Exploring stress detection and management with an everyday object for children with Autism Spectrum Disorder

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Abstract
Children with ASD often experience high levels of anxiety and stress problems that can cause some well-known phycological disorders. Many children with ASD have difficulty in being aware of their stress and communicating distress to family and caregivers. Thus, stress detection and management are vital for keeping mental and emotional well-being in children with ASD as well as their families. This paper presents the stress-aware pen that detects real-time stress-related behaviors and offers vibrotactile and light feedback regarding interpreted stress levels. It is a context-aware design from enhancing an everyday object aiming to detect behavioral data in terms of stress and increase users' stress awareness. The prototype has been tested with four children without ASD in field experiments. And preliminary results have shown that the pen is capable of detecting stress-related behaviors and capture the user's attention with designed sensory feedbacks.

Author Keywords
Everyday objects; Stress detection; Children with ASD; Connected objects; Internet of Things(IoT); Home Systems of Smart Things; context-aware design.

1. Introduction
1.1 Background
1.1.1 Stress in children with ASD
Children with Autism Spectrum Disorder (ASD) overall have a higher prevalence of anxiety disorders and poorer stress management than in the general population(Merikangas et al., 2010). Since the neuro-deficits in reciprocal social interactions and communication skills in children with ASD(Taj-Eldin et al., 2018), they have difficulty in awareness of stress and communication distress to family and caregivers, and these are impediments to perceiving and managing emotional dysregulation(Goodwin et al., 2018; Sappok et al., 2014). Accompanied by challenging behaviors , often like restrictive and repetitive behaviors, even self-injurious behavior(Taj-Eldin et al., 2018), stress is extremely dangerous for children with ASD. Moreover, high levels of stress and long-term pressure can worsen the autism disorder to developing some severe psychological disorders such as anxiety and depression, along with seizures, panic attacks and other harmful behaviors to their surroundings. Therefore, timely stress detection and management are highly required for enhancing healthcare in children with ASD.

1.1.2 Stress and Measurement
Stress is categorized into three types including acute stress, episodic acute stress and chronic stress(Bakker et al., 2011). Acute stress and episodic acute stress last for a short period, making people anxious and frightened(Gul Airij et al., n.d.). Chronic stress lasts longer than the other two types of stress, and can be occurred as the long-standing pressures or the accumulating of a lot of short-term stress(Can et al., 2019).

Depending on the stress reaction, stress also can be classified into physiological stress that can be detected in the physiological response of an individual and perceived stress that is based on mental appraisal and psychological response of an individual(Sharawi et al., 2008). Physiological stress has been quantified from several biomarkers such as: the heart rate (HR), the hate rate variability(HRV), the skin conductance(EDA), the blood pressure (BP)(Picard, 2003).

Perceived stress often be measured with a clinical approach such as: a periodical self-report collected from the individuals(Sharawi et al., 2008). Psychological stress has more collective context from the perspective of data collection, but it is highly subjective that results in low availability and low credibility(Bolger et al., 2003). Nevertheless, researchers believe there are coherency between psychological stress and physiological stress(Can et al., 2019).

People respond to stress in different ways, physiologically, psychologically, and behaviorally(Hekkert, P.P.M. et al., 2010). Significantly，children appear to exhibit a clear behavioral response under stress. One of the anxious behaviors is object manipulation(e.g. playing with an object) (Fleege et al., 1992). Therefore, the embedding of sensors in these related objects could detect stress-related behaviors, providing interpretation on stress levels in relation to the object manipulation is accessible(Hekkert, P.P.M. et al., 2010).

1.2 Design challenge

To detect stress/anxiety in children with ASD, researchers have been using various techniques including measuring physiological and psychological stress(Hufnagel et al., 2017). Conventional biomarkers of stress are in blood volume pulse(PPG), skin conductance(EDA), and electroencephalogram(EEG), the sensors and the equipment associated with collecting these data are intrusive and not able to detect stress in real-time(Taj-Eldin et al., 2018).

Most of products indicate stress of an individual based on singles such as HR, HRV, respiration, or electro-dermal activity. However, any of them alone cannot detect stress accurately(Gul Airij et al., n.d.). Also, for some physiological signals like HR and respiration, different activities such as exercising，changes in environmental conditions and different emotions can result in similar signals as a stressful state(Can et al., 2019). Hence, differentiation of real life context is an open research problem.

However, there is a limited amount of products that are specially designed for children with ASD to detect their stress. The current commercial devices are often devoid of detecting stress since lacking for context in daily life(Can et al., 2019). Because of the abovementioned unresolved challenges of daily life stress monitoring, it remains an open space for designers and researchers to explore new design solutions.

1.3 Design space

With the ubiquity of the Internet of Things (IoT), it may be feasible to use connected everyday devices for detecting stress. Everyday objects, from the daily life of children with ASD, have the non-invasive trait and high usability that can help detect stress without being conscious or noticed by users.

On the other hand, to build a context-aware system and detect stress accurately, a design solution should not only monitor stress from physiological signals, but also detect psychological and environmental variables(Carr & Durand, 1985) for analysing behaviours related to stress(Marvar et al., 2012; Parlak et al., 2018; Tonhajzerova et al., 2016).

Koo et al.(Koo et al., 2018) reported in their research that one of the most common challenges for children with ASD is being aware of their growing stress and controlling their anxiety and anxious behaviour. Also, they found from their survey that parents or caregivers of children with ASD prefer a stress detection device that can aid awareness and management. In this way, parents and caregivers can understand children's stress level so they can cope with it in time.

It is shown the similar concerns to stress awareness from our interview finding with 3 families having a child with ASD. Families often asked for stress detection devices that give them alerts when stressful signals are detected.

According to the aforementioned requirements, the design solution can be single or multiple pervasive everyday objects for detecting stress and helping increase stress awareness of users in the meantime. The object is likely to be connected and be embedded with sensors to detect stress signals with a rich context.

1.4 Design context and Research questions

Changes happen all the time during Covid-19 pandemic. Children with ASD feel overwhelmed by the changes in their routine and the changes in social interaction. Children have hard time on concentrating or staying on tasks, the restriction on activity and social interaction also brought difficulties for distance learning in children with ASD. It has been reported from families that their children with ASD often have meltdowns during distance learning.

