

MEASURING AUTONOMIC AROUSAL DURING THERAPY

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ABSTRACT

How can measuring children's Electrodermal Activity (EDA) help improve the design of an occupational therapy experience? Twenty-two children with sensory challenges such as Autism and ADHD participated in the study. Children attended occupational therapy as usual, while their physiological arousal (i.e., EDA) was measured with a wireless device on the bottom calf. Combining the EDA signal with video, researchers could better understand the emotional experience of therapy. All 22 children were able to wear the portable EDA sensors throughout the vigorous activities with minimal impact. Five insights generated from these observations are described in detail, with emphasis on how therapists used the findings to re-design their therapeutic process. This paper demonstrates how the ambulatory measurement of EDA can directly help with the emotional design of therapeutic services.

Keywords: Methodology, Psychophysiology, Experience Design, Service, Children

INTRODUCTION

After climbing on a six-foot high rock wall, Scott was lying on the ground. The therapist asked Scott if he was ready for the next activity. He replied that he didn't want to and that he would rather go to lunch. His therapist predicted that Scott had a low amount of energy, and needed to be "woken up" so he could better participate in therapy. She continued to try and excite and motivate Scott, with little improvement. To

help increase Scott's arousal, the therapist prepared Scott to ride a zip line and drop into a ball-pit.

While on the zip line, Scott still appeared outwardly drowsy and unmotivated, asking if he could leave for lunch. The therapist turned to the researchers and said, "I bet you see his arousal is real low right now." Strangely enough, we saw Scott's physiology was opposite of what the therapist believed. Watching Scott's electrodermal activity, we saw that his physiological arousal was at an all-time high; he was autonomically overwhelmed, and was probably trying to cope by outwardly shutting out new stressful stimuli. When the therapist saw how the therapy was affecting Scott's physiological arousal, she immediately re-designed the therapy for Scott, making a better emotional experience.

Children with Autism, ADHD, or other sensory challenges can often times be overwhelmed during new experiences, where they may become out of control. In our studies, we have observed children losing the ability to speak, running out of the therapy rooms, and hitting other children. For occupational therapists, helping children remain emotionally regulated is an important goal of therapy (Parham and Mailloux, 2001). To achieve an optimal arousal level, a primary focus of therapy is helping children achieve a "calm but alert" state before working on specific skills (Kimball, 1999). Based on the work of Hebb (1949, 1955), the importance of achieving an optimal level of arousal is linked to achieving a maximal level of performance, as over- or under-arousal is postulated to have a direct negative relationship with performance. An optimal level of arousal maximizes

the opportunity for a child to observe and process information needed for cognitive and other executive functions (Greenspan & Wieder, 2008). In order to help children better obtain an optimal level of arousal, therapists often employ different methods to either decrease or increase arousal. How could therapists improve these methods to help better calm or excite children?

The first step in answering design questions like above is to observe the current reality (Dubberly & Evenson, 2008): what is the current emotional response to therapeutic methods? This paper looks at improving the observation of emotions: how can designers better observe children's autonomic (internal) arousal, which can then inspire what "could be".

Below, we show how observing children's physiological arousal can directly inform design. While these findings are focused on creating a better emotional experience in occupational therapy, the method and results can be transferred to other service settings where people's arousal level is important.

OBSERVING CHILDREN'S AROUSAL IN THERAPY

The typical way to measure a person's arousal is to conduct a survey or interview (e.g. Thayer, 1967). Children, in particular, have challenges expressing their emotions verbally (Ammentorp et al., 2006). In addition, some children in occupational therapy have an even harder time describing their emotions. For example, many children diagnosed with Autism Spectrum Disorders (ASD) have challenges both identifying and describing their emotional state (Hill, Berthoz, & Frith, 2004).

An alternative method of observing arousal, used by therapists, is to observe children's behavioral cues. When children become overwhelmed, their behavior can change: a child hiding under a table, unable to speak, suggests she may have a higher arousal. But beyond the extremes, determining when and how much a child's arousal changes with each intervention is difficult. We have seen in our research that visible behavioral cues do not always match the child's internal arousal: a child may be sitting still and looking

calm while his or her physiological arousal is high or is increasing dramatically. The difference between outward behavior and internal arousal is likely a result of many individual differences. Such individual differences can make inferring physiological arousal states via behavioral observation imprecise.

