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Embodied technologies for stress management in children: A systematic review

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***Abstract*— Stress-related health problems in children have increased in recent years, resulting in significant negative physical and mental impacts on children's daily lives. This systematic review explores the potential of embodied technologies, such as robots, smart wearables, and the Internet of Things (IoT), as tools for managing stress in children. The goal of this systematic review is to identify the design opportunities of embodied technologies in stress management, by looking for answers in terms of different technologies, users, issues, and challenges addressed in the 91 selected papers. Through the frequency and thematic analysis, we identified six main challenges and eight design opportunities for embodied technologies. Where there are gaps and opportunities in research, we propose to focus on connectivity and active sensing through connected objects, by exploring the potential of the Internet of Robotic Things (IoRT) as an M-health solution for providing real-time and personalized stress detection and interventions for children in various daily life settings.**

I. Introduction

A. Stress and Stress Management in Children

Children experience stress as a natural response to the demand of various challenges in everyday life. The experience of acute (short-term) and situational stress is crucial to shaping healthy development because it can have an adverse impact on the brain and body’s stress response systems [1]. However, when stress becomes chronic, overly intense, and persistently unresolved, it can take a tremendous toll on multiple aspects of healthy development, including brain development, hormonal systems, mental health as well as behavioral control [1]. Evidence to date reveals the importance of stress regulation for children in early care and education [1]. Therefore, it is essential for both children and their caregivers to be aware of stress levels and have interventions to cope with stress.

Children with neurodevelopmental disorders such as Autism spectrum disorder (ASD), Attention deficit hyperactivity disorder (ADHD)， and mood disorders are especially prone to negative stress-related consequences because they are more likely to perceive unexpected experiences and everyday social situations as chronically stressful or potentially traumatic [2]. Furthermore, these groups of children frequently struggle with understanding, communicating, and regulating their emotions [3]. Therefore, caregivers play a vital role in assisting with stress management for children with neurodevelopmental disorders. However, the process of stress management, including detecting stress, providing feedback, and regulating stress, requires professional knowledge, is very time and energy-consuming, and brings high costs. Several parts of this process can be automated by using non-invasive novel technologies such as robots as companions and wearable sensors for stress detection [4], [5].

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B. Embodied Technology for Stress Management

Technologies, especially embodied technologies, offer a range of options to support children in managing their stress and improving their mental health. The goal of using embodied technology is to create a seamless and effortless interaction between humans and technology, through which technology becomes an extension of our bodies and senses. Various kinds of embodied technologies, including robots, smart wearables, and augmented reality, have been exploited and evaluated by researchers and practitioners for stress management.

Previous review papers in the field of embodied technology in mental health applications mostly focused on one specific technology and its application. Blake et al. [6] conducted a review of smart wearable technologies for monitoring stress-related physiological data. Welch et al. [7] overviewed machine learning (ML) technology and Artificial Intelligence (AI) applications for children that allowed remote diagnosis of psychiatric diseases. Many studies have looked into the use of robots as mental health interventions for children. Socially assistive robots (SAR) have been integrated into conventional therapies for helping children with stress management [8]. Kabacińska et al. [9] conducted a scoping review and found that robot interventions positively impact children’s mental health. Robot interventions are typically incorporated into engaging child-robot interactions. Aside from robots, interactions between children and other tangible objects, such as interactive toys, have been shown to improve children’s mental health and well-being. Ofir et al. [10] provided an overview of interactive technologies for emotion regulation (ER) training in a recent review study. The review found design opportunities created by interactive technologies but technical challenges in terms of integrating sensing with diagnosis, and interventions were noted in most of the reviewed articles [10].

Applying IoT in psychological applications has gained much attention in recent research as it provides holistic solutions and technical infrastructures. In their survey, Vahdat et al. [11 concluded that IoT had been implemented with a focus on morale improvement, psychological diagnosis, and mental health monitoring, where IoT can provide better solutions for system design, data mining, hardware invention, and signal processing. Yet, no review has a comprehensive evaluation or discussion on embodied technologies that are embedded in everyday physical objects and offer bodily-based physical experiences for managing stress in children, especially in relation to connectivity and embodiment. The current review aims to investigate embodied and connected technologies applied to stress management in children. We aim to identify the design and research opportunities mainly from technical perspectives in supporting this emerging field.

C. *Research questions*

This article provides a systematic review of utilizing embodied connected technologies with the goal of assisting children in managing stress. Through this review, we hope to identify novel perspectives on designing embodied and connected solutions for stress management in children. The main research question is: "What are the potential design opportunities for embodied technologies to support children with stress management?" To answer this question, the following sub-questions were explored and answered:

1) Which embodied technologies have been exploited for stress management in children?

2) Which group of children can benefit from using embodied technologies for stress management

3) What specific issues and challenges can be addressed by embodied technologies in supporting children with managing stress?

II. Methodology

This systematic review followed the process based on the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines[12].

A. *Data Sources and Search Strategies*

We found that studies that used embodied technologies as support tools in psychiatry have sharply increased since 2010 [6]. Therefore, we searched for literature between 2010 and 2023 in electronic databases ACM and Scopus. We chose these databases as they have a comprehensive collection of articles from most fields focusing on technology and HCI. Aligning with the research aims and questions, we retrieved articles that address three aspects of the research focus: “Embodied technology”, “Stress Management”, and “Children”. The search terms were a combination of keywords from the three aspects and their synonyms and spelling variations. Three keywords had to appear in conjunction in the title, abstract, or keywords of the article: 1) **Embodied technology** ("Connected objects" OR "connected things" OR "connected product" OR toy* OR wearable* OR IoT* OR "Internet of Things" OR robot* OR embodied* OR intelligent*) AND 2) **Stress Management** (stress* OR distress* OR anxiety* OR relaxation* OR "emotion regulation") AND 3) **Children** (child*)

B. *Selection Criteria*

We excluded abstracts, review articles, non-English publications, and unpublished materials. Although, the related review articles are discussed in section B of the introduction of this review paper, which supported us in identifying the current gaps of the review papers in this field. We also used the following exclusion criteria: articles only about digital applications such as VR, video games, or mobile applications are excluded; non-technological approaches such as animal therapy or conventional therapies were also excluded; the review focuses only on stress management for children on an everyday basis, therefore, we excluded studies performed with hospitalized children due to physical illnesses and children who have diseases or have experienced traumas; any articles on non-children groups (below the age of 2 or above the age of 12) were excluded.

