A Perspective on Intervention Approaches for Children with Autism Spectrum Disorder*

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Abstract. Autism spectrum disorder (ASD) is a neurodevelopmental disorder that affects 1 in 160 children globally. Autism is characterised by abnormalities in communication, social interactions and behavioural challenges. Sensory processing difficulties affect two-thirds of children with autism. This causes anxiety and typically leads to repetitive behaviour referred to as problem behaviours. Stereotypy and aggression are some of the most frequently observed problem behaviours. Behavioural interventions may help manage symptoms and develop cognitive skills, thus promoting a child's participation in social activities. A growing body of literature suggests that technological advancements in mobile health (mHealth) systems can be utilised to develop various intervention modalities. The central goal is to help children with ASD adapt to their surroundings by managing their problem behaviours. A promising possibility is to monitor physiological signals with wearable sensors to anticipate the onset of problem behaviour and provide intervention through wearable assistive devices. This paper presents a new perspective to manage problem behaviour and concept guidelines for a potential mHealth framework to deliver vibrotactile and thermal stimuli for sensory-based intervention.

Keywords: Autism · Wearable Devices · Vibrotactile Intervention · Thermal Intervention · mHealth.

1 Introduction

ASD is one of the most common childhood disorders (1 in 160) [17]. Autism is a neurodevelopmental disorder that results in significant psychological, emotional, and behavioural difficulties. Autism is further considered a pervasive disorder that can cause sensory-perceptual anomalies, such as a hypersensitivity to contact with other people. Children with ASD may also have sensory integration

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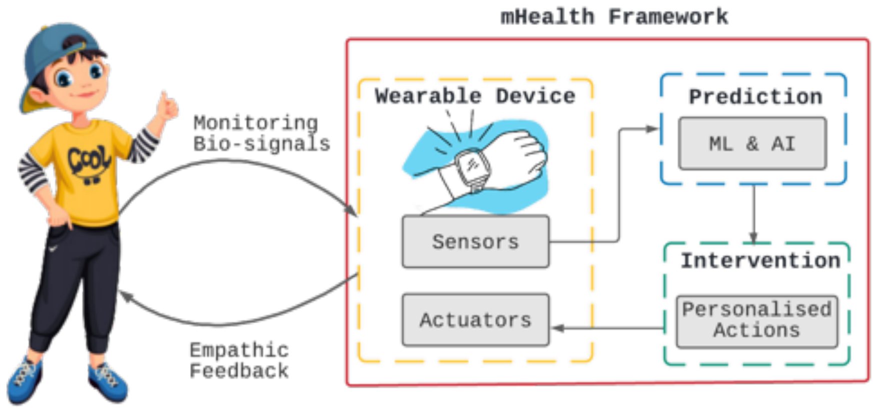

Fig. 1. The underlying idea of adopting wearable technology based interventions.

difficulties in processing the visual, auditory, kinaesthetic, tactile, and olfactory sensory systems [9]. Sensory integration is the ability to process and regulate sensory stimuli in the surroundings for adaptive functioning. A behavioural meltdown may occur due to overwhelming external stimuli, resulting in a temporary loss of control. This loss of control usually leads to repetitive, distracting behaviour known as stereotypical motor movements or stereotypy [8]; often expressed verbally (e.g., shouting, crying), and/or physically (e.g., kicking, lashing out, biting). Physical aggression is particularly debilitating as it may happen suddenly and without notice, and sometimes even long after the effect of the stressor (external stimuli). This unpredictability makes it difficult for them to participate in social activities. These individuals have a hard time understanding the social world and interpreting it, thus resulting in diminished situational awareness. This acts as a barrier to accessing essential services such as access to healthcare, education, and employment for individuals on the spectrum. Management of these challenges requires some form of behavioural therapy. Therapeutics for autism incorporate a multidisciplinary approach. It includes a combination of psychological and behavioural therapies, speech therapy, educational interventions, and psycho-pharmacological treatments.

