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

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Abstract. Autism spectrum disorder (ASD) is a neurodevelopmental disorder affecting 1 in 160 children globally. Autism is characterised by abnormalities in communication, social interactions and behavioural challenges. Sensory processing disorders (SPD) 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 in children with autism. Behavioural interventions may help reduce symptoms, develop cognitive capacity, and improve the child's ability to participate in social activities. A growing body of literature suggests that technological advancements in mobile health (mHealth) services may provide effective interventions to address the core symptoms of autism. One of the central challenges is to help children with ASD adapt to their surroundings by mitigating 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 on state-of-the-art intervention technologies in managing problem behaviour and discusses potential proactive intervention methods. We present a novel mHealth framework for behavioural interventions with the proactive use of wearable devices for empathic multi-modal auditory-visual-tactile feedback.

Keywords: Autism · Wearable Devices · Tactile Intervention · mHealth.

1 Introduction

Autism spectrum disorder (ASD) is one of the most common childhood disorders (i.e., 1 in 160) [11]. Autism is a neurodevelopmental disorder resulting 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 difficulties (SPD) in processing the visual,

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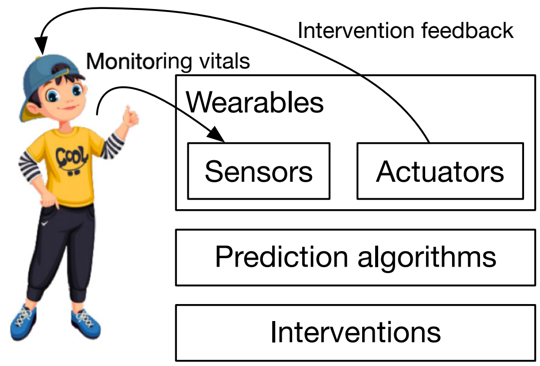

Fig. 1. The underlying idea of adopting wearable technology-based interventions.

auditory, kinaesthetic, tactile, and olfactory sensory systems [6]. Children with SPD are often considered to have sensory integration challenges [46]; it 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 [5]; often expressed verbally (e.g., shouting, screaming, crying), physically (e.g., kicking, lashing out, biting) or both. Physical aggression is particularly debilitating for children with autism; it may happen suddenly and without notice. Sometimes, long after the effect of the stressor (external stimuli), this unpredictable activity makes it difficult to access. Individuals with autism have a hard time understanding the social world and interpreting it, thus resulting in diminished situational awareness (SA). Difficulties with SA act as a barrier to accessing essential human 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 children with autism incorporate a multidisciplinary approach. It includes a combination of psychological and behavioural therapies, speech therapy, educational interventions and psycho-pharmacological treatments.

This paper focuses on non-pharmacologic 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 abnormalities in autistic. The underlying idea is as shown in Fig. 1. The use of assistive technologies in ASD can be helpful in communication, cognition, and sensory integration. In terms of innovation, size, and usability, wearable device development is fast expanding. These technologies can be used in various ways, such as an agent for motivating pedagogy or an alternative and augmentative communication (AAC) device that mainly focuses on communication and social interactions for autistics. This article offers a fresh perspective on existing intervention technologies and presents proactive intervention strategies for managing problem behaviours. One promising approach is collecting physiological biosignal data using commercially available wearable devices to monitor and analyse the data using machine learning (ML) and artificial intelligence (AI) models to predict the onset of problem behaviours [19, 20, 26]. The objective is to provide fresh insight into behavioural actions using wearable devices proactively for rendering empathic multi-modal auditory-visual-tactile feedback.

The paper is organised as it follows. A synopsis of related research works on intervention approaches is provided in Section 2. The research aspirations for a feasible proactive intervention framework are presented in Section 3. Finally, in Section 4, the concluding remarks are outlined.

1.1 Perspective Strategy

The adopted strategy for this perspective paper is to present a scoping assessment of the current literature on wearable assistive devices and digital health interventions. We seek to stimulate global efforts towards the development of wearable intervention technologies for rendering empathic multi-modal auditory-visual-tactile feedback. We made the following decision consciously as this paper is not a systematic literature review but rather a perspective on the current state of the art in wearable behavioural intervention technologies. Primarily, we decided only to include works of literature related to autism spectrum disorder, particularly on problem behaviours (aggression, stereotypy, anxiety) in children with autism. Furthermore, we focused on wearable and mobile technologies for intervention. Particularly, devices that augment the sensory functions of the somatosensory systems, namely visual, auditory, kinaesthetic and tactile - VAKT systems (sensory systems that are concerned with conscious perception of touch, vibration, pressure, temperature, and position).