A more direct way to assess physiological arousal is to measure biological signals. As one becomes aroused, the sympathetic nervous system activates. Many measureable biological signals change with sympathetic activation including electrodermal activity, blood pressure, heart rate, and pupil dilation. Electrodermal activity (EDA) is a measure of sweat excreted by the eccrine glands, which are innervated by the sympathetic nervous system (Goodall, 1970; Dawson et al., 2000). Thus, measures of EDA are frequently used as an indicator of changes in sympathetic arousal.

EDA has been used in previous design research (e.g., Mahlke & Thuring, 2007). However, these studies are often conducted in a controlled laboratory, looking at emotional responses to a product, rather than a service. In addition, design researchers have noted that having a participant tethered to a computer, with sticky electrodes will often in itself change the emotional experience (Lemos, 2008). This novelty of the sensors can further increase arousal for children with sensory issues, as having to sit still and wear a new device on the skin can be overwhelming (e.g., Goodwin et al., 2006)

For this research, a newly developed and validated measurement system, iCalm, was used to record EDA wirelessly in therapy (Fletcher et al., 2010). The sensor can be worn in a way that does not interfere with activity. Children could participate in therapy as usual while physiological arousal data was collected, typically without the child's awareness of the data collection after the first few minutes. The iCalm sensor uses 1.5 mm Ag-AgCl electrodes without gel and has been used in previous in-situ studies: employee's stress (Hernandez et al., 2011), mother's frustration at learning games (Hedman, 2011), children with epilepsy's likelihood of having a seizure (Poh et al, 2010), and people's sleep patterns (Sano & Picard,



Figure 1. Child Wearing iCalm during Occupational Therapy. The iCalm sensor was housed in the black sweatbands on the child's legs. Children were able to wear the iCalm sensors with minimal distraction during therapy.

2011) have all utilized iCalm or a similar commercial version.

EDA is traditionally measured on the palm, fingers, or soles of the feet (Edelberg, 1967; Venables & Christie, 1980). For this experiment, children wore the sensors inside a snug sweatband on the bottom of the calf. In this location minimal movement of the sensor occurred even when the children twisted and moved their feet. Phillips Research suggests that the EDA measured from the bottom of the calf and EDA from the palm moderately correlated for adults ($r = 0.496$, $n = 17$). These measurements were ipsilateral, and stimuli were video clips aimed at inducing different emotional states (van Dooren et al., in prep.).

PROCEDURE

Twenty-two children and their therapists participated in the study. All children were already attending the STAR Center in Colorado, which specialized in helping children with Sensory Processing Disorder. The original research goal of the study was to develop an understanding of how occupational therapy affected children's physiological arousal.

Children arrived 15 minutes prior to their OT session and put the iCalm sensors on upon arrival, allowing

time for the sensors to acclimate. One research assistant videotaped the therapy session and one research assistant monitored data collection from the wireless sensors on a portable PC laptop. To increase the likelihood of recording reliable EDA, data were collected from both legs in case the children's activity caused more motion artifacts in one or the other leg's sensors. In these case studies, only one sensor's data are shown to make interpretation easier, but most of the time, the two signals showed similar patterns.

In the 77 hours of sessions with recorded video and EDA, children participated in many different therapeutic activities. Therapists helped us interpret and re-design therapy within a participatory design context (Schuler & Namioka, 1993). As the EDA was recorded live, we often showed the therapists the recordings during therapy. Afterwards, videos of the children in therapy were combined with their EDA, so that therapists could re-watch the therapy session and better understand how therapeutic methods and EDA corresponded. Many insights were derived through this process about how therapy affects children's physiological arousal. In the Design Insights section, we highlight five insights that each led to a direct change in how therapy was conducted at the STAR center. These insights are evidence that the

measurement of ambulatory EDA can be a useful tool for designing better occupational therapy experiences.

