ApEn: A Stress-Aware Pen for Children with Autism Spectrum Disorder

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Abstract. Children with Autism Spectrum disorder (ASD) often experience high levels of anxiety and stress. Many children with ASD have difficulty in being aware of their stress and communicating distress to family and caregivers. Stress detection and regulation are vital for their mental well-being. This paper presents a stress-aware pen (ApEn) that detects real-time stress-related behaviors and interacts with users with vibrotactile and light as a feedback indication of interpreted stress levels. ApEn is a context-aware tool for collecting behavioral data related to the expression of stress and can increase users' stress awareness. A pilot test was conducted with typical developed children to investigate how to detect stress in their daily environment. The pilot test results indicate that ApEn is a promising tool for detecting stress-related behaviors and can attend the user about the detected stress through designed sensory feedback.

Keywords: Smart everyday objects · Children with ASD · Stress detection

1 Introduction

Children with Autism Spectrum Disorder (ASD) have a higher prevalence of anxiety disorders and poorer stress management than in the general population [16]. They have difficulty in having sufficient awareness of stress and communicating their distress to family and caregivers [28]. Stress is extremely dangerous for children with ASD, since it can result in restrictive, repetitive behaviors, and even self-injurious behavior [28]. Therefore, timely stress detection and regulation are highly required for enhancing the well-being in children with ASD.

Devices for monitoring physiological signals (e.g. smart wristbands, and chest bands) are widely applied in stress research by children with ASD [2,6,12,28]. These devices often do not embody a potential of behavior change. In addition, the existing devices mostly monitor physiological responses that provide limited

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contextual information [19]. We argue that everyday objects that are already used in the daily life of children with ASD, can help unobtrusively detect stress from psychological, behavioral and environmental variables [7] and allow continuous and more accurate estimation and indication of stress [15,21,29].

Children with ASD often have a hard time staying focused on learning tasks, and thus stress is more noticeable during moments of learning. Therefore, stress detection during studying is important for children with ASD and their caregivers. Apen is therefore designed for monitoring stress in the natural learning environment. We explored which types of interactions with everyday objects were potential indicators of stress under the context. A stress-aware pen was introduced since there was a predicted correlation between the writing behavior and stress. Data were collected through a design probe - ApEn to find out "How an everyday object as a pen should detect and respond to stressful behaviors to increase the awareness of stress in children with ASD? ".

We conducted an exploratory experiment in typical developing children to investigate if ApEn can detect stress behavior and provide awareness of stress. It reveals the correlation between stress and pressure applied in writing and holding the pen. ApEn provided vibrotactile and light feedback to children's stress levels. The data from the pressure sensors was collected and the designed feedback was evaluated with children and their families.

2 Related Work

Stress Measurement. Stress can be classified into physiological stress and perceived stress. Physiological stress can be detected mainly in the physiological response of an individual, and perceived stress is based on mental appraisal and psychological response of an individual [25]. Physiological stress can be quantified from several biomarkers such as heart rate (HR), and heart rate variability(HRV) [22]. Perceived stress is often measured through periodical self-report collected from the individuals [25]. Perceived and physiological stress were shown to be correlated [6].

People respond to stress in different ways, physiologically, psychologically, and behaviorally [5]. Children exhibit a clear behavioral response under stress. The anxious behaviors can be observed in object manipulation(e.g. playing with an object) [5,8]. Research reports results on stress detection from behavioral data such as movements or activities [9,19] with sensors embedded in objects.

Smart and Interactive Everyday Objects. Previous research has identified several requirements for designing stress detection devices for children with ASD [12]. The device has to be a non-invasive [2]; it should be easy to use and easy to learn [20]; and, the cost of purchasing and maintaining the device should be affordable for families [28].

Everyday objects that we are comfortable and familiar to live with, such as a cup, a lightbulb, a table, etc. The way we interact with them does not require a new set of skills, and we don't have to learn new gestures, icons, color codes, and button combinations [23]. Those pervasive everyday objects can be used to collect stress related information through human-product interactions [14,17,18] in an unobtrusive way [23], to further help recognize stress situation and identify stressful behavior [19].

Behavior Study. Research has been conducted on evaluating which behaviors are associated with a pen when one feels anxious and stressed. The work of Bruns [5] found that pressure or force could indicate stress, and squeezing and pressing are predictors of stress while one interacts with a pen. Other studies [10,11] reported that more pressure was detected on handwriting when people are under stress. The above evidence leads us to measure the handwriting pressure, and the pressure applied on the body of the pen.