For family members and caregivers, it is important to be aware of the stress of loved ones on the spectrum arousing from social distancing, distance learning, and ongoing change. During studying at home, parents have to spend more time to company their children for accomplishing virtual learning, home assignments and make sure to cope with children's stress in time.

Stress Detection in children with ASD during homeschooling is becoming vital for assisting the special group and their family. It can help reduce mass attention from adults and build an independent system with design intervention. So a clear contextualization around "monitoring stress during homeschooling" is the design background in this paper.

However, a few outstanding research questions need to be answered to fulfill everyday objects' qualities and traits for contributing to a stress detection and management system for children with ASD.

In this paper, I focused on exploring what types of behaviors are associated with everyday objects that are indicators of stress in the design context. Then, I introduced the stress-aware pen with the objective to validate the correlation between the pressure of handwriting and handholding with stress. Besides, the pen is enabled data collection and interaction to inquire "how an everyday object responds to stressful behaviors to increase the awareness of stress in children with ASD? ” and “How an everyday object intervenes in stressful behavior to support in stress management?” in the design research experiments.

Based on the result of the exploratory experiments with non-autistic children to experience the stress-aware pen, it reveals the correlation between stress with handwriting and handholding pressure. The vibrotactile and light feedback regarding children’s stress levels has been evaluated through the experiments. The study provides a starting point for creating a stress detection and management system with connected everyday objects.

2. Related work

There are many stand-alone devices that can identify stress with the help of some physiological signals such as skin perspiration and heart rate by processing them further in order to decide if the person is under stress. Since the design is targeting to the special group – children with ASD, there are some important concerns highlighted in different research works(Koo et al., 2018; Taj-Eldin et al., 2018), for instance, the necessity of building a context-aware system besides detected physiological signals(I. R. de Moura et al., 2021) and a unobtrusive design that does not interrupt but also fits in everyday life and activities of users(Koo et al., 2018).

2.1 Wearable devices

Wearable devices (e.g. various smart wristbands, gloves, and chest bands) are widely applied in research for monitoring physiological signals(Can et al., 2019; Gul Airij et al., n.d.; Koo et al., 2018; Taj-Eldin et al., 2018) in children with ASD. In daily life application, adopting wearable devices can potentially monitor the internal physiological states related to stress, and may helps caregivers and care-receivers understand what they are experiencing in real-time(Taj-Eldin et al., 2018). However, most existing wearable devices on the market are designed for the general population with little attention to children with ASD(Taj-Eldin et al., 2018).

Furthermore, those conventional design on wearable devices often overlook the context and behavior change detection in daily life, but only focusing on monitoring physiological responses, that limits the accuracy of stress detection in children with ASD(I. R. de Moura et al., 2021).

2.2 Connected Everyday Objects

There is a trend that more and more self-tracking technologies are embedded in everyday objects(Ding et al., 2021). Enhanced Everyday objects can be integrated in a smart stress detection system that is able to actively and passively sense behavioral input from the user and interpret it into stress related information (Hekkert, P.P.M. et al., 2010). The features of everyday objects shows a delighted direction to the advancement of detecting stress in vulnerable groups like children with ASD.

There are several most common requirements for designing stress detection devices for children with ASD(Koo et al., 2018). First of all, it has to be a non-invasive stress detection approach(Gul Airij et al., n.d.). Second, it should be easy to use and easy to learn(Pantelopoulos & Bourbakis, 2010). Third, the cost of purchasing and maintaining the device should be affordable for families(Taj-Eldin et al., 2018).

Everyday objects are surrounding us that we are comfortable and familiar to live with. They can be a cup, a lightbulb, a table, etc. They are natural, ordinary, even invisible sometimes. The way we interact with them without requiring a new set of skills or needing to learn new languages, gestures, icons, color codes, and button combinations(Rose, 2014).

Everyday objects have high potential for collecting contextual in daily life as the rich interaction between users. When everyday objects are enhanced with emerging technologies like sensors, actuators and wireless connection, they can be more useful, more informative, more sensate, and more connected in an unobtrusive way(Rose, 2014).

Those pervasive everyday objects are associated with daily behaviors related to stress(Liang et al., 2019; Mohr et al., 2017; I. Moura et al., 2020) through human-product interactions, which fulfill with valuable context in terms of behavioral data to further help recognize stress situation and identify stressful behavior patterns(I. R. de Moura et al., 2021). As Miguel concluded the potentials of everyday objects from his study(Hekkert, P.P.M. et al., 2010):
"*Enhanced Everyday objects can be integrated in a smart stress detection system that are able to actively and passively sense behavioral input from the user and interpret it into stress related information*."

A lot of design research has tried to detect stress by involving behavioral data such as motion or activities(I. R. de Moura et al., 2021; Gjoreski et al., 2016, 2016), and voice (Kurniawan et al., 2013; Tomba et al., 2018; Wang et al., 2009) with sensors embedded in objects, to enrich the context from behavioral changes.

3. Method

3.1 Interview with families having a child with ASD

Before starting the design process, desk research on general stressors for children with ASD and interviews with three families which have children with ASD have been conducted. The three families have children with autism between levels 1-2 (DSM5 Diagnostic Criteria Autism Spectrum Disorder, 2013), their ages are between 8-10 years old.

Besides stress in social interaction for autism, the interview result showed that stress in children with autism is often noticed during studying. Since the difficulty with paying attention for some children with ASD, sometimes, sitting a long time to study can be challenging and increase their stress level. Especially, changes happen during Covid-19 pandemic, distance learning and homeschooling time becomes longer than the past. Children with ASD feel overwhelmed by the changes and they are easily distracted even have meltdowns or emotional outbursts during studying at home.

There are some typical stressful behaviors in children with ASD depending on parents' description, for example, mumbling, crying and some repetitive body movements. On the other hand, these stressful behaviors are often associated with objects, objects like pen and eraser are often mentioned that children use it to release strength sometimes. Behaviors such as aggressive drawing, bending, rubbing, punching, squeezing objects are often seen when children are perceived in a high stress level.

During distance learning, it is becoming vital but challenging for parents to company their children for accomplishing virtual learning and home assignments while coping with children's stress timely. It requires mass attention from adults and highly dependent on human intervention.