This work focuses on non-pharmacological treatments (evidence-based therapies) using wearable and mobile technologies that support optimal outcomes for children with autism. Wearable technology-based interventions provide a promising option for improving sensory integration in autistic children. The underlying concept is as shown in Fig. 1. The use of assistive technologies in ASD can be helpful in communication, cognition, and sensory integration. These technologies can be used in various ways, such as an agent for motivating pedagogy or an alternative and augmentative communication device that mainly focuses on social interactions for autistics.

In a review by Wali & Sanfilippo [54], the prevailing implementation, as well as the research challenges of supporting technology for individuals with autism, were presented; the study highlights both therapeutic and technological solutions. In another study by Sanfilippo et al. [43, 44]; a prototype of an integrated wearable health sensor monitoring system with haptic feedback was presented. In line with this viewpoint, our research team presented a novel architecture for customising the surrounding environment using information from multiple sensory channels to increase situational awareness [45].

The objective for this work is to provide fresh insights on intervention mechanisms based on the evidence presented in the existing literature on wearable assistive devices and digital health systems. A promising approach is monitoring physiological biosignal data using commercially available wearable devices to predict the onset of problem behaviours using machine learning and artificial intelligence models, to provide proactive behavioural intervention.

We seek to stimulate global efforts towards the development of wearable intervention technologies for delivering empathic vibrotactile and thermal stimulus as intervention. This paper is not a systematic literature review but rather a new perspective on the current state of the art in wearable behavioural intervention technologies and our research aspirations for a proactive intervention framework. This work includes a background on psycho-physiological aspects of problem behaviours (aggression, stereotypy, anxiety). We focus on wearable and mobile technologies for intervention, particularly devices that augment the sensory functions of kinaesthetic and tactile somatosensory systems. This paper is divided into two sections; the first section looks into the existing intervention approaches; the second section presents the guidelines for the mHealth framework.

2 Intervention Approaches

2.1 Visual and Auditory

Virtual reality (VR) has evolved as a tool for cognitive behavioural therapy in treating psychological disorders, and it has been proven to help individuals cope with stressful situations. Studies [12, 14] show vision-based techniques have been used for cognitive training. Visual learning methods are suitable for children with autism, as they may aid in sensorimotor integration and social communication. The benefits of employing VR therapies, such as computer-based representations of reality, to help people with autism practice demanding social interactions in a less anxiety-inducing environment are noteworthy. With advancements in VR glasses and mounted displays, point of view scenarios are utilised to develop safe environments for visual intervention. Studies [42, 52] have found improved results in sensorimotor accuracy when virtual reality and kinaesthetic methods are used together with no short term negative consequences. Researchers that have used VR together with cognitive behavioural therapy have shown improvements across social communication, overcoming fear, and reduced stereotypes [11, 32].

Studies have demonstrated that individuals with autism prefer auditory stimuli to other types of stimuli. A study by Hall L et al. [24] has reported improvements in children's behaviour related to sensory processing and visual-motor delays. They reported that when an auditory stimulus is presented, children interact for a more extended period. Gee et al. [20] has demonstrated that negative and stimming behaviours have decreased in a participant who was provided sound-based intervention combined with occupational therapy for 10 weeks. This intervention technique has shown that it reduces auditory sensory over-responsivity.

2.2 Vibrotactile Prompting

Tactile (sense of touch) processing difficulties are among the most frequently reported sensory complaints in ASD patients. Tactile empathy is the ability to perceive and interpret emotions through touch. The perception of touch is essential for laying the foundation for social connection, communication, and other behaviours. Touch and pressure generating modalities are widely used as non-pharmacological therapeutics in the management of sensory hypersensitivity in autistics. Deep pressure stimulation (DPS) is a form of tactile stimulation that uses weighted blankets, vests, and vibrotactile devices to help reduce anxiety in children with hyposensitivity. DPS is regarded as an evidence-based intervention mechanism for reducing stress and creating a sense of relaxation. In empirical studies [19, 41] the effects of DPS on problem behaviour are fairly promising. A study by Bestbier et al. [7] has shown that deep pressure touch has immediate effects on the somatosensory response and benefits the population.