Feedback Exploration. Light effects are widely applied in the interaction design, with the purpose of informing, alerting also influencing human behaviors. Different light color and light patterns especially breathing light often applied in stress-related design [27,31]. The breathing light pattern is also implemented in the final design of an ApEn, in consonance with the levels of the detected pressure from the pen, for increasing users' stress awareness and influencing their behaviours. Vibrotactile effects has great value in passing on information [24]. A library called VibViz1 [24] has been built to reveal the possible interpretation from users depending on the intensity, duration, rhythm, and location of vibration signals. Based on the library, we selected and tested the vibration patterns for drawing attention and influencing behaviours for the final design.

3 Method and Design Process

We conducted interview with parent couples having a child with ASD. Three families with children with autism severity 1–2 [26] and age between 8–10 years old took part in the research. The interviews indicated that stress in children with autism is often noticed during studying. Sitting for a long time and focusing on study can be challenging and increase their stress level. The parents mentioned some typical stressful behaviors in children with ASD such as mumbling, shouting and some repetitive body movements. These stressful behaviors are often associated with some objects, such as a pen and an eraser. In the interviews the parents reported that children with ASD tend to put harder force on writing, and bend or squeeze the pen when they are under pressure. Parents think it is important but challenging for them to accompany children during studying activities while coping with children's stress timely, since it requires a great attention and a huge amount of time from the parents. Thus, we focus on detecting and regulating stress in children with ASD during their focusing time.

We followed a Research-through-Design process [13] that involved creation of a design probe, testing, data collection and analysis and a corresponding redesign of the design probe towards the final ApEn design.

4 Final Design

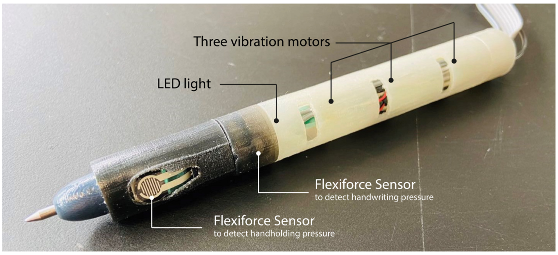

Fig. 1. Apen: the stress-aware pen.

The stress-aware pen(ApEn, as shown in Fig. 1) is designed to detect stress-related behaviors by sensing the handwriting and hand-holding pressure. Two Flexiforce sensors are embedded to detect pressure through the pen lead and the pen body. In order to draw children's attention to their stress-related behaviors, three vibration motors and one LED light are used to provide feedback, as Fig. 2(a) left side shows. In the ***feedback mode***, there are three thresholds set for handwriting and hand-holding pressure. When the average handwriting pressure is above threshold 1 for 10 s, the LED light turns on with blue color, and the vibration is growing gradually from low to high in one second. When the average handwriting pressure is above threshold 2 for 10 s or the hand-holding pressure is above threshold 3, the LED light turns red, and one vibration motor vibrates 3 times with a short duration and a strong intensity. The thresholds are calibrated according to the handwriting and hand-pressing habits of each user.

The other mode is the ***feedforward mode***, as Fig. 2(b) right side shows. It is designed not only for helping users be aware of stress but also for evaluating if ApEn can intervene and cope with stress. The breathing blue light changes the breathing rate depending on the different ranges of handwriting pressure. The higher the average pressure of handwriting is, the faster the light breathes. The maximum breathing rate of LED is once each two seconds that is within the average respiration rate of a child. In this way, the breathing rate of LED can not only indicate the stress levels but also be expected to influence users' respiration when users start to breath with it. In the meantime, when handwriting force is above the threshold 3, the vibration starts from the bottom vibration motor, moving to the middle one and then the top motor. With the vibrotactile guide on bottom-up direction, the users are expected to adapt their handwriting behavior, for example, lifting hands from writing when the high pressure is detected. The pen also reacts to handholding pressure in real-time when above threshold 4, with a short and intensive vibration to alert users.

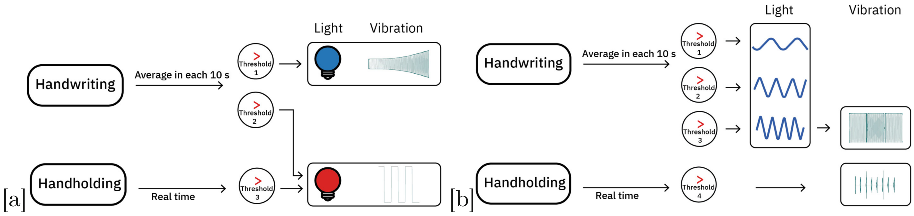

Fig. 2. The feedback mode of the stress-aware pen (a). The feedforward mode of the stress-aware pen (b).