Hence, we decided to focus the design context on detecting stress in children with ASD during homeschooling and further applying design intervention for stress management.

3.2 Research Through Design

In order to answer research questions, the study began by exploring the everyday objects that are associated with stress behaviors in the design scenario. We started with desk research and interview with parents of target users, specifically focused on finding a representative object. After targeting a pen as the studying object, I investigated what kind of user behaviors and movements while interacting with a pen are indicators of stress. For that, I created a pen embedded with pressure sensors to monitor user interaction in terms of pressure and force.

Based on observation and literature support(Hekkert, P.P.M. et al., 2010), the handwriting and squeezing behaviors showed a high relation with stress. Taking the two types of behavior to further study, I then followed a Research-through-Design process(Koskinen et al., 2013) where the two types of behaviors are interpreted to help indicate stress levels in research experiments with children. Also, the designed experiment with the objective to explore "how to increase the awareness of stress in children with ASD as well as their caregivers? " and "how to use design intervention to help coping with stress?".

These explorations showed that there is a potential correlation between handwriting and handholding pressure with stress. We iterated the interactive feedback with different modes to help children aware of their stress levels and supports its reduction based on the findings and results from the exploratory experiments.

3.2.2 Framework (proposed process)

Figure 1 shows the vision of designing an object to intervene in the stress of children with ASD. The process is inspired by the affection loop from Miguel's work(Hekkert, P.P.M. et al., 2010). There are two steps in the process of building a stress management system by connected objects. The left circle is the first step "Stress detection" where this design research focuses on. In the "Stress detection" circle, the user starts expressing stress on an object with stressful behaviors when stress is aroused. Then, the object detects the abnormal behavior and gives feedback in order to increase the user's or their caregivers' awareness of the stress level. Explorations within this circle aim to answer the research questions mentioned in 1.4.

The next step is the "Stress management" circle. With the goal of building a connected object system for stress detection in children with ASD, physiological data such as HR and EDA will be collected from connected devices as a different type of resource to indicate stress. Through combining physiological data with

Figure 1: An example of online brainstorm workshop with families having autistic child.

behavioral data, the interpreted stress levels of children can be reliable. Next, the object will proactively cope with stress by interacting with users and their caregivers in different forms of feedback.
Eventually, it is expected that the user's stress is affected by the intervention and their behaviors associated with the object change gradually. In this way, the object evolves to a stress management system that not only can detect stress but also support coping with stress in children with ASD by building the bridge between the target group with their parents or caregivers with design intervention.

The proposed framework provides a clear process on how to enhance an everyday object to work as a part of a system of connected objects for stress detection and management. In designing for the stress-aware pen, I focused on exploring inherent stressful behaviors associated with a pen and creating meaningful feedback. Furthermore, in order to evolve the design to step two in the future, physiological data like HR and EDA have been collected in the experiments to be used as a control reference in exploring the correlation between stress and pressure.

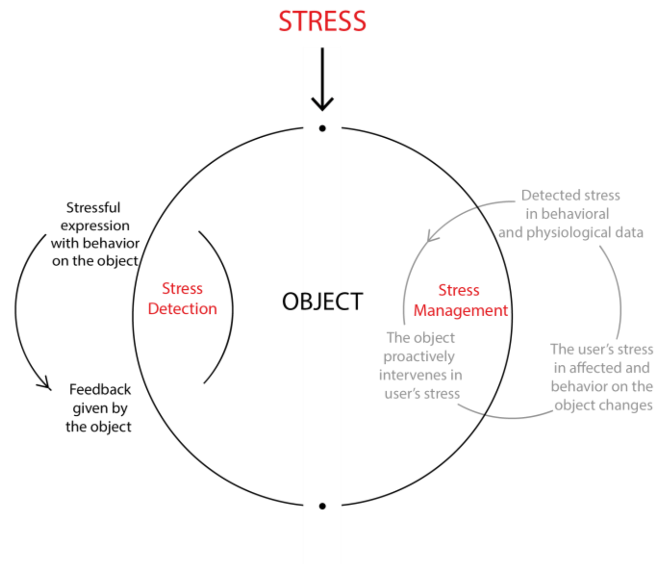

Figure 2: The two steps to design an object for intervening in the children's stress. The left circle is the first step "Stress detection" that is explored in this study. The right circle is " Stress management" that is the future step to build a connected object for coping with stress in children with ASD.

4. Design process

In this project, the prophase of design inspiration and ideation were developed based on literature research and findings through interviews with target group families and co-design workshops with student design researchers.

Starting from exploring everyday objects in the design context, the design focus shifted from collecting

1. https://www.miro.com/

2. https://www.karakter.com/

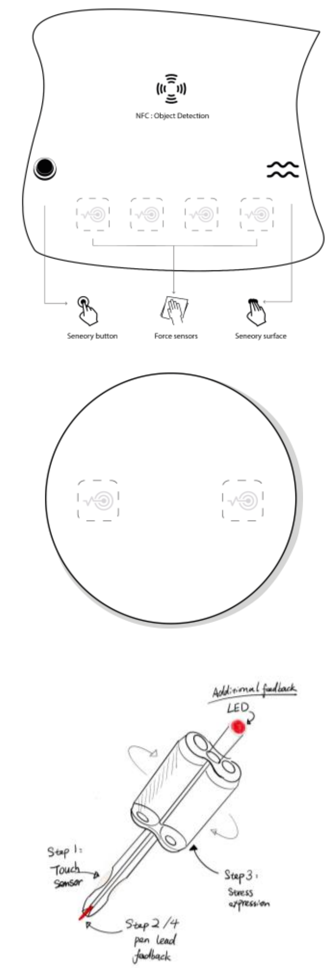

Figure 3: Some examples of design ideas with different objects (From top to bottom are desk pad, sitting mat and pen respectively)

massive environmental data by several objects towards behavioral data by a compact object. Through elaborating and revisiting the design concept, it enabled me to explore different forms of interaction and evaluate various stress feedback for users.

The design process is divided into three stages, from first to final iteration. Each stage encompassing various design activities with applying proper design and research methods and strategies, instructed in Delft Design Guide(Boeijen et al., 2014).