Prompting is a method of making individuals execute desired behaviour by providing additional stimuli (prompts). Taylor et al. [49] in their study used vibrational prompts at routine intervals to maximize verbal initiations in children. Anglesea et al. [4] in their research employed vibrational prompts at variable intervals (range of 10–30 s) to prompt participants to bite at each vibration, resulting in reduced rapid eating for all three participants. Safety skills were targeted in research by Taylor et al. [48], to successfully train three participants to request support while they were lost in a group environment. Anson et al. [5] compared their prompting approach to verbal and gestural prompting and found that the discreet, non-intrusive tactile prompt was as effective as the more conventional prompting method.

Studies [23, 29, 36] have shown that apparent haptic movements could potentially help with social communication. This motion is observed when two stimuli are presented in alternation at a relatively high frequency. Apparent haptic motions create the illusion of continuous motion, this resembles the sense of touch and could be a relaxing stimulus based on the individual's sensitivity to touch [27].

2.3 Wearable Assistive Devices and Applications

With constant improvements in technological and functional design applications of wearable assistive devices, real-time feedback of physiological biomarkers is becoming a reality. This has enabled affect sensing for monitoring emotional state and valence of individuals. Various studies have utilised wearable sensors and smartwatches for affect/emotion recognition [3, 22, 28, 47, 56]. A feasibility study by Di Palma et al. [13] identified a correlation between children's physiological responses and their engagement in cognitive tasks using wearable devices. Another research by Daniel et al. [10] has reported the support among children for the usability of wearable devices for affect sensing. Studies have also explored the possibility of using wearable devices for emotional regulation and behavioural interventions. Torrado et al. [50] in their study, reported that children recovered from mild episodes of stress when using smartwatches for interaction. Voss et al. [53] utilised Google glass as a digital intervention to improve socialisation in children with autism. They reported a 4.58-point average gain on the Vineland Adaptive Behaviour Scale involving 71 participants.

While researchers have examined the various uses of wearable devices, only a few have looked at the possibility of employing wearable assistive devices for behavioural and cognitive intervention. Table 1, presents a few of the selected wearable sensors and solutions that are available commercially. This table does not review all the devices/prototypes in this area of research. However, it focuses more on wearable sensors and assistive devices for behavioural intervention and highlights the design gaps. Current intervention approaches are reactive, i.e., behavioural intervention is only delivered when physical symptoms of problem behaviour are observed. We believe there is little evidence of existing work that combines prediction science and intervention mechanisms for problem behaviours.

3 Guidelines for mHealth Framework

3.1 Motivation

Intervention approaches within the gamut of behavioural and developmental interventions have become the primary method for treating children with autism to promote social, adaptive and behavioural functioning. There are many potential uses of affect sensing for individuals with autism. These include developing physiological and behavioural measures to classify emotional states associated with preclinical symptoms of problem behaviour and monitoring physiological and behavioural reactions to tailor treatment to an individual. Evidence [30, 35, 46] suggests that problem behaviour causes physiological changes preceding the onset of an emotional meltdown episode. Researchers have shown success in utilising the changes in the physiological state by monitoring biomarkers to predict emotional state [22, 26, 28, 37]. Even though wearable and digital intervention solutions need more evidence-based research and clinical trials, studies have shown such solutions are accepted amongst most individuals.

Table 1. Overview of Selected Wearable Sensors and Intervention Solutions for Autism.

Ref.	**Form Factor**	**Biomarkers**	**Intervention Method**	**Type**	**Description**
Emotibit [1]	Wristband	HR, HRV, EDA, RR, SpO2	-	Open-source prototype	Real-time monitoring of biomarkers.
E4 [15]	Wristband	HR, HRV, EDA, ST	-	Commercial device (research grade)	A research-grade wearable device for real-time physiological data acquisition.
PulseOn OHR [40]	Wristband	HR, HRV, Acc	-	Commercial device	Arrhythmia detection and analysis software.
ViSi Mobile System [16]	Wristband with electrodes	HR, HRV, ST	-	Commercial device (clinical use)	Monitoring vitals for arrhythmia and fall detection.
AIO Sleeve [2]	Arm sleeve	HR, HRV	-	Commercial device	Monitors stress in real-time.
My Feel Sensor [34]	Wristband	HR, EDA, ST	In-app alert	Commercial device	Monitors biomarkers throughout the day and learns to recognize your emotional patterns.
Awake Labs [6]	Smartwatch	HR, EDA	In-app alert	Commercial Device	Stress and anxiety management
Moodmetric Smart Ring [33]	Ring	EDA	In-app alert	Commercial device	It helps to identify personal stress triggers.
Pip [39]	Fingertip Sensor	EDA	In-app alert	Commercial device	Looks for variations in EDA using fingertip sensors to monitor stress.
Touchpoints Europe [51]	Wristband	-	Alternating tactile simulation	Commercial device	Produces bi-lateral vibrations for calming.
Feelzing [18]	Ear patch	-	Neuro-stimulation	Commercial device	Uses a proprietary waveform to stimulate the nervous system.

