).
8. Both the therapists and children were being videotaped (Section 7.3).
9. Both the therapists' and children's EDA were being measured during therapy (Section 7.3).
10. We created a new way for labeling when a guided activity happened (Section 7.4).
11. There was a challenge in determining when a guided activity began and ended (Section 7.4).
12. Sensors would malfunction- batteries would die and wires would break (Section 8.1).
13. The sensor would move on the body, changing EDA values (Section 8.1).
14. In some locations the sensor could not wirelessly transmit data (Section 8.2).
15. Sometimes only one EDA signal was correctly measured, other times two (Section 8.3).
16. Sensors usually could not read an EDA signal in the beginning of sessions (Section 8.4).
17. EDA values below 0.5 μ mhos were ignored (Section 8.4).
18. Events that happened pre- and post-epoch were not controlled for (Section 9.2).
19. Children may have been excited during transitions (Section 9.2).
20. How changes in EDA relate to non-linear changes in arousal is unclear (Section 9.4).
21. The Wilcoxon Sign Test does not take into account "no change" (Section 9.5).
22. Not enough epochs were observed to make conclusions (Section 9.5).
23. Multiple statistical tests were conducted (Section 9.5).
24. A therapist's intent affects many factors that affect EDA responses (Section 11.1).
25. Environmental factors influence EDA responses (Section 11.2 and Section 12.2).
26. Children with different diagnoses may respond differently to a guided activity (Section 11.3).
27. Previous epochs may affect new epochs (Section 12.1)
28. Measured EDA values tended to increase across time (Section 12.3).
29. Time of day appeared to affect EDA responses (Section 13.1)

12.6 Addressing Limitations in the Future

Statistically comparing EDA responses across subjects, in natural occupational therapy, has many confounds. Overall, these limitations suggest that statistical analysis may be better suited for individual case studies. By further analyzing the case studies presented in the Case Study section, we could gain insights into important factors that influence children's arousal. If enough of these case studies were analyzed, we could potentially make more generalized claims. EDA is a quantitative measurement but many factors influence EDA, that making conclusions about one factor is difficult. Time series analysis in conjunction with these case studies, could help us better understand what events change EDA.

In addition to focusing more on individual analysis, a more robust method for analyzing EDA in natural settings needs to be developed: how do you determine if someone is acclimated? What values are true EDA responses? How can we detect and remove movement artifacts? These confounds potentially could be answered with a controlled study that had a large, diverse sample with special attention paid to individual differences.

More physiological signals should be measured to better understand how a child's arousal changes. Recording biological signals such as the child's metabolism and heart rate would help us better conclude how general activities affect arousal. We should also take into account therapists' opinion and their summary of the session's experience as a confirmation of reliability.

In summary, EDA should not be analyzed without additional measurements to better describe context.

13 Future Studies

Despite concluding that statistical analysis was a weak form of generating insights, many new research opportunities were identified through the different case studies.

13.1 Between Subjects Comparison

While analyzing equipment effectiveness on a group level was uninformative, other more specific questions could be looked at for between subject comparisons.

1. The relationship between time and arousal

Therapists and researchers noticed that the child's arousal and EDA was very low in the morning and very high in the evening. A repeated measure ANOVA could compare how time of day affects EDA responses. Each child would participate in therapy during 4 distinct times of the day. If results show similar patterns as above, time of therapy could be a factor to consider for therapy: if the child is usually over-aroused, perhaps a more productive therapy can take place early in the morning or right after lunch?

2. The relationship between arousal and behavior

How does a child's EDA affect their behavior during therapy? If a child is overwhelmed, having temper tantrums, or being self-injurious – how does this relate to a high EDA reading? Can we predict when the child's negative behavior is about to occur?

The child's communication patterns could be measured- the proportion of time the child is speaking compared to the time the therapist is speaking. Does EDA correlate with an ideal state of communication – where the therapist and child are in an active dialog? Measuring EDA could be used as a tool to help therapists create a better therapy experience for the child – help the child be at an optimal EDA level.