RESULTS

FEASIBILITY

As Lemos noted, there is often a concern that measuring EDA from a subject will have a large emotional impact, making ambulatory measurements of EDA impractical (2008). In our pre-trial of the tool, we had children wear iCalm on the wrist. With the seven children wearing the sensor on the wrist, we did notice a large emotional impact: most children asked for the sensor to be removed. Others would stare at the sensor on their wrist, instead of paying attention to the therapist or activity at hand.

Moving the sensor to the bottom of the calf considerably reduced this emotional impact. Children treated the sensors like socks putting them on with minimal resistance. During the therapy, the sensors were out of the children's eyesight so the children did not focus or look at them. Additionally, the children never appeared to bend down to adjust their sensors. Afterwards, some children would forget to take the sensors off as they left, and the therapists would need to remind them to remove the sensors. These results were remarkable, considering that many of these children were extra sensitive to touch (one child refused to wear underwear), and, yet, all the children wore the sensor on the leg with minimal distraction.

However, one child did leave the study as the therapist felt having other researchers in the room (with camera and notebook) caused the child to act out. This event serves to remind us that observing children with a researcher or camera can also have an emotional impact at times (Wrigley et al., 2010).

DESIGN INSIGHTS

From the 77 hours of observed therapy and the corresponding EDA, many insights were generated about how therapy and EDA interact. However, for this paper, only the insights that therapists used to re-design their therapeutic process are presented.

Arousal Fluctuates for a Child with Autism

Sandy (all names are pseudonyms) is a six-year-old child with autism spectrum disorder who could speak in two to three word sentences. During her therapy, Sandy was presented with two challenges that created anxiety for her (Figure 2). In the first occasion, Sandy's EDA increased upon seeing a tunnel in the ball-pit. The therapist explained to us that for Sandy, having the equipment out of its original setting can often be frustrating.

During another time in the therapy, Sandy's arousal increased as she anticipated climbing onto an elevated swing. Once again, Sandy's EDA increased during this emotional experience. Afterwards, the therapist explained to us that Sandy has challenges with motor planning, and she was likely becoming anxious climbing onto the swing.

In addition to better understanding the points that create anxiety, we also observed times when therapeutic processes helped Sandy reduce her arousal. For example, both times when Sandy lay in the ball-pit, we saw her EDA decrease.

The therapist was partially aware of how these therapeutic events would affect Sandy, but with the additional objective EDA measurement, she was more confident about how therapy affected Sandy in future sessions. These types of insights were found in almost every therapy session.

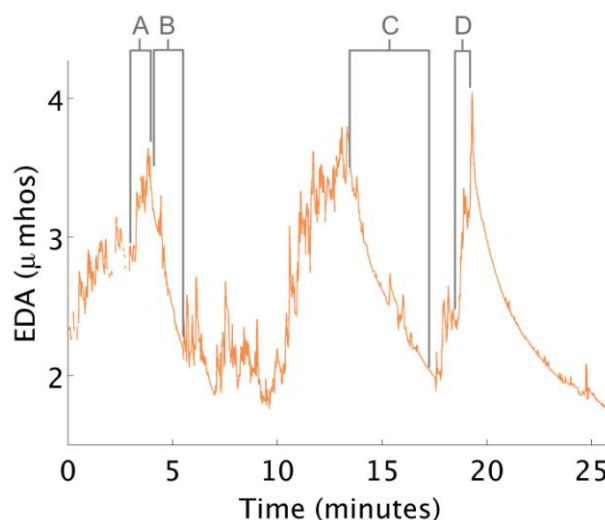


Figure 2. Sandy's EDA changed during therapy. (A) Sandy responds to a tunnel in the ball-pit. (B,C) Sandy lies in the ball pit. (D) Sandy anticipates climbing onto a swing.

Arousal Increases with Rolling on a Scooterboard

At other times, EDA changed opposite of what the therapists expected. At the STAR center, therapists often attempted to lower children's arousal by having the children pull themselves on a scooter board. When children pulled themselves on the scooter board, we consistently saw large increases in physiological arousal, the opposite of what therapists intended (Figure 3). Upon showing this information to the therapists, some therapists redesigned their future therapy sessions to not include scooter boards for activities in which they were attempting to calm children down.