We suggest integrating promising intervention approaches with affect/emotion prediction, thus enabling proactive just-in-time solutions for managing problem behaviours. We present concept guidelines in this section for a potential mHealth framework. This is divided into two parts. First, it predicts the probability of a meltdown antecedent to the occurrence of the episode. Based on this prediction, the second part delivers vibrotactile and thermal feedback as stimuli for managing problem behaviours.

3.2 Background

Sensory and attention abnormalities of stimuli are an important area of study in autism psychophysiology. It is known that abnormalities in physiological arousal underlie behavioural issues in autism; Several researchers have hypothesized that abnormalities in physiological reactivity may underlie emotional meltdowns and arousals [25]. Arousal is a type of emotion that occurs when the autonomic nervous system (ANS) is actuated. The ANS is a division of the nervous system that controls many organic functions, and is critical to maintaining homeostasis; it is a dynamic equilibrium in which continuous changes occur, yet relatively uniform conditions prevail. Among various neurophysiological traits in autism, the role of ANS has gained more attention. The ANS is one of the body's major systems for maintaining homeostasis. It has two main branches: the sympathetic nervous system (SNS) and the parasympathetic nervous system (PNS). The SNS and PNS work together to maintain homeostasis. Individuals are sympathetic-predominant when facing a challenge or stress, whereas parasympathetic activity increases during resting and relaxation. The SNS is dominant in emergencies; it triggers pervasive and dramatic changes in the body, including heart rate (HR) acceleration, elevated electrodermal activity (EDA), bronchiole dilation, dopamine release and blood pressure enhancement. The PNS contains cholinergic fibres that produce enzymes that control the contractility of smooth muscles and slow HR.

3.3 Sensing Using Viable Biomarkers

As mentioned above, when the system is regulated by sympathetic behaviour, the HR is increased. When the parasympathetic system actively modulates sympathetic activity, the HR declines towards a resting rate. Another physiological signal for assessing an individual's anxiety is assessing electrodermal function. An increase in EDA reflects SNS activation, while stable and decreasing EDA indicates PNS activity. Psychophysiological functionality may also be assessed by heart rate variability (HRV), which is a marker of autonomic cardiovascular activity and is generally accepted as a good predictor of the relationship between psychological and physiological processes. Preliminary research suggests that cardiovascular reactivity can be used to characterise anxiety [21]. As sympathetic and parasympathetic modulations control heart functions, HRV is widely accepted and convenient in measuring the signal of autonomic function; its variability can reflect autonomic activity.

HRV measures the beat-to-beat variation in heart rate and reflects the interplay between sympathetic and parasympathetic systems. Greater variability in the beat-to-beat rhythm indicates a balance between sympathetic and parasympathetic contributions and is predictive of an overall good mental health. HRV has also been used to investigate physiological differences in generalised anxiety disorder, social anxiety, post-traumatic stress disorder, and panic disorder. While EDA is not a direct measure of sensory processing, it is a reliable measure of SNS arousal. Activation of the SNS results in the secretion of sweat, which conducts electricity, from eccrine sweat glands throughout the body. Eccrine sweat glands are only innervated by the sympathetic branch of the ANS, so increases in EDA can be, in part, attributed to increases in physiological arousal.