5 Experiments

Participants. Three parent couples of in total four typical developing children (age 7–10 years, two girls and two boys) were included. The child participant with one of their parents joined in the experiment. The children from these three families all experienced stressful situations in studying.

Experiment Design and Data Collection. Stress detection experiments are often designed in the laboratory with inducing stress deliberately [9]. Since stress is less common and distinct in real life [9] to be detected in short time experiments and the physiological measurement is easy to be disturbed in the field experiments [9]. Therefore, our experiments in the field were designed similar to laboratory experiments, with structured context containing potential stressors.

The experiments were done in the context of studying at participants' home. In order to conduct experiments in the field, the context of the experiment needs to be personalized depending on each child's educational background in order to induce potential stress. To do so, studying tasks consisting of mathematic and linguistic questions for each child were prepared from easy to hard level depending on their educational progress. For motivation and pressure consideration, a reward was promised to all children if they finished the tasks on time with a certain accuracy.

The data collected in the experiments consist of psychological, physiological, and behavioural data. The physiological data were collected by parents via self-assessment manikin(SAM) [4]; physiological data, including HR and BVP, was captured using an E4 wristband equipped with sensors. ApEn detected the real-time behavioural data in terms of handwriting and hand-holding pressure. Additionally, video was recorded during each experiment to provide additional insights of the user behavior and the contextual information.

Procedure. Before the experiment, each child participant was asked to try out ApEn with their normal and high pressure to calibrate the thresholds. Each experiment consisted of two sessions: the feedback and the feedforward sessions. When the experiment started, the children were asked to wear the E4 wristband

and use ApEn to finish the prepared tasks independently. Each session took up to 20 mins. The children had a 10 mins break between the two sessions to reduce the possibility of accumulated stress interfering with the second session. Parents were requested to stay beside the children only to annotate their children's emotions using the SAM form once every 5 mins. When the experiment ended, Parents were interviewed by the facilitator to reflect on the experiment and the use of ApEn.

6 Results

Stress and the Corresponding Behaviors. The experiments were carried out without fully controlled stressors, however, the study needed to have an objective evidence of aroused stress. Physiological data specially HRV allows the reliable identification of stressful events [3]. Thus, HRV was calculated. It was analyzed from photoplethysmography (PPG) data from the E4 wristband using Kubios [1] in MatLab.

The detected stress from HRV of one of the children during feedback session shows an abrupt change in mean HR between 7 to 13 minuses after the experiment started. Correspondingly, Fig. 3 shows that pressure data in handwriting and hand-holding had an elevation, and feedback (light and vibration) was given by ApEn a few times during the same time slot. Simultaneously, parent marked a raise (from level one to level two) in arousal index in SAM form during 5–10 minuses and it stayed at level two till the end of the next time slot. There was only one stress event detected among all participants' physiological data. Moreover, the pressure signals from force sensors dropped every time after feedback given by the pen, as shown in Fig. 3.

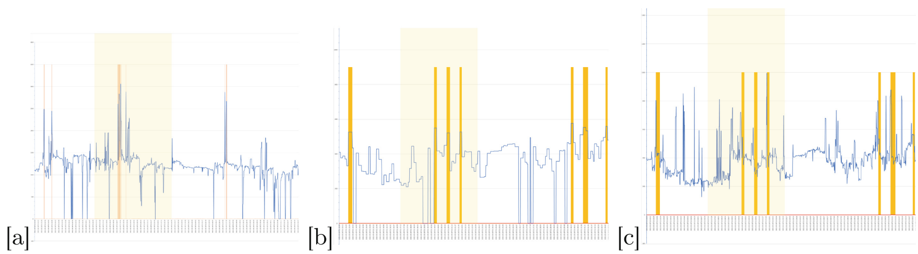

Fig. 3. Handholding (a), Handwriting average every 10 s (b), and real time (c) pressure of one of the children in feedback session (in blue). Orange column is when feedback is given. Light yellow space is a marked growth in arousal (SAM). (Color figure online)

Observed Stress and the Corresponding Behaviors. Besides detected stress in physiological data, stress was also marked in one of the parents' annotation and observed from video footage and the handwriting of her child. Figure 4