4.1 First iteration : Idea exploration

In this stage, the goal is to define a means of stress detection and identify an everyday object as the physical entity to collect data in the context of homeschooling. Besides, design requirements were also set up based on the insights from interviews and expert consultation.

I started investigating the stress situation of children with ASD when they study at home to gain insights on their stressful situations and stress behaviors through interviews with three target group families. Moreover, online brainstorm workshops via Miro[1](an example as figure 2 shows) have been conducted with these families to identify objects related to stressful behaviors during homeschooling and define the design requirements. The design requirements were further validated by child psychiatry experts Wouter Staal and Martine van Dongen-Boomsma who work at Karakter[2]- a specialized institution for children with psychiatric problems and synthesized with experts' proposition. The finalized design requirements are as follows:

- The design has to be robust and safe to use by children with ASD.
- The design interprets collected data from behavior to stress accurately.
- The design can aid awareness and management of stress implicitly.
- The design can give parents and caregivers alters when the stressful signals are detected.
- The design can adapt to children's daily life and does not interrupt everyday activities.
- The design is easy to learn and unobtrusive.

The design requirements provide a benchmark to analyze and evaluate design concepts.

There are several objects defined to be the most representative object manipulations by children with ASD in the design context, including a digital tablet, stationery(pen, notebook, eraser), a desk pad, a sitting mat, and some fidget toys. These objects are associated with different stressful behaviors that can have sensors embedded to detect relative behaviors to measure stress. Several design ideas with different objects are elaborated in figure 3. The design ideas were evaluated together with target group families in a co-design workshop. A pen for having the most related object manipulations and the least invasively during homeschooling is an appropriate physical entity to further explore the stress detection process including stress-related behavior and the feedback possibilities in the second iteration step.

4.2 Second iteration: behavior study and feedback exploration

The second iteration includes research and design activities, which are defining the object manipulation

Figure 4: An example of online brainstorm workshop for exploring means of stress feedback with student designers

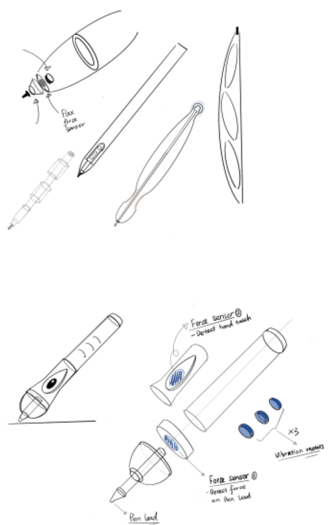

Figure 5: Sketches of design exploration

behaviors, exploring the structure & aesthetics, as well as the means of the stress feedback around the physical entity --- a pen.

4.2.1 Stress-related behavior with a pen

Research has been conducted on evaluating which behaviors are associated with a pen when people feel anxious and stressed. Table 1 listed the synthesized stress-related behaviors based on the study by Miguel (Hekkert, P.P.M. et al., 2010) and interview insights with target group families. The work of Migure (Hekkert, P.P.M. et al., 2010) found that pressure or force could indicate stress, and squeezing and pressing are the best predictors of stress while people are interacting with a pen.

Parents of children with autism reported in the interview that children with ASD tend to put harder force on writing, and bend or squeeze a pen with strength when they are under pressure. More studies(*Handwriting and Emotional Stress - Petra Halder-Sinn, Claudia Enkelmann, Karin Funsch, 1998*, n.d.; Keinan & Eilat-Greenberg, 1993) found that more pressure detected on handwriting when people are under stress.

Table 1 indicates that pressure/force can be a promising parameter that is associated with all behaviors, offering comprehensive insights on different stress-related behaviors. There are two main aspects to measure the pressure though a pen, one is the handwriting pressure, the other is pressure acted on the body of a pen. Therefore, flexiforce sensors for measuring pressure were explored by attaching to different positions of a pen to detect behaviors.

Behaviour	*Sense*	*Sensor*
 *Press/squeeze*	Force/Pressure	Capacitive material (capacitive touch sensor) Force sensor
 *Bending*	Force/Pressure Displacement	Flex sensor Conductive elements Magnetic sensors
 *Spinning/rotating*	Frequency Speed Force Displacement	Accelerometer
 *Pressing/Clicking*	Frequency Speed Force Displacement	Buttons Force sensor Touch sensor
 *Rubbing*	Force Friction	Force sensor Touch sensor
 *Punching/Hitting*	Force Speed Displacement	Force sensor Accelerometer

Table 1: Synthesized stress-related behaviors with a pen and the type of sensory needs behind each behavior as well as the possible sensors for detecting behaviors.

4.2.2 Feedback exploration

In order to raise the awareness of stress in children with ASD, feedback about real-time stress interpretation needs to be given to users through the pen. Adequate feedback should capture users' attention and respond to users' behavior needs. Moreover, since the feedback is the afore step of intervention in users' stressful behaviors, it has to be clear and informative to users to complete the design loop of stress management.

Another brainstorm workshop has been conducted to explore different forms of feedback (as figure 4 shows) with four student designers. It delves into five aspects: sensory-related, emotion-related, information-related, media-related, and physiological-related, to analyze what kind of feedback the target group may need.

The results of the brainstorm have been evaluated by design requirements, it concludes and categorizes the designed feedback to visual and tactual information. To simplify the realization in design and keep the designed feedback in an implicit way, I decided to use light interaction as visual information and vibration interaction as haptic information.

4.2.3 Idea visualization and prototyping

It is essential to visualize and physicalize the design concepts by synthesizing previous design decisions. Structure and aesthetics exploration have been done by sketching firstly(as figure 5 shows), in the meantime, the first experimental prototype was built with flexiforce sensors and vibration motors embedded. The sketches(Figure 5) and physical prototype(Figure 6) enabled me to test and evaluate the design concept.

Figure 6: First experimental prototype that is using for evaluating the function of behaviors detection and feedback

4.3 Final iteration: tactile feedback and respiration intervention

Before the final design, the last iteration has been done to finalize the design concept that what kind of light and vibration interaction is considered to be the most effective one in terms of increasing awareness of stress. Furthermore, the combinations of different types of haptic feedback, tactile properties, and lighting effects were also designed and evaluated in terms of their qualities in raising awareness of stress.