3.4 A Novel Approach to Proactive Intervention

Based on the hypothesis that physiological changes occur prior to the occurrence of a problem behaviour, this work lays the groundwork for developing user-centered proactive wearable intervention device. This device will potentially reduce the impact of problem behaviour by predicting an emotional meltdown prior to its occurrence in individuals with ASD. We present guidelines for the design of an mHealth framework for delivering empathic vibrotactile and thermal feedback. As previously stated, the framework is divided into two parts: (a) Prediction of problem behaviour by monitoring biomarkers using wearable sensors; (b) Intervention by delivering vibrotactile and thermal feedbacks as a stimulus using a novel wearable assistive device.

Prediction: The ability to assess changes in emotional valence during a meltdown without interfering with everyday routines could revolutionize behavioural healthcare. Researchers [30, 35] have studied the practicality of employing wearable biosensors for affect sensing in autistics using data obtained from participants in artificial environments that replicate problem behaviour. While these findings are intriguing, previous research in this field has relied on contrived experimental conditions and activities. In our work, we plan to conduct data collection in naturalistic environments, such as in schools and therapy sessions. This information will be used to develop prediction models based on time-series analysis of the biomarker data (HR, HRV, EDA). The prediction model will subsequently be used to detect problem behaviours using biomarkers in real-time using a wearable open source commercial-off-the-shelf sensor. We plan on exploring two methods for developing the prediction algorithm: statistical and ML. Statistical methods such as Bayesian non-parametric clustering and the non-homogeneous Poisson point process are a few methods we plan to implement. Machine learning models such as support vector machines, linear regression classifiers, principal component analysis and other pattern recognition algorithms will be utilized. Furthermore, deep neural networks for time series classification is also a possible approach to consider for developing a prediction algorithm.

Intervention: Existing research provides some evidence that the tactile prompt can increase verbal initiation in children [5]. However, a hypothesis that has not yet been tested is whether incorporating a tactile stimulus as an intervention mechanism regulates problem behaviours. Based on this hypothesis, the ultimate goal of our research is to develop a real-time automated prediction system that parents, teachers, and caregivers may utilize to deliver just-in-time intervention for children with autism. C-Tactile (CT) afferents are low-threshold mechanoreceptive units found in lower densities in glabrous human hand skin [55]. The axons of CT afferents are unmyelinated, which means there is no insulation around them, as found in the wrists and arms. Taking advantage of this, we will design, test and validate a novel wearable device that stimulates CT afferent neurons to provide empathic tactile feedback. Mechanical/haptic actuators such as eccentric rotating mass, linear resonant actuators, and piezoelectric vibrational actuators are possible elements that could generate vibrotactile motions that mimic the sense of touch and pressure. Studies [31, 38] have shown that the proprioception of warmth can also help reduce stress and anxiety in the general population, but this hypothesis has not yet been studied in individuals with autism. Thus, combining thermal stimuli with tactile stimuli might be beneficial to render thermo-tactile feedback as a stimulus. We can achieve this by integrating flexible thermal pads and other Peltier elements in the design of the wearable device prototype.

4 Conclusion and Future Work

Many studies looked into the relationship between physiology and psychology in autism, only a few have looked into predicting problem behaviours using biomarkers in autistics. There is lack of sufficient literature integrating prediction and intervention mechanisms for problem behaviour in children with autism. This paper presents a guideline for the use of physiological biomarkers to predict problem behaviours and render empathic vibrotactile feedback for behavioural intervention. This research project relies on the hypothesis that stimulating the somatosensory system reduces stress/anxiety, thereby reducing the effect of problem behaviours. Noticeably, there is overwhelming evidence suggesting that physiological signals can be used as indicators of certain psychological states of humans. Biomarkers such as heart rate, heart rate variability, and electrodermal activity have been shown in studies to be extremely useful in detecting aggression, emotional distress, and stereotypy. There is a need to develop solutions targeting problem behavior in individuals to improve sensory integration for situational awareness in autistics. It will be interesting to combine prediction algorithms and intervention approaches, especially focusing on the use of wearable devices for empathic auditory-visual-tactile feedback and contribute towards the design, implementation and validation of a proactive framework.

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