3. Look at the overall effect of therapy

By measuring EDA over more sessions, we may be able to see longitudinal effects of therapy. Does a child's response to stimulus (perhaps a consistently used equipment) change over time? By looking at long-term effects, this research could provide new evidence for effectiveness of occupational therapy.

4. Cluster Analysis of Sensory Processing Disorder

Some children with a clinical diagnosis of Sensory Processing Disorder showed extraordinarily high EDA responses. Other children's EDA was observed to be near 0 across the entire session. Are there characteristics that distinguish these children with extreme EDA? Do children who are sensory over-responsive show higher peaks, more SCRs, or a larger base level? Miller suggests there could be differences in responses for controlled stimulus (McIntosh and Miller, 1999). Could a child's "naturally observed" EDA also help predict a child's sensory diagnosis? Hedman, et al. began looking at how EDA could potentially cluster children with various machine-learning algorithms (2009).

13.2 Individual Analysis

Focusing on individual cases can generate richer and more informative results. Below are a few studies that could be conducted from the already obtained data.

1. Time Series Analysis

We could use time series analysis tools to better understand if interventions are effective for children on an individual level. Can we definitively say that a specific guided activity helped a child decrease their arousal? In what cases can we see EDA change and in which cases are the changes non-existent or in the opposite direction? Can we identify possible factors that affect why some interventions are effective at increasing or decreasing EDA?

2. Qualitative Analysis for each Individual

What new information can we learn about a child when their EDA is clearly mapped out? This qualitative information could help us better understand therapy sessions and provide evidence for measuring EDA being used as a therapeutic tool.

13.3 Using iCalm in new ways:

iCalm was used as an observation tool in this study. How can we incorporate these measurements into therapy?

1. Arousal Feedback for Child

What happens if we show a child his or her own EDA? In one session a 5 year old watched his EDA and could intentionally make his EDA go up and down. Can seeing their own EDA increase a child's motivation and awareness about self-regulation?

2. Arousal Feedback for Parents, Therapists, and Clinicians

Could seeing a child's EDA better help parents, therapists, and clinicians improve their relationship with their child? How can EDA information be presented to stakeholders without data being misinterpreted – many factors affect EDA and it would be easy to make false conclusions.

3. Real-Time Evaluation of Equipment Effectiveness

When using specific pieces of equipment, children's EDA responses varied. We could measure these responses in real time and this information could be delivered back to the therapists- helping the therapist know how equipment is affecting their child's EDA.

14 Contributions

While this thesis lacks strong statistical conclusions, various contributions were provided to the fields of occupational therapy and psychophysiological measurements through this study. A new form factor was designed for sensitive children in a therapeutic session. By using this form factor, we also looked at the effects of measuring EDA on the back of ankles. This study was successful in collecting EDA during in situ therapy. A thorough process was outlined for interpreting this type of data, and we showed visual patterns that corresponded with therapeutic epochs.

15 Conclusions

We started with the hypothesis: When children with SPD participate in guided activities within an occupational therapy direct setting, informative changes in EDA can be detected using iCalm. By measuring the child's EDA and simultaneously videotaping their therapy sessions, we could see how equipment use corresponded with EDA. Statistical analysis, attempting to group guided activities by equipment was inconclusive, in part due to low power. Case studies suggested that some guided activities corresponded with changes in EDA. Future research that measures physiological measurements (EDA in this study) in natural (non-laboratory) environments should consider focusing on case studies to better understand key factors, before attempting to make generalized statistical conclusions.

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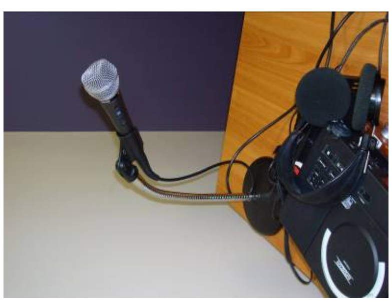
Appendix A- Pictures of Equipment

Below are pictures of the actual equipment children used throughout the therapy sessions. These pictures describe the equipment mentioned in the displayed graphs. A better understanding of what the children were doing can be obtained by looking at the pictures.