2 Intervention Approaches

2.1 Visual and Auditory

Virtual reality (VR) has evolved as a feasible cognitive therapeutic alternative in various medical fields, particularly in the treatment of psychological disorders [8]. Virtual reality therapy can help individuals cope with stressful situation [9]. Studies [15, 35] shows vision-based techniques have been shown to reduce problem behaviour.Hence, visual learning methods may be suitable for children with ASD, and visual approaches may aid kids with ASD in addressing interfering behaviours. With advancements in highly immersive head-mounted displays, VR scenarios can be customised for individual needs making visual learning advantageous for individuals in the autism spectrum. Meanwhile, studies have demonstrated that people with autism prefer auditory stimuli to other types of stimuli. When auditory stimuli are presented, they interact with the stimuli for a more extended period than typically developing children. For instance, neurological music therapy has shown to improve social skills in children with autism [12].

2.2 Kinaesthetic and Tactile

Tactile processing difficulties are among the most often reported sensory complaints in ASD patients [50]. As a result, touch must be considered in socio-communicative development, as it lays the groundwork for communication from infancy. Touch is essential in the early development of social connection, communication, and other behaviours in ASD because the perception of touch is essential for laying the foundation for social connection, according to Luken et al. [30]. An intriguing hypothesis about somatosensory modalities is that unmyelinated tactile mechanoreceptors may contribute to tactile hypersensitivity in autism. CT (C tactile) afferents are unmyelinated C fibres that respond to light and stroking stimuli, according to Olusson et al. [39]. Because of its response properties, the CT afferent system is assumed to be specialised for affective touch rather than discriminative touch [34]. Touch and pressure generating modalities are widely used as therapeutics in ASD. Deep pressure touch (DPT), such as that produced by weighted blankets and vests [36], has been shown to help reduce anxiety in children and adults with sensory processing disorders [31]. DPT is commonly regarded as an evidence-based intervention mechanism for reducing anxiety and creating relaxation for people on the autism spectrum who have SPD. According to researchers, DPT is used to assist autistics to minimise anxiety and stay calm in potentially stressful circumstances. Sensory integration therapy, such as DTP, has frequently been used by practitioners, according to Quigley et al. [44]. DTP is a form of tactile stimulation usually involving weighted garments, swaddling, or therapeutic brushing, which is used for sensory stimulus integration, aiming to relax individuals with ASD. In empirical studies, the effects of DTP on attention [14], problem behaviour, self-injury [10], and stereotyped behaviour have been shown to be fairly promising. Based on neuroscience, we can categorise empathy into four pieces: motor, emotional, tactile and cognitive empathy [16,24]. The ability to sense, understand and/or manipulate emotions through touch is known as tactile empathy [48]. Some data suggest that in autism, deliberate motor empathy might be intact, whereas spontaneous motor empathy might not be [17]. These findings motivate the exploration of technologies for rendering cutaneous tactile feedback [7].

2.3 Wearable and Mobile Devices

With constant developments in technology and functional design applications, wearables and mobile technologies are becoming lighter and more discrete. People with autism can benefit from assistive technology in areas such as communication, problem behaviour, and sensory integration [51,52]. Wearable assistive devices that solve these issues could give children and parents more control of the situation. These technologies can be utilised in various ways, such as an advanced audio coding device for communication or as a personal digital assistant that creates regular routines and habits to aid in behaviour management. In a survey by Wali et al. [53], the prevailing implementation, as well as the research challenges of supporting technology for individuals with autism in the workplace and daily life, were presented. The study highlights both therapeutic and technological perspectives. In concordance to this perspective, our research team earlier presented a novel architecture for customising the surrounding environment using information from multiple sensory channels to increase situational awareness [45]. The framework facilitates environmental monitoring by integrating data from several sensor channels, including personal sensors (such as those found on mobile devices) and environmental sensors/actuators (i.e., embedded in intelligent buildings).

3 Proposed Framework

3.1 Premise

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 in autistic individuals, such as 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. With only minor progress in wearable technologies specifically for intervention, this paper proposes a framework for proactive intervention using wearable tactile devices. One interesting possibility is monitoring physiological signals using commercial-off-the-shelf (COTS) sensors to predict the onset of interfering behaviour using ML and AI models and provide proactive behavioural intervention using a wearable tactile device. Evidence [32, 37, 47] implies that problem behaviour causes physiological changes preceding the onset of an emotional meltdown episode (anxiety, problem behaviour). Thus, we investigate if it is viable to exploit the preceding physiological changes, predict an emotional meltdown antecedent to its occurrence in individuals with ASD, and offer behaviour interventions. The framework is divided into two parts, namely *prediction* and *intervention.*

3.2 Psychophysiological 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. 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 it is critical to maintaining homeostasis. Among various neurophysiological traits in autism, the role of ANS has gained more attention. The autonomic nervous system is one of the body's major systems for maintaining homeostasis. The ANS has two main branches: the sympathetic nervous system (SNS) and the parasympathetic nervous system (PNS).