The experimental prototype is further improved, enhancing with 3D printed material, and lighting effects(as figure 6 shows).

In this stage, a user test session/experiment was conducted with children without autism to evaluate the visual and haptic feedback.

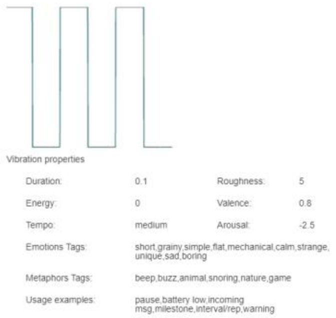

Figure 7: An example of vibration pattern with the growing intensity. Data is from VibViz[1].

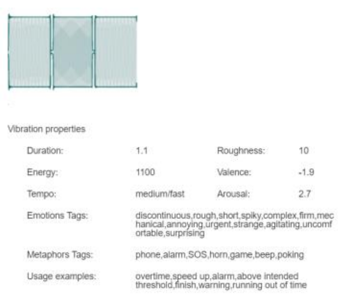

Figure 8: An example of vibration pattern with the growing intensity. Data is from VibViz[1].

1.https://www.cs.ubc.ca/~seifi/VibViz/main.h

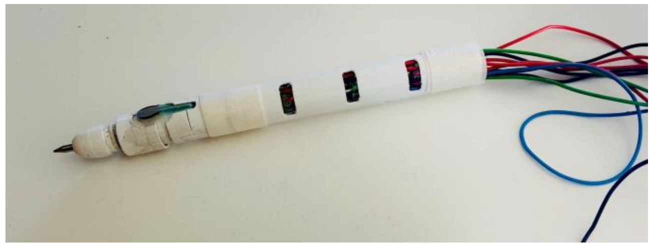

Figure 6: Second experimental prototype that is using for validating the design concept

4.3.1 Light effects

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Light effects are widely applied in the interaction design, with the purpose of informing, alerting also manipulating human behaviors. The LED light was only used for indicating the detected stress levels with its color change. However, different light patterns especially breathing light is often applied in stress-related design works such as the Soma mat(Ståhl et al., 2016) that proving the slow-speed breathing light brings the feeling of relaxation, and DeLight**(Yu, Hu, et al., 2018)** that using ambient light intervenes in breath rate and further manages stress. Therefore, the breathing light pattern is enabled in the final design, and the breathing rate of LED is in consonance with the levels of the detected force for the purpose of increasing users' stress awareness and further influencing their behaviors.

4.3.2 Haptic effects

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Vibrotactile feedback has great value in passing on information(Seifi et al., 2015). A library called VibViz[1] (Seifi et al., 2015) has been built to reveal the possible interpretation from users depending on intensity, duration, rhythm, and location of vibration signals.

Based on the library, I selected a few vibration patterns by the usage context of providing awareness. After applying filters in the library, the suited vibration patterns were collected and implemented in the user test. Based on the results of the user test/experiment, the vibration patterns presented better in drawing attention and manipulating behaviours have been kept in the final design.

It is found in the user test that a vibration pattern, as figure 7 shown with short repetition and high intensity, is likely to catch the user's attention quickly. A vibration pattern, as figure 8 shown, with the long duration and implicit movements, is prone to change behaviours.

Eventually, I combined different light and vibrotactile patterns for realizing different feedback modes based on the results of the user test.

5. Final Design: Stress-aware pen

5.1 Design overview

The stress-aware pen is designed for children with ASD with the purpose of aiding stress detection and management. To be specific, as the proposed design process, the first step is detecting their stress-related behaviors, then increasing their awareness of stress, next intervening in their behaviors, and finally coping with stress.

5.1.1 Working principle

In the first step, the focused stress-related behaviors can be interpreted as handwriting and handholding force. Therefore, force sensors are embedded to detect force/pressure through pen lead and pen body two times a second. In order to draw children's attention to their stressful behaviors and give implicit feedback(visual& vibrotactile) in terms of stress levels, the reaction of vibration motors and light are designed, as figure 9 shows. Under the feedback mode of the stress-aware pen, there are three thresholds set for handwriting and handholding pressure. When the average handwriting pressure in 10 seconds is above threshold 1, 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 in 10 seconds is above threshold 2 or the real-time handholding pressure is above threshold 3, the LED light turns red color, and one of the vibration motors vibrates 3 times with short duration and strong intensity. The thresholds are customized depending on the handwriting and hand-pressing habits of each user.

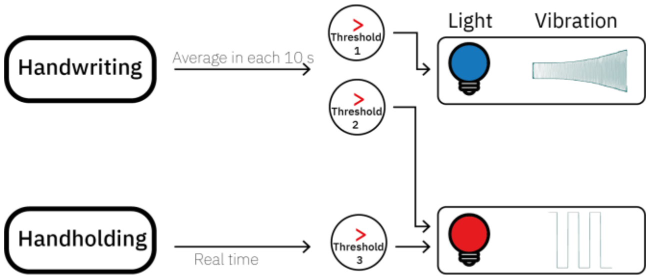

Figure 9: The feedback mode of the stress-aware pen

The other mode is called the feedforward mode. It is designed not only for aiding users to be aware of stress but also for intervening in users' behaviors and coping with stress. The breathing blue light is enabled to change the breathing rate depending on the different ranges of handwriting force. The higher the average pressure of handwriting in 10 seconds is detected, the faster the light breathes. In this way, the breathing rate of LED can indicate the stress levels also influence users' respiration ideally.

In the meantime, when handwriting force is above the highest threshold, the vibration starts from the bottom one moving to the top one. With the vibrotactile guide on direction, the users are expected to adapt their handwriting behavior, for example, lifting hands from writing with high pressure. The pen also reacts to handholding pressure in real-time when above threshold 4, with a short and intensive vibration to alert users.