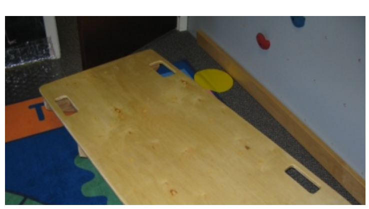


Rainbow Lycra **Tactile Toys** **Climbing Net**


Weighted Blanket **Rock Wall**




Microphone **Headphones**


Makoto **Rocker Board** **Kawar Board**

Roller Racer

Balance Beam

Bosu

Scooter Board/ Ramp

Jungle Gym/ Monkey

Barrel

Zip

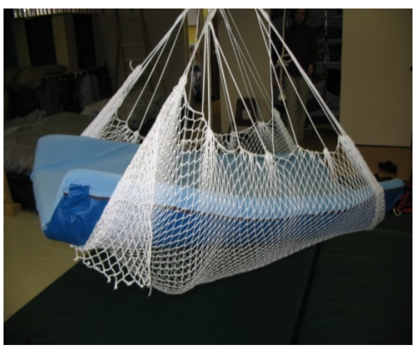
Trapeze Bar

Butterfly Lycra Swing

Cuddle Swing

Platform Swing

Frog Swing



Net Swing

Flexion Disc Swing

Bolster Swing

Helicopter Swing **Whale Swing** **Tire Swing**

Appendix B- Label Guide

The below explanation was given to video labelers for identifying different parts of epochs by analyzing videos. The phrasing and specific details can be used to better understand how we determined when a guided activity began and ended.

Mention New Activity Frame #:
When the therapist mentions that they will be going to the next activity. This requires two components:
The specific activity has to be mentioned: "We will now be painting" NOT "Are you ready for the next activity?"
A transition to that activity needs to be mentioned as well: "Are you ready to get off the slide and go to the trampoline?" NOT "Are you excited to go on the trampoline today?"

If the therapist uses the visual schedule, this counts as well.

Start Activity Frame #:
When the child physically begins an activity. The child needs to be fully ready to begin the activity – has equipment, is positioned correctly, etc. If they are swinging, they will already be holding on or sitting or standing on the swing. If they are shooting darts they will have the dart gun in their hands. This is the point where the child is no longer anticipating the activity because it is the moment they start the activity.

Mention Transition Frame #:

When the therapist mentions that they are going to transition away from the current activity. This could involve saying "We are now going to the rainbow room" or the therapist saying "We have 5 minutes left of playing in the ball pit". The difference between the Mention Transition and Mention New Activity is that the transition does not need to involve an explanation of what is happening next, only a clear description of an ending. Sometimes the mention transition frame # and the mention new activity can actually be at the same time: "Time to get off the swing and go to the ball pit". These subtle differences in mentioning may have different effects on the child's anticipation.

End Activity Frame #:
When the child physically ends the activity. The child is physically off the swing, putting the scooter away, etc. If the previous activity was swinging fast and the child has to slow down to get out, still wait for the child to get out of the swing before you mark the end. If the child takes a long time to get out of the ball pit, do not mark end till they are completely out.
Special Note: Sometimes a child will leave an activity for a brief moment – fall out of the swing, jump out of the ball pit. Do not count this as an end, unless they transition to another activity.

Equipment:

Label equipment the child is using. The equipment needs to be a piece of equipment that is used often. You can select two pieces of equipment if necessary (e.g. shooting a gun on a bolster swing would be "nerf guns" and "bolster swing", having a giant pillow on your back while on the scooter would be "giant pillow on back" and "scooter board"). Make sure to specify the activity. We will have a list with a photo of all of the activities that we are keeping track of for your reference. If you think you found a new activity, we can add it to the list.

Do not label transitional activities that last less than a minute and are not repeated. For example, walking on squeaky dots, zip line, and a quick sliding out of the ball pit would not be labeled as they are too short to see changes in arousal. We are primarily looking for interventions that we will see over and over again.

Activity with Equipment (optional): Describe more fully what they are doing with the equipment. This could involve – searching for animals, telling a story, fishing, etc. It is possible that a child can be on one piece of equipment and switch the activity. In this case, treat this as two different interventions. The activity needs to be clearly different.