The SNS and PNS work together to maintain homeostasis: a dynamic equilibrium in which continuous changes occur, yet relatively uniform conditions prevail. Individuals are sympathetic-predominant when facing a challenge or stress, whereas parasympathetic activity increases during resting and relaxation [41]. 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 in children with autism [21]. Because sympathetic and parasympathetic modulations control heart rate, HRV is widely accepted and convenient in measuring the signal of autonomic function; its variability can reflect autonomic (especially parasympathetic) activity [18, 28]. 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 overall better mental health. HRV has also been used to investigate physiological differences in generalised anxiety disorder, social anxiety, post-traumatic stress disorder, and panic disorder [1]. 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 Proactive Intervention Framework

To the best of our knowledge, relatively little literature exists that integrates prediction science and intervention mechanisms for problem behaviour in individuals with autism. Current intervention approaches are reactive, i.e., behavioural intervention is only delivered when symptoms of problem behaviour are observed. Based on the hypothesis that physiological changes occur prior to the occurrence of a problem behaviour, this study lays the groundwork for developing user-centred proactive wearable intervention device(s) that reduce the impact of problem behaviour by predicting an emotional meltdown prior to its occurrence in individuals with ASD.

We present a multi-modal user-centred mHealth framework for rendering empathic visual & tactile feedback. As previously stated, the framework is divided into two parts: (a) Prediction of problem behaviour by monitoring biosignals using COTS device; (b) Intervention by rendering somatosensory feedbacks using a novel wearable device. The framework draws influence from applied behavioural analysis (ABA) [4], ABA is an applied science that focuses on creating processes that result in measurable behavioural improvements. Furthermore, the technique also aims to provide socially acceptable solutions to problem behaviours.

Prediction: The ability to assess changes in emotional valence during a meltdown without interfering with everyday routines could revolutionize behavioural healthcare. Researchers [32,37] have studied the practicality of employing wearable biosensors for affect sensing in autistics using data obtained from participants in artificial situations that replicate problem behaviour in autistics, with various methodologies and findings. 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 volunteer data collection from autistic children in naturalistic environments, such as in schools and treatment sessions. This information will be used to develop and train prediction models based on time-series analysis of the gathered biosignal data (HR, HRV, EDA). The prediction model will subsequently be used to detect problem behaviours using biomarkers in real-time using a wearable COTS 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 investigate. *Machine learning* models, both supervised and unsupervised learning algorithms, such as support vector machines (SVM), linear regression classifiers, principal component analysis (PCA) and other pattern recognition algorithms, will be utilized. Furthermore, deep neural networks (DNN) for time series classification is also a worthwhile approach to consider for developing a prediction algorithm. [13].

Intervention: Existing research provides some evidence that the tactile prompt can increase verbal initiation for children with autism [2,49]. However, a hypothesis that has not yet been tested is whether incorporating a tactile stimulus as an intervention mechanism regulates problem behaviours in children with autism. Based on this hypothesis, the ultimate goal of our research is to develop a real-time automated problem behaviour prediction system that parents, teachers, and caregivers may utilize to deliver just-in-time intervention for children with autism. As mentioned in the section 2.2, CT (C tactile) afferents are a type of unmyelinated, low-threshold mechanoreceptive unit found in humans on hairy but not glabrous skin. 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 present a novel wearable device that stimulates CT afferent neurons to provide empathic tactile feedback for situational awareness.

Mechanical actuators such as haptic force sensors, servo motors, and piezoelectric vibrational actuators are likely components that could generate vibrotactile motions, which mimic the sense of touch and pressure. Studies [3, 33, 42] 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. Based on this theory, coupling thermal stimuli could be a potential candidate for rendering thermo-haptic feedback as a stimulus. By incorporating thermal diodes and other peltier components into the design of the wearable device, we can deliver proprioceptive stimulus such as touch, pressure and thermal through a single wearable device. In addition, employing apparent haptic motions (AHM) cutaneously will help with the spatio-temporal processing of tactile stimuli in autistic children. Apparent motion is observed when two stimuli are presented in alternation at a relatively high frequency. AHM creates the illusion of continuous motion rather than successive and simultaneous movements. Studies [22, 29, 38] have shown that apparent haptic movements could potentially help with social communication.

4 Discussions and Remarks

While many studies have looked into the relationship between physiology and psychology in autism, only a few have looked into predicting problem behaviours using biomarkers in autistics. To the best of our knowledge, relatively little literature integrates prediction and intervention mechanisms for problem behaviour in individuals with autism. This position paper outlines the strategy to investigate the use of physiological biomarkers to predict problem behaviours in children with autism and render empathic tactile feedback for behavioural intervention. This research project relies on two hypotheses: (a) that problem behaviours (aggression, anxiety, stereotypy) cause physiological changes preceding the onset of an emotional meltdown episode; (b) stimulating the somatosensory system reduces the effect of problem behaviours. Noticeably, there is overwhelming evidence suggesting that physiological signals can be used to analyse human psychology. 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 in people on the autism spectrum. We conclude that this research approach is in alignment with works of Goodwin & colleagues [18–21, 23, 40] and Kushki & colleagues [25–27, 43]. However, these works focus exclusively on prediction sciences, they do not offer solutions for the problem behaviour. In the future, our research group is committed to contribute towards the design of a comprehensive framework to combine prediction algorithms and intervention approaches, especially focusing on the use of wearable devices for empathic multi-modal auditory-visual-tactile feedback.

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