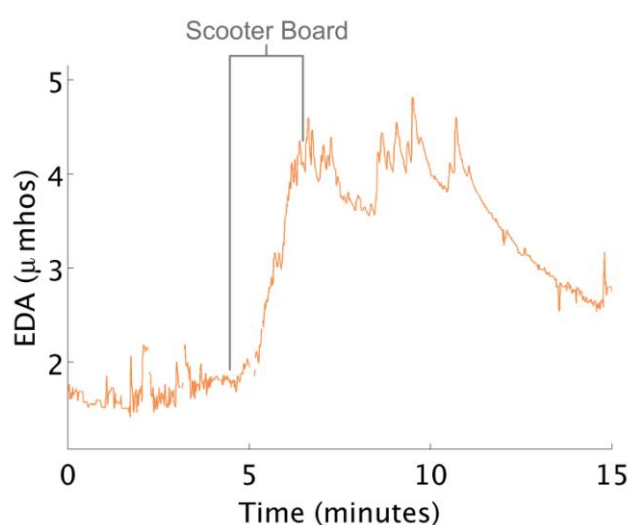


Figure 3. Contrary to therapist's beliefs, children's EDA often increased while using the scooter board to transition to different activities.

A Child's Arousal Decreases with Sitting

We also identified parts of therapy in which arousal surprisingly decreased. One child, Anna, was over-sensitive with touch, taste, sound, and smell. Often when Anna was asked to eat food or smell strong scents she would become overwhelmed, as could be observed by her behavior. Anna had such trouble eating that she had to consume most foods via a tube in her stomach.

On a special day in therapy, the therapist allowed Anna to paint a tile to place on the STAR center wall. This activity was not meant to affect Anna's arousal. Yet, we noticed that Anna's EDA decreased to a level lower than any other time in therapy (Figure 4). The therapist was surprised by this result and wondered if she could use this knowledge to help Anna eat food.

Later on in the therapy session, the therapist had Anna sit in a small room and paint with pudding on a sheet of paper. At times, Anna licked her pudding-covered fingers. Like painting, Anna's EDA continued to decrease and she did not appear overwhelmed, despite having food present.

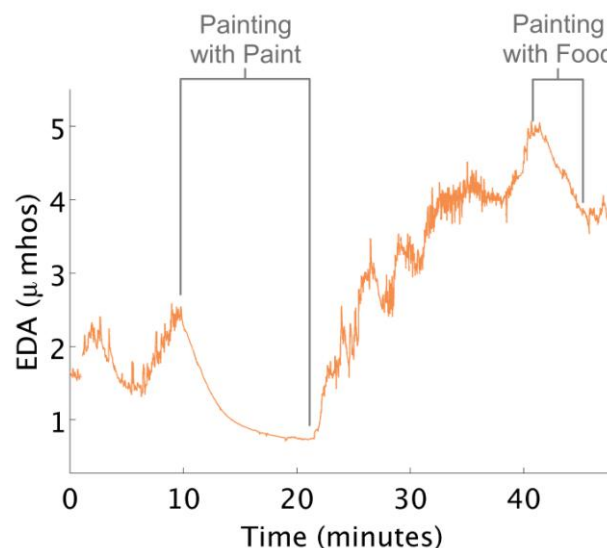


Figure 4. We discovered that Anna's EDA decreased while painting. Using this knowledge, the therapist designed an activity where Anna painted with food. Eating food often is overwhelming for Anna, yet her EDA decreased while she painted with her food.

Active Listening Can Excite Children

While the above examples were about preventing children from being over-aroused, at times children in occupational therapy can be under-aroused as well. In these cases, children behave tired and inattentive. They may struggle to pay attention to a task and may not be enthusiastic at the task at hand. When children's arousal is too low, having an effective therapy can become challenging.

We observed many cases where children started off therapy with very low EDA (often times in the early morning sessions). We then observed therapists attempting to increase the child's arousal in many different ways. For example, Kara, a young girl with autism spectrum disorder and limited verbal abilities, attended an early session of therapy where she appeared tired. The therapist tried many activities (Figure 5). Playing in the ball-pit, swinging on a bolster swing, crawling through a tunnel, and jumping on a trampoline all appeared to have minimal to no effect in increasing Kara's physiological arousal. But near the end of the session, the therapist mentioned to Kara that they were going to do Listening Actives. In

Listening Actives the child wears earphones and listens to herself talk. When Kara began Listening Actives, her EDA spiked up.