Body Position:

Take note of the child's body position when he or she is using equipment:

Laying down on stomach (prone)Laying down on back (supine)
Sitting
Standing UpOn all four limbs (crawl position) (quadruped)
Running/Jogging/Skipping/Jumping
Walking

Hanging from hands

Who is the child interacting with BESIDES the OT:

The parents
One or more other children
Interaction requires that both children are using the same equipment at the same time. Having your mom or sister watch you swing does not count. If they are pushing you, that does count.

Cognitive challenge/Motor Planning:

Are the children being asked to solve a problem mentally (in their head) or complete a challenging activity that requires planning? Find the animals, pick up only green been bags, climb across an obstacle course that requires tricky maneuvering, hit moving targets, etc.

Timing Challenge:
Is the child being timed to finish the task: If the therapist says “get the animals AS FAST AS YOU CAN” or the child is competing with the therapist to hit a target before the therapist does. Anything with a timer would count as well. The one exception to this is the count back counter which is used to prepare for transitions. With this timer, the therapist will say “when the red is gone, it will be time to leave”.

Things to Note:

We should expect to have mentioning transitions for almost every part in both mention activity and mention transition frame.

1) equipment not on annotation sheet: planning binder, Mr. Bucket, Cuddle Swing, Zipline, Tree House, fuzzy tactile things (err, yeah), smelly paints, trapeze bar, washcloth (this instigated a big response so I thought it worth having on there)

If the equipment is not on the sheet write it in the Equipment Used (not in list). Take note of this by selecting "other" in the options.

2) How does the child mentioning new activities that the OT then agrees with count towards 'transition mentioned' and 'new activity mentioned'?

The OT is the boss so if Lilly says: "Lets paint" and the OT says "OK" - then this counts as both transition and new activity mentioned when the OT says "OK". A child cannot do anything on their own.

3) What if a child goes to different pieces of equipment during a cognitive exercise, e.g. like during planning activities?

Equipment is USING the equipment for more than 30 seconds. So this definitely does not count. There will be times when the child isn't using any equipment.

4) What do we do with intermediate activities, like using the cuddle swing as a warm-up for the main activity of Mr. Bucket?

We do not judge whether an activity is intermediate or the main activity. List all activities (that last more than 30 seconds). You can get weird mentioning transitions where activities take a long time to go from mentioning to doing, but don't worry about that.

5) Does setting up for an activity (the child is interacting with the piece of equipment) count as 'start activity'?

Setting up the activity does not count as an activity. So hanging up a swing does not count until the child is ON the swing. You have to wait for the child to be ON the equipment.

6) Should 'hanging' be included in the positions category since a number of activities involve this, e.g. zipline and trapeze.

Great idea, it is now included.

1. Are we using the time or frame numbers? If we use the time, Alex and I would be saved about 30 hours of work, but it may inconvenience things for later... so you should just let us know.

Use frame numbers (I think we have resolved this issue yes?)

2. What do we do with a suggestion of just starting an activity- " do you want to go to the cuddle swing?"- even though an end isn't mentioned, I feel like Lily would still be anticipating the activity. (If we don't include that, then you should ignore 2 of my columns)

This would be written as "Mentioning activity". If they never go to the equipment, then you would not record this. We only care about interventions that are actually done.

3. What if there is a different activity with the same equipment- like the smelly stuff and paint

The Smelly Stuff and Paint would be two different activities. If I recall it's actually 3: smelly stuff, swinging, and painting. In this case just mark this in the notes and I'll take care of it later (get rid of the equipment we don't care about).

4. Should all of the buzzies and tactile toys be grouped together?

Yup. All of them are tactile toys now.

5. When does the zip line end? When they get out of the ball pit or let go of the zip line?

For all of our sanity we are removing the zip line from this analysis. If they are zip lining into the ball pit, and get out really quickly ignore this too. Remember, the activity has to last more than 30 seconds.

Appendix C- Parental Consent Form

This consent form shows how parents were informed about the study.