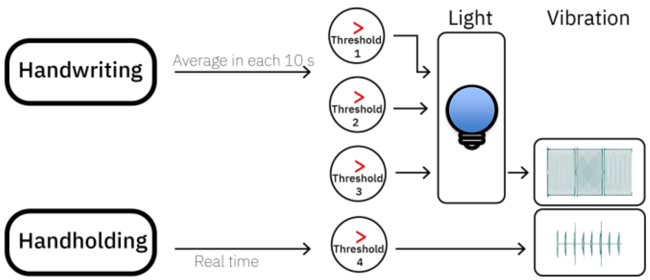

Figure 10: The feedforward mode of the stress-aware pen

5.1.2. Prototype

As you can see in figure 11, the prototype is 3D printed with a combination of soft and rigid plastic for having a pleasant tactile sensation. The upper body of the pen is half-transparent to present the light effects well. Sensors and actuators are embedded inside of the pen but connected with an external control board and a battery by electric wires.

The final product exploded view(Figure 12), and demonstration(Figure 13) are rendered in Keyshot.

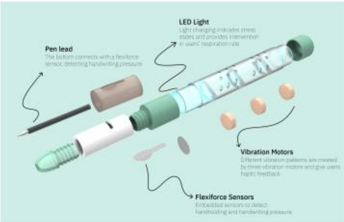

Figure 12: The exploded view with specification of the stress-aware pen

Figure 13: Product rendering and demonstration

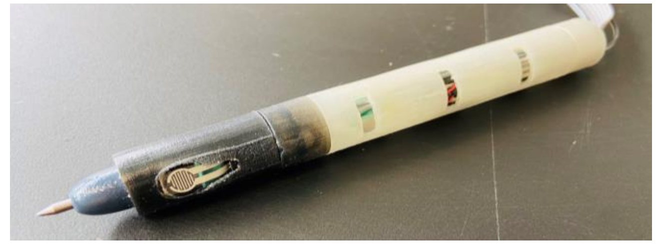

Figure 11: The stress-aware pen

5.2 Hardware & Software

The visualization of the circuit design is shown in figure 14. The electric hardware consists of:

- ESP 32 WiFi board * 1
- Flexiforce sensor * 2
- Resistor 20k Ω * 2
- Vibration motors * 3
- LED 5050-RGB * 1

The reason to use ESP 32 WiFi board is that all detected data needs to be uploaded in real time and stored at Data Foundry[1]- a Cloud server via OOCSI[2]- a prototyping middleware during experiments.

The Arduino IDE software is used to realize the visual and vibrotactile interaction design. The code document can be found in Appendix 2.

1. https://data.id.tue.nl/

2. https://oocsi.id.tue.nl/

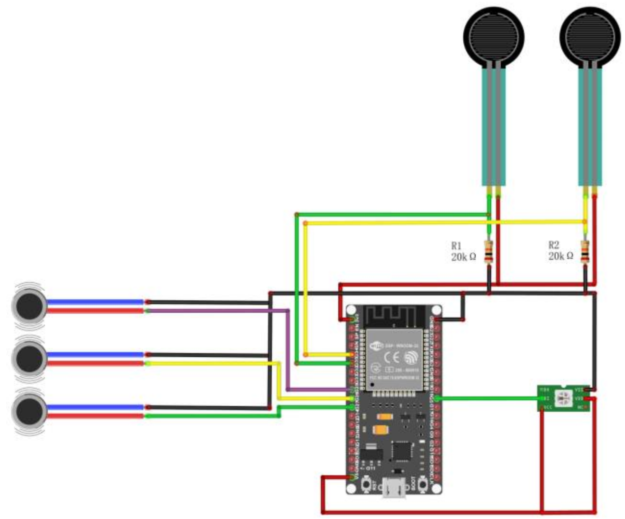

Figure 14: The circuit of electric hardware

6. Experiment

Considering the experiment has to be done in the context of homeschooling, as well as the ethic concerns about stress study, the exploratory experiments were conducted in the field - at participants' home. However, stress is less common and distinct in real life(Gjoreski et al., 2016) to be detect in short time experiments. Stress detection experiments in the laboratory are often designed to induce stress deliberately(Gjoreski et al., 2016). On the other side, stress is subjectively labelled and the physiological measurement is easy to be disturbed in the field experiments(Gjoreski et al., 2016). Therefore, the experiments were designed in the way of laboratory experiments in the field, with structured context containing potential stressors.

Subjective data, objective data and context information were all collected in the experiments to make sure the accuracy of stress detection and evaluation.

6.1 Participants

The families with non-autistic children were recruited and attended the experiment. In total, three families with four children participated the experiments, two girls(one is 7 years old and the other is 8 years old) and two boys(one is 8 years old and one is 10 years old). Each child with at least one of his/her parents joined the experiment every time. The children from these three families all experienced stressful situations during homeschooling.

The reason to start experiments with non-autistic children is to avoid potential risks to the special group at the exploratory stage. It is expected that the experimental results from the children without autism cannot represent the children with autism. However, it is still possible to gain valuable insights on the research questions and future works as an exploratory study.

6.2 Experiment design

6.2.1. Design context

Stress detection in the field relies on subjective ground truth(Can et al., 2019). In order to conduct laboratory experiments in the field, the context of the experiment needs to be personalized depending on each child's studying background and therefore to induce potential stress. To do so, the homeschooling test consisting of mathematic and linguistic questions for each child had to be prepared from easy level to hard level depending on their educational progress. Thus, the label of each task could be " Low potential stress" and "High potential stress." To be clear, the tasks in terms of

Data	Data Type	Device
Behavioral data	Pressure	Pen
Physiological data	HR; EDA	E4
psychological data	Affection	SAM

Table 2: Collected data type and the corresponding method of data collection

1. https://www.empatica.com/en-int/research/e4/

difficulty are only potential stressors for children in the context of homeschool since the prepared stressors may not be suitable for an individual. For motivation, a reward was promised to all children participants if they finished the tasks on time with a certain accuracy, to put some pressure on them at the same time.

6.2.2. Data collection

The data collected in the experiments consist of psychological data, physiological data, and behavioral data. As shown in figure 15 and table 2, the physiological data were collected by parents via self assessment manikin(SAM)(Bradley & Lang, 1994); physiological data, which are HR and EDA signals, was captured using an unobtrusive E4 wristband1 equipped with sensors. The stress-aware pen detected the real-time behavioural data in terms of handwriting and handholding pressure. Additionally, the video was recorded during each experiment as evidence for validation later.