We showed this data to Kara's therapist, and she was quite surprised at the results. Listening Actives was a separate activity from normal therapy, and was not used as a means to regulate children's arousal. We continued to see this pattern of increased arousal during Listening Actives for multiple children.

Another child, Lizzy, was also under-aroused during therapy. Talking to the therapist about our findings with Active Listening, the therapist changed Lizzy's Active Listening from the end of therapy to the beginning of therapy. During that next session with the changed schedule, Lizzy's average EDA was higher.

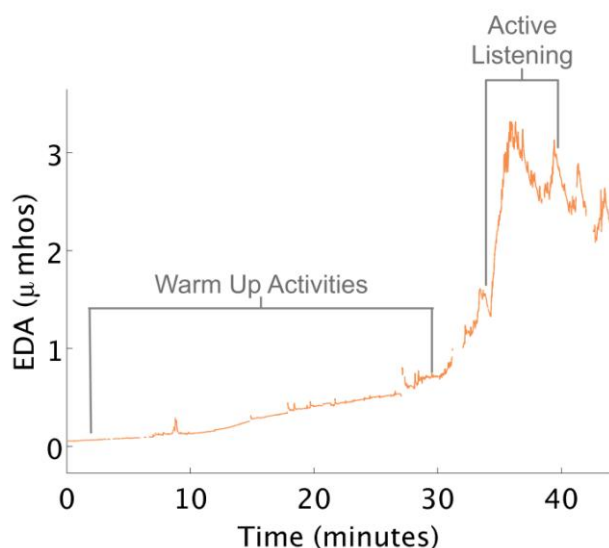


Figure 5. The therapist had Kara participate in a variety of activities to help energize her for therapy. None of these activities appeared to be successful. However, when Kara began Listening Actives, her EDA increased substantially.

Outside Behavior Can Differ from Internal Arousal

Returning to the introductory story, Scott's EDA was exceedingly high after rock climbing, but the therapist believed the opposite, Scott's arousal was too low (Figure 6). The therapist attempted to further increase Scott's arousal, and Scott continued to tell the therapist that he was bored and wanted to eat lunch.

We then explained to the therapist that Scott's physiological arousal was actually exceptionally high at the moment. Upon hearing this information, the therapist stopped her intervention. She explained that perhaps, for Scott, saying that he's hungry or bored is

his way of trying to calm down. She also hypothesized that he may have an oral fixation, and that is why he was stating he was hungry. The therapist went into a small kitchen area where Scott blew bubbles.

Afterwards, he chewed on gum. During both of these activities, Scott's EDA decreased back to the level before he was rock climbing. As a special note, Scott's EDA was measured on his wrist, as this session was conducted during the pre-study before the sweatband was moved to the ankle.

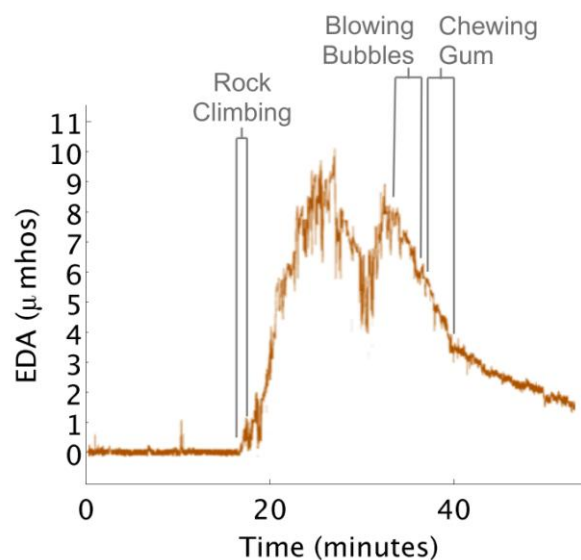


Figure 6. After rock climbing, Scott's EDA increased substantially but his therapist thought he was under aroused, judging by his behavior. After we told the therapist that Scott was actually over aroused, the therapist had Scott blow bubbles and chew gum. Both of these activities corresponded to a decrease in EDA.