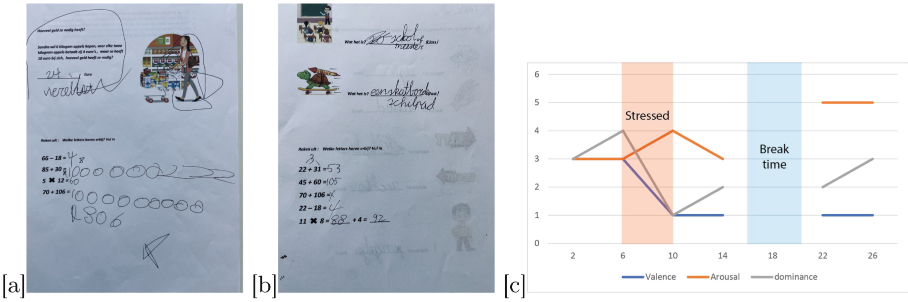

Fig. 4. Handwriting at stress moments (a) as observed by the parents and Handwriting without noticed stress (b). Data Visualization of one participant's SAM (c), the red period was "stressed" moment between 4 to 10 mins after feedback session started, and the empty area was during the break without annotation data.

(a) and (b) shows the comparison between the child's handwriting with and without stress. The detected stress moments are based on the stress assessment by the parent in (c) Fig. 4. The handwriting shows more aggression and strength on (a) comparing to (b).

User Experience with ApEn. We collected user experience feedback from the parents and children. First, the vibration feedback was sensed well by the children, also noticed by parents in general. For example, a child mentioned: "After vibration happens, I relaxed my fingers or re-positioned my fingers on the pen." Second, regarding the light feedback, both parents and children could notice the light and the color change in the feedback session without putting too much attention on it.

7 Discussion

Potential Difference in Stress Responses of Children with ASD. Physiological measures such as skin conductance and heart rate variability are common indication for stress [28]. Therefore, we can expect a lower HRV by the children with ASD during testing the ApEn. The expressions of stress behaviors in children without ASD in this study could be different from children with ASD. The reason to conduct experiments with typically developing children is to avoid potential risks to the vulnerable group of children with ASD at this early stage of research. We expected that even behavioral expression of stress could differ by children with and without ASD, physiological expression are similar and it is possible to gain valuable insights on the research questions and provide input and benchmark for the next steps. Further research needs to be done with the target group.

Exploratory Study. The exploratory experiments were done at participants' home. There was no direct evidence that stress did arise in children during the experiments in this study since stress is a subjective feeling. All stress related data collected from experiments only indicates stress, but this was not validated since we were not allowed to ask the children about their stress levels. The explorative study shows the indication that the change of handwriting and hand-holding pressure can be related to stress.

Bias in User Experience. The thresholds of triggering different types of feedback were set only based on each child's short time calibration. In general, to make sure giving the same user experience to every participant and study the effect of the feedback, it requires more calibration for better thresholds, or instead of thresholding, more advanced machine learning to detect stress patterns. This study is exploratory and the focus is not user experience or stress reduction, but the forms of sensory feedback in raising awareness of stress in children. Nevertheless, we should still consider the potential bias in users' feedback.

Future Work. Firstly, ASD is a heterogeneous condition. The profile of each child or adult with ASD is unique. Thus, a personalized system needs to be built to learn behavioral patterns from daily life. Also, physiological data can be used not only for detecting stress events but also for designing biofeedback [30] to increase stress awareness to cope with stress. The ultimate goal of this research is to intervene and help children's stress reduction. Social support from family and people around children with ASD is essential to cope with their stress, so their stress can be managed with external assistance in time. Enhancing ApEn to a connected object can contribute to data collection for the daily-based or clinical assessment on stress. Ultimately, involving ApEn to an IoT system that enables children, caregivers and clinics can work together on data collection and stress coping strategy is a promising direction for stress detection and regulation in children with ASD.

8 Conclusion

This research aims to study stress-related behaviors in the natural environment and explore how to enhance everyday objects for stress detection and regulation. The results indicate that the relation of children's interaction with Apen with their stress. There is a great potential to learn children's stress from their interaction with everyday objects. Although the design focus is on children with ASD, ApEn can be applied for different scenarios. For example, ApEn can be used for clinical research in assessing children's stress level. ApEn can also support children with stress regulation when they have heavy study load at school. This paper offers an example of enhancing everyday objects to support stress detection and insights on intervening in stress. Based on the preliminary results, further design can explore how to make the pen as a connected object to better support stress detection and reduction.

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