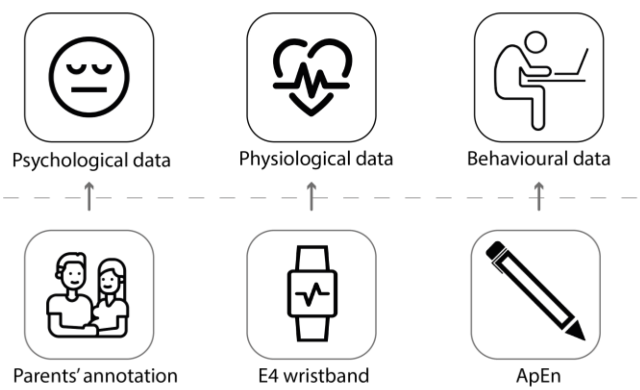

Figure 15: The three types of data collected from experiments and the respective approaches to collect them.

6.3 Procedures

Informed consent for participation and data sharing was obtained from parents prior to initiating the protocol. Before the experiment, parents received instructions on the detailed schedule of the entire experiment process, and how to use the SAM form to annotate the emotions of their children by one facilitator. Also, the difficulty levels of prepared tasks were confirmed with parents. Each child participant was asked to use the stress-aware pen with their general and high pressure. This step is for calibrating thresholds for each individual.

Each experiment consisted of two sections: the feedback and the feedforward sections. When the experiment started, the children were requested to wear the E4 wristband during the entire process and use the pen to finish the prepared tasks. Each section has to be done within 20 mins. The children had a 10 mins break between the two sections that is labelled "no stress" when they were allowed to do free drawing or free writing with the pen. The rationale is that it can avoid accumulated stress interfering with children's behaviors in the second section.

Parents were requested to stay beside children to annotate their children's emotions on the SAM form once every 5 mins. Parents were supposed to encourage their children to work on the task independently when they were asked for help from their children, but only assisting when children were not able to continue the tasks. When the experiments end, Parents had a short interview with the facilitator to reflect on the experiment and user experience with the pen. The experiment duration for each child was about 30-50 mins. The facilitator left participants to

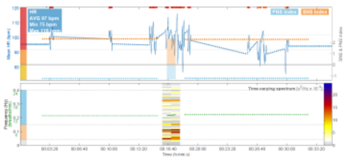

Figure 17: The stress report of participant **I** based on HRV. It shows that stress is detected between 7 to 13 mis (orange area) after the experiments started.

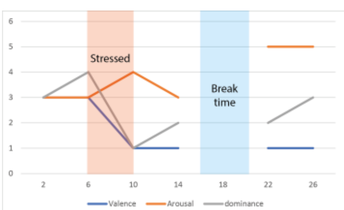

Figure 20: Data Visualization of one participant's SAM, the red period was "stressed" moment between 4 to 10 mins after feedback section started, the empty area was a break time without annotation data.

accomplish experiments alone during each section, only coming to switch the pen mode between two sections.

To remark, the prepared tasks in each section have the same amount of workload, from easy questions to difficult questions, personalized for each child.

Figure 16: Children used the stress-aware pen in the experiments.

7. Data analysis and Preliminary Results

7.1 Stress event with corresponding behaviors

The exploratory experiment in the field was without fully controlled stressors, but the stress study needs to have an objective evidence of aroused stress. Physiological data specially HRV allows the reliable identification of stressful events(Azzaoui et al., 2014; Dutheil et al., 2015). Thus, HRV was calculated as evidence of physiological stress. It was analyzed from photoplethysmography (PPG) data via Kubios[1] based on MatLab.

Data analysis of 4 participants' physiological data, psychological data and behavioral data as well as video footage of experiments are enormous work with high complexity. In order to ensure the reliability of the results, I only presented results when there was detected stress in HRV here.

The detected stress from HRV in a child participant during feedback section is shown in figure 17. An abrupt changes happen in mean HR between 7 to 13 mins after the experiment started. Correspondingly, figure 18 shows that pressure data in handwriting and handholding had an elevation and feedback(light and vibration) were given by the pen a few times during the same time slot. And simultaneously, parent marked a raise(from level one to level two) in arousal index in SAM form during 5-10 mins and it stayed at level two till the end of the next time slot 10-15 mins. But, there is only one stress event detected among all participants' physiological data.

7.2 Perceived Stress with 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 on task papers of her child.

As you can see in figure 19, it is a comparison between the child's handwriting with and without stress. Here, the detected stress moments (Graziotin et al., 2015) are based on the assessment by the child's parent in

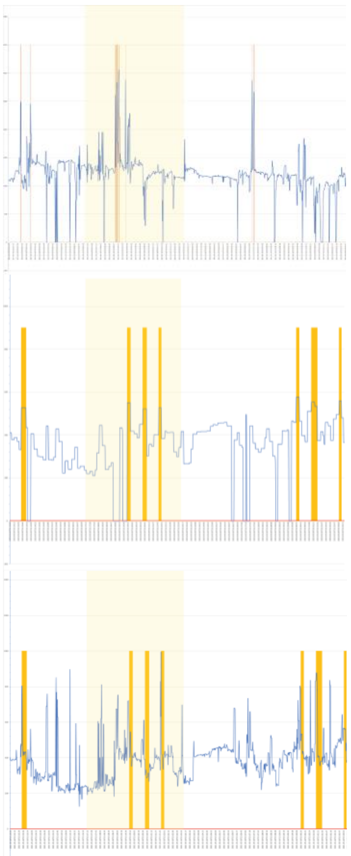

Figure 18: Handholding(Top), Handwriting average every 10 seconds(Middle), and real time (Bottom) pressure of one participant in feedback section with blue data, orange column is when feedback happened. Yellow space is a marked growth in arousal (SAM).

the SAM(as figure 20 shows). There are more detected aggression and strength put in handwriting on the left comparing to the right one. The handwriting on task paper reveals the association between handwriting behaviors and perceived stress moments in children.