CHALLENGES

While this paper is a first attempt to promote the measurement of ambulatory EDA as a way of conducting design research, limitations still exist. One of the larger challenges with these examples is that results are child specific. In Example 4, Anna's EDA decreased while painting. We cannot conclude that painting decreases all children's EDA, and it may be the case, that for some other children, painting may increase EDA.

On the other hand, some results began to appear generalizable. For all 5 children using scooter boards, an increase in EDA was consistently observed. Similarly, EDA increased at the beginning of active listening for 3 out of 4 children. Children's EDA responses may prove to be more predictable and generalizable with more trials. Furthermore, testing the extremes in design has also been shown to be a

strong method to generate insights (Dong et al., 2005). So, while not everyone may be bothered by climbing onto a swing as much as Sandy was in Example 1, making the swing easier to approach may be a benefit to many children, though possibly not to the same degree as for Sandy.

A second challenge to measuring ambulatory EDA is determining the cause of increases and decreases. In Example 2, it is unclear whether the children's physiological arousal increased because of the child's body position and hard work (Pugh, 1966), the emotional challenge of transitioning to a new activity, an unknown factor, or a combination of all these factors. This challenge persists across other similar methods that use outside observation as a means to understand emotion. For the examples above, even when the exact cause may not be identified, the negative events could still be mitigated: for example, using the scooter board was still avoided, despite not knowing how the scooter board increased physiological arousal.

Finally, an increase in arousal does not describe the complete story of an emotional experience. Whether a child is excited, anxious, frustrated, etc. cannot be determined with EDA alone (Lang et al., 1998). To have a complete understanding of a person's emotional state, a researcher must infer additional information from video observations, interviews, and more. That said, as modulating arousal is a direct goal within occupational therapy, EDA can often be enough information. For example, when children participated in Active Listening in Example 3, it was not clear whether the children were excited, anxious, or a combination of both when participating, and yet, the observations we provided still proved useful from a design perspective for modifying the therapy.

CONCLUSION AND FUTURE WORK

Overall, this paper shows that the ambulatory EDA of children with sensory challenges can be measured with minimal interference. These five examples show that by measuring ambulatory EDA, occupational therapists are able to design better therapeutic services. Therapists were able to better understand how children become over-aroused and what helped children calm down in therapy. From these generated

insights, therapists were able to directly design better therapeutic experiences for the children. We showed how some of these changes affected the children's state of arousal.

Traditionally, design research has focused on group averages and mean differences. Future psychophysiology and design work should take into account the diversity of emotional responses different individuals can have: some children tended to have too low arousal; others tended to have too high. A ball-pit helped some children calm down, while excited others. As shown, each individual has his or her own perception to therapy, which directly leads to unique emotional responses. Rather than attempting to erase or control for these differences, designers can appreciate and take advantage of the variety of emotional responses.

While this paper mainly focuses on therapy, the findings and results do transfer to design research in other service industries as well. What parts of flying an airline create anxiety, which designers may not even be aware of? How can buying a new cellphone be more relaxing? Any service where regulating a person's arousal has importance can benefit from observing individual's EDA in a natural setting. With this work, we also hope to see more therapeutic services actively observe children's physiological arousal as a means to design better therapy experiences.

REFERENCES

- Ammentorp, J., Mainz, J., & Sabroe, S. (2006). Kommunikation i sundhedsvæsenet—med fokus på den patientoplevede kvalitet hos voksne og børn/unge. *UGESKR LÆGER*, 168(40), 3437.
- Dawson, M. E., Schell, A. M., & Fillion, D. L. (2000). The electrodermal system. *Handbook of Psychophysiology*, 2, 200-223.
- Dong, H., Clarkson, P. J., Cassim, J., & Keates, S. (2005). Critical user forums—an effective user research method for inclusive design. *The Design Journal*, 8(2), 49-59.
- Dubberly, H., & Evenson, S. (2008). On modeling the analysis-synthesis bridge model. *Interactions*, 15(2), 57-61.
- Edelberg, R. (1967). Electrical properties of the skin. *Methods in Psychophysiology*, 1, 1-53.
- Fletcher, R. R., Dobson, K., Goodwin, M. S., Eydgahi, H., Wilder-Smith, O., Fernholz, D., . . . Picard, R. W. (2010). iCalm: Wearable sensor and network architecture for wirelessly communicating and logging autonomic activity. *Information Technology in Biomedicine, IEEE Transactions on*, 14(2), 215-223.