PARENTAL CONSENT FORM

Measuring Physiological Arousal in Children with Sensory Proccessing Disorder during Occupational Therapy

Date:

Dear Parent/Guardian:

I am writing to ask for your consent to have your child participate in a collaborative research project between researchers at the Massachusetts Institute of Technology (MIT) Media Laboratory and [Occupational Therapy Associates or Sensory Therapies and Research Center]. Your child was selected as a possible participant in this study because he or she receives Occupational Therapy sessions from [Occupational Therapy Associates or Sensory Therapies and Research Center], and may benefit from the aims of the project. You should read the information below, and ask questions about anything you do not understand, before deciding whether or not to let your child participate.

PARTICIPATION AND WITHDRAWAL

Your child's participation in this study is completely voluntary and he or she is free to choose whether to be in it or not. If you choose to include your child in this study, you may subsequently withdraw him or her at any time without penalty or consequences of any kind. The investigator may also withdraw your child from this research if circumstances arise which warrant doing so.

PURPOSE OF THE STUDY

This study will explore if state-of-the-art, wireless sensors that record physiological arousal can help enhance Occupational Therapists' (OT) assessment and intervention strategies. The physiological sensors are non-invasive and include a wristband that records temperature, movement, and sweat from the skin; and two adhesive electrodes that record heart activity from the chest. Changes in the amount of sweat that passes through skin and changes in heart activity are both commonly used measures of a person's physiological arousal state. Gathering this information from your child may help OTs better understand and manage their arousal levels.

PROCEDURES

If you volunteer to have your child participate in this study, here is what will happen:

We will ask your child's OT to put the wristband and heart monitor on your child while he or she engages in an OT session. We would like your child to do this for at least one full OT session, but he or she is welcome to continue wearing the sensor during subsequent OT sessions if they like. We may also ask you to arrive up to 30 minutes before and/or stay up to 30 minutes after one of your child's OT session to try the physiological sensors in various ways, and to get your and your child's feedback. Arriving before and/or staying after your child's OT session is voluntary and not required for your child to participate in this study. Finally, we may ask if you would like to try some of these sensors at home for your own use, your child who receives OT, or their sibling if they have one. If this interests you, we will provide instructions and a demonstration for using these sensors, and may ask you some questions about your experience after you've had a chance to use them. Again, taking the sensors home with you is voluntary and not required for your child to participate in this study.

The study may continue for the duration of your child's therapy sessions. This may be up to 45 sessions depending on what program your child is enrolled in. If at any time during these sessions, you or your therapist would like to discontinue using the sensors, you can do so with no penalty.

POTENTIAL RISKS AND DISCOMFORTS

It is possible that anybody who wears these sensors will experience mild skin irritation, itching, or other discomfort. If any discomfort is reported or observed, we will ask you and/or your child's OT to remove the sensors. Since one of the goals of using these sensors is to help reduce stress and overload, we want to make sure that nobody feels pressured to wear them. You will be notified if your child is withdrawn from the study due to any distress with the equipment or procedures.

Although extremely rare, there is potential for our sensors to cause mild irritation to delicate skin if there is lotion (especially sunscreen, moisturizers, oils, etc.) on the skin where the sensor is being worn. To prevent the possibility of injury, please avoid using lotions on areas where the sensor makes contact with skin. If lotion has been applied, please wipe the area clean with alcohol on a cotton ball or wipe firmly with a wet (water only) washcloth or towel until the skin feels clean and free of any oil before using the sensor. If any discomfort is reported or observed, please remove the sensor and notify study personnel.

POTENTIAL BENEFITS

The information collected in this study may help you and the OTs who work with your child better understand when your child is aroused, and what may have caused it. Knowing your child's arousal may also help you and your child's OT to assist your child in regulating their arousal.

PAYMENT FOR PARTICIPATION

Your child will be given a $10 Target gift certificate or toy of equal value for completing 4 sessions wearing the sweatbands. Your child will receive the gift card or toy whether or not all sessions are completed.

CONFIDENTIALITY

Any information that is obtained in connection with this study and that can be identified with you or your child will remain confidential and will be disclosed only with your permission or as required by law. Videotapes and/or audiotapes of your child's participation may be collected. This data will be used for experimental purposes only and will be archived in a password protected, secure network at the Media Lab. Portions of this record may be published and/or presented in scientific journals and/or in scientific conference proceedings. Further, no information, such as name, address, or other private information will be included in these presentations or publications. Apart from this possible usage, such data will only be viewed/used for research and educational purposes. At any time during or after the study you may request to review or edit your child's tapes and/or request that his/her tapes be destroyed.