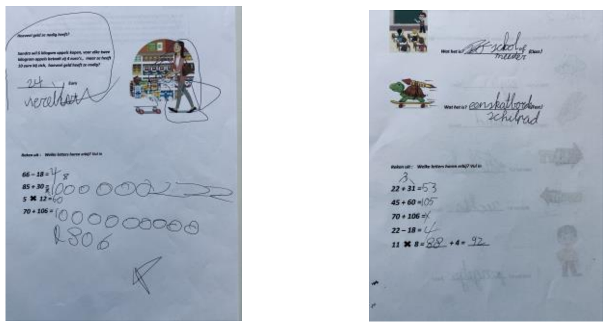

Figure 19: Handwriting at parent's perceived stress moments(Left) and Handwriting without noticed stress(right)

7.3 User experience with the stress-aware pen

It is noticed in the pressure signals from force sensors that the handholding pressure and handwriting pressure diminished every time after feedback happened. Examples are as figure 18 shows. However, there is no significant evidence to prove that the pen increased the awareness of stress in children or children's behaviors were changed, or stress was intervened by the pen.

But, user experience data could also reveal if the pen can help stress awareness and behavior changes. I collected user experience data from user feedback of parents and children in terms of several aspects. First, the vibration feedback was sensed well by children, also noticed by parents in general. For example, a child mentioned: "After vibration happens, I relaxed my fingers or repositioned my fingers on the pen." Second, regarding light feedback, both parents and children could notice the light on and color change in the feedback section but without putting too much attention on it or changing any behavior. And, no one noticed the breathing rate of the breathing light changed in the feedforward section.

8. Discussion

This section discusses the limitations and future work. First, different results are expected when we conduct the same study with the target group – children with ASD. Second, I have to remind as an exploratory study, the experiments have been done in the field with the uncontrolled stressor and context. Also, the thresholds for giving feedback were set in short time that could lead to the different user experience for the different participants in terms of their interaction with the pen. Finally, I discuss my vision on the future work to complete the proposed process for building a personalized stress detection and management system with everyday objects.

8.1 Difference in children with ASD

The way children with ASD show their anxiety and stress can look a lot like common characteristics of autism. Behaviorally, they may have some stimming, obsessive, repetitive, and ritualistic behaviors(Baron et al., 2006). In the physiological reaction, they may respond obviously in their skin conductance and heartbeats when they are stressed(Taj-Eldin et al., 2018). Therefore, we can expect more manifest stress events to be detected through analyzing the HRV or

EDA from children with ASD when the experiments are conducted with them. On the other hand, the characteristic of stress behaviors in children without ASD in this study may not be representative in children with ASD. Further research needs to be done with the target group.

8.2 An exploratory study without control stressor

Unlike a lab study, the exploratory experiments have done in participants' home without inducing stress intentionally. Therefore, it is not reliable to label the different levels of the tasks with different stress levels. And there was no strong evidence to prove that stress aroused in children during any experiment in this study since stress is a subjective measurement. All stress related data collected from experiments only indicates stress indirectly instead of asking children themselves.

Also the sample size of the participants were to small to make any solid statement to answer research questions. But, there are many valuable data providing insights on the hypothesis "handwriting and handholding pressure are a sort of stress-related behavioral expression" and " it is possible to indicate stress levels by analyzing handwriting and handholding pressure".

8.3 Bias in user experience and user interaction study

The thresholds of triggering different types of feedback were set only based on each child's short time testing result. In general, to make sure giving the same user experience to every participant and study if the feedback intervenes in stress, it requires long-term behavior learning to decide the thresholds for indicating stress levels. Since it is an exploratory study and the focus of this study is not user experience or stress reduction, it only aims to test which forms of sensory feedback are better in raising awareness of stress in children. Nevertheless, we should still consider the potential bias in users' feedback.

8.3 Future work

As my proposed process in section 3.2.2, the design of everyday objects for stress detection and management should complete the light loop of figure 2 in future work. In order to achieve the goal, further research can be conducted from several aspects. 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 validating stress events but also designing biofeedback(Yu, Funk, et al., 2018) to increase stress awareness in children with ASD and to cope with stress. To zoom out and have a bigger picture,

Eventually, the design should have an intervention in stress and help children's stress reduction that can be achieved in different means. Social support from family and people around children with ASD is essential to cope with their stress besides awareness training and behavior guiding by an object. More research can be conducted to answer "How an object gives the awareness or alter of autistic children's stress to people around them?" so their stress can be managed with external assistance in time.

To build a stress detection and management system supported with rich context, an IoT ecosystem where enables smart and non-smart objects, connected and ordinary objects to cooperate on data collection harmoniously is a promising solution for children with ASD in the future smart environment.

9. Conclusion

A context-aware stress detection through enhancing everyday objects is a new approach to study stress. Studying stress-related behaviors in the context is the beginning of building a system of stress detection and management with connected everyday objects. Even the design focus is on children with ASD. Still, the implementation of the stress-aware pen is broad and open to apply for different scenarios when we decontextualize the concept. For example, the stress study in general children/adolescents when they have heavy study load at school. Therefore, it is encouraged that designers and researchers enable everyday objects' potentials in data collection and contribute to realizing a context-aware smart system for aiding stress detection and management in particular groups like children with ASD. This paper offers an example of enhancing everyday objects to support stress detection and insights on intervening in stress with design interaction. Based on the preliminary results, further design can explore how to make the pen connected with other objects to support stress reduction.

Acknowledgements

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Appendix

Appendix 1. Demo day with Introduction Video
https://demoday.id.tue.nl/projects/4eRXnwqj38

Appendix 2. Code of Feedback & Feedforward sections (saved on google drive)
https://drive.google.com/drive/folders/1S5EKU5ulTZmv7QwkAJj1fmnnSH-sC1Dv?usp=sharing

Appendix 3. Results of Brainstorm workshops(saved on Miro)
https://miro.com/app/board/o9J_lRdAEgU=/

Appendix 4. Interviews results with families having children with ASD(saved on google drive)
https://drive.google.com/drive/folders/1v0GKNYx6DsbdvQA7ziyKescri52V8WwP?usp=sharing

Appendix 5. Data collected by the pen in the experiments(saved on Data Foundry)
https://data.id.tue.nl/datasets/1250#!

Appendix 6. Experiment process & ERB & Self-assessment manikin(SAM) data & finished tasks(saved on google drive)
https://drive.google.com/drive/folders/1SvmQ6QV2JwpPICxo_6QmvNoyiSiXWIv8?usp=sharing

Appendix 7. Physiological data collected via E4 wristband(saved on Empatica Cloud)
https://www.empatica.com/connect/sessions.php