- Goodall, M. C. (1970). Innervation and inhibition of eccrine and apocrine sweating in man. *The Journal of Clinical Pharmacology*, 10(4), 235.
- Goodwin, M. S., Groden, J., Velicer, W. F., Lipsitt, L. P., Baron, M. G., Hofmann, S. G., & Groden, G. (2006). Cardiovascular arousal in individuals with autism. *Focus on Autism and Other Developmental Disabilities*, 21(2), 100-123.
- Greenspan, S. I., & Wieder, S. (2008). The interdisciplinary council on developmental and learning disorders diagnostic manual for infants and young Children—An overview. *Journal of the Canadian Academy of Child and Adolescent Psychiatry*, 17(2), 76.
- Hebb, D. O. (1949). The organisation of behaviour.
- Hebb, D. O. (1955). Drives and the CNS (conceptual nervous system). *Psychological Review*, 62(4), 243.
- Hedman, E. (2011). The frustration of learning monopoly: The emotional tension of entering a new game encounter. *The Ethnographic Praxis in Industry Conference*, Boulder. September 18-21.
- Hernandez, J., Morris, R., & Picard, R. (October 9-12, 2011). Call center stress recognition with person-specific models. *Affective Computing and Intelligent Interaction*, Memphis.
- Hill, E., Berthoz, S., & Frith, U. (2004). Brief report: Cognitive processing of own emotions in individuals with autistic spectrum disorder and in their relatives. *Journal of Autism and Developmental Disorders*, 34(2), 229-235.
- Kimball, J. (1999). Sensory integration frame of reference: Theoretical base, function/dysfunction continua, and guide to evaluation. *Frames of Reference for Pediatric Occupational Therapy*, , 119-125.
- Lang, P. J., Bradley, M. M., & Cuthbert, B. N. (1998). Emotion, motivation, and anxiety: Brain mechanisms and psychophysiology. *Biological Psychiatry*, 44(12), 1248-1263.
- Lemos, J. (2008). Measuring emotion and attention by analyzing eye properties. *Design Emotion Conference*, Hong Kong. , 6
- Mahlke, S., & Thüring, M. (2007). Studying antecedents of emotional experiences in interactive contexts. *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, 915-918.
- Miller, L. J., Anzalone, M. E., Lane, S. J., Cermak, S. A., & Osten, E. T. (2007). Concept evolution in sensory integration: A proposed nosology for diagnosis.
- Parham, L. D., & Mailloux, Z. (2001). Sensory integration. *Occupational Therapy for Children*, 4
- Poh, M. Z., Loddenkemper, T., Reinsberger, C., Swenson, N. C., Goyal, S., Madsen, J. R., & Picard, R. W. (December 3-7, 2010). Sympathetic changes associated with epileptic seizures. *Ann Meeting American Epilepsy Society*, San Antonio, TX.
- Pugh, L. A., Oldroyd, C. R., Ray, T. S., & Clark, M. L. (1966). Muscular effort and electrodermal responses. *Journal of Experimental Psychology*, 71(2), 241-248.
- Sano, A., & Picard, R. (2011). Toward a taxonomy of autonomic sleep patterns with electrodermal activity. *IEEE Engineering in Medicine and Biology Society Conference*, Boston.
- Schuler, D., & Namioka, A. (1993). *Participatory design: Principles and practices* CRC.
- Thayer, R. E. (1967). Measurement of activation through self-report. *Psychological Reports*,
- Van Dooren, M., De Vries, J. J. G., & Janssen, J. H. (in prep). Emotional skin conductance across the body: Comparing 16 different measurement locations. To be Submitted to *Physiology & Behavior*.
- Venables, P. H., & Christie, M. J. (1980). Electrodermal activity. *Techniques in Psychophysiology*, 54(56), 3.
- Wrigley, C., Gomez, R., & Popovic, V. (2010). The evaluation of qualitative methods selection in the field of design and emotion. *International Conference on Design & Emotion*,