IDENTIFICATION OF INVESTIGATORS

If you have any questions or concerns about the research, please feel free to contact, Dr. Rosalind Picard, Principal Investigator (617)253-0611, Elliott Hedman, Co-Principal Investigator (970)389-3047, or Lucy J. Miller (303)794-1182.

EMERGENCY CARE AND COMPENSATION FOR INJURY

If you feel your child has suffered an injury, which may include emotional trauma, as a result of participating in this study, please contact the person in charge of the study as soon as possible. In the event your child suffers such an injury, M.I.T. may provide itself, or arrange for the provision of, emergency transport or medical treatment, including emergency treatment and follow-up care, as needed, or reimbursement for such medical services. M.I.T. does not provide any other form of compensation for injury. In any case, neither the offer to provide medical assistance, nor the actual provision of medical services shall be considered an admission of fault or acceptance of liability. Questions regarding this policy may be directed to MIT's Insurance Office, (617) 253-2823. Your insurance carrier may be billed for the cost of emergency transport or medical treatment, if such services are determined not to be directly related to your child's participation in this study.

RIGHTS OF RESEARCH PARTICIPANTS

You are not waiving any legal claims, rights or remedies because of your or your child's participation in this research study. If you feel you or your child has been treated unfairly, or you have questions regarding you or your child's rights as a research subject, you may contact the Chairman of the Committee on the Use of Humans as Experimental Subjects, M.I.T., Room E25-143B, 77 Massachusetts Ave, Cambridge, MA 02139, phone 1-617-253 6787.

SIGNATURE OF RESEARCH SUBJECT OR LEGAL REPRESENTATIVE

I understand the procedures described above. My questions have been answered to my satisfaction, and I agree to have my child participate in this study. I have been given a copy of this form.

____

Name of Child

____

Name of Legal Representative (if applicable)

____ _______________

Signature of Subject or Legal Representative Date

SIGNATURE OF INVESTIGATOR

In my judgment the subject is voluntarily and knowingly giving informed consent and possesses the legal capacity to give informed consent to have his or her child participate in this research study.

____ ______________

Signature of Investigator Date

Appendix D – Select Code

This function removes noise spikes when measuring EDA. In the future programmers can use this code to filter out noise from EDA sensors that may be subject to movement artifacts. The program is written for Matlab, but can easily be adapted.

```
function [t1,e1,killIndex]=removeTheDipsv3(time1,eda1);

%adjust these parameters to change filter
threshold=.9;
bump=8;

%EDA and Time do not need to be received at a constant rate
e1=eda1;
t1=time1;

%i=index for comparison
i=2;
%killCirc contains data not used
killCirc=[];
killCircTime=[];

%KillIndex keeps track of data that has not been removed
killIndex=1:length(eda1);

%move through the entire EDA signal
while i<length(e1)-bump
 A=e1(i);
 killed=false;

 %If the value before * threshold is still greater than the current
 if e1(i-1)*threshold>A
  for j=1:bump
   %and one of the values in the next 'bump' after is also greater
   if e1(i+j)*threshold>A && ~killed
    %remove this point
    killCirc=[killCirc A];
    killCircTime=[killCircTime t1(i)];
    e1(i)=[];
    t1(i)=[];
    killIndex(i)=[];
    killed=true;
   end
  end
 end
 %if you didn't remove the point, go to the next time
```

```
 if ~killed
  i=i+1;
 end
end



%this itteration is the same, but catches points that spike up
i=2;
threshold=1.2;
while i<length(e1)-bump
 A=e1(i);
 killed=false;
 if e1(i-1)*threshold<A
  for j=1:bump
   if e1(i+j)*threshold<A && ~killed
    killCirc=[killCirc A];
    killCircTime=[killCircTime t1(i)];
    e1(i)=[];
    t1(i)=[];
    killIndex(i)=[];
    killed=true;
   end
  end
 end
 if ~killed
  i=i+1;
 end
end
```