C. *Evaluation procedures*

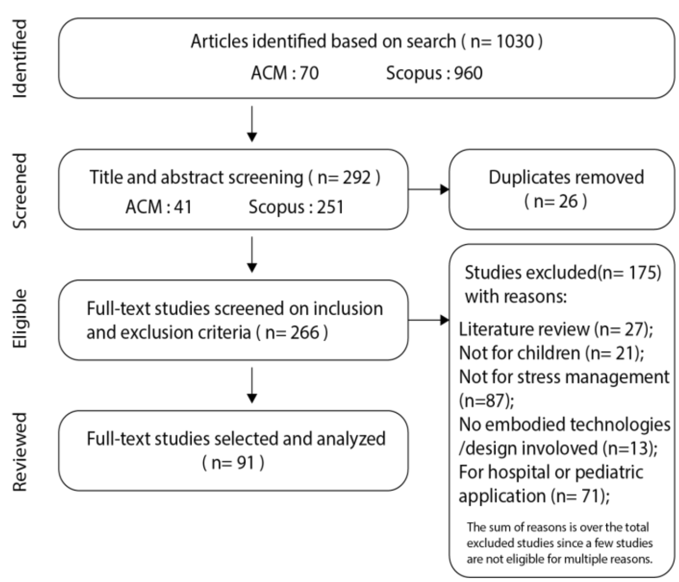
The identified articles were screened by two reviewers. Each reviewer independently screened the titles and abstracts of the articles. The results were compared and discussed with a consensus on the identified studies, and duplicate articles were removed during this step. In the second round of screening, the full-text articles were evaluated by the two reviewers independently. For any discrepancies regarding the inclusion between the two reviewers, a third reviewer finalized the decision. The final included articles were combined and stored in the Dedoose tool [13], where we conducted the thematic analysis.

III. Results

A. *Search results*

The systematic search process is presented in the PRISMA flow diagram (Figure 1). The literature search yielded 1030 articles from 2010 to 2023. We identified 266 articles after screening the titles and abstracts and removing the duplicates. The remaining 266 went through a full-text evaluation, and 175 studies were excluded for not meeting the inclusion criteria (Figure 1), primarily due to not focusing on stress management for children in everyday uses or not being related to embodied technology approaches. The remaining studies in the final selection (n = 91) were analyzed, and information related to the research questions was coded and analyzed in Dedoose tool. A summary of the 91 articles was extracted and stored in a table (check Appendix).

Figure 1. Flow diagram of the results of study selection



B. *Embodied technologies in stress management*

The embodied technologies identified in the selected studies can be categorized into five types. They are robots, wearables, connected objects, IoT, and ML/AI. These technologies are commonly applied to one solution and often co-occur in the reviewed studies. In many application contexts, "Connected objects" and "IoT" are two highly related but distinctive technologies. "Connected objects" refer to physical devices that are connected to the internet or to each other, affording data exchange or interaction between human-object and/or object-object. IoT is a network of physical devices. That is, the underlying network infrastructure that allows connected objects to communicate with each other and with other systems.

In total, 121 codes were generated out of the 91 articles since some applied more than 1 type of technology. Wearables and Robots were the most applied technologies, with them being exploited in 37 and 33 studies, respectively. ML/AI, IoT, and Connected Objects were applied in 20, 18, and 13 articles, respectively. According to the results of the code co-occurrence matrix (Figure 2), IoT mostly appeared together with Wearables. They were combined as solutions and exploited in 8 studies. 5 out of 13 studies extended Connected objects to an IoT system. However, robot technology was mostly exploited independently in the selected studies. Robotic applications were only enhanced by ML in 3 articles. Two studies connected robots to the cloud or with other objects [14]. Wearables have been developed mainly by applying ML/AI technology to improve the reliability of solutions in 10 studies. 3 studies [15]–[17] connected wearables to other smart objects and devices with brain-computer interfaces.

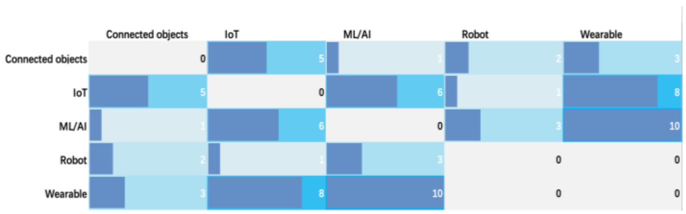


Figure 2. Code co-occurrence matrix regarding to technologies in reviewed studies

Embodied technologies for stress management are often separated into sensing devices and interaction mediums. Figure 3 is a schematic representation of a stress management system with applied embodied technologies.

The input (to the embodied system device) typically measures physiological signals, motion, eye tracking, facial expression, and voice/speech. The physiological signals measuring devices, including heart rate, blood pressure, and skin conductance, were prevalent in the reviewed studies (reported in 34 studies for stress monitoring). In addition, 17 studies detected motion, 7 studies had voice/speech detection, 4 studies analyzed facial expression, 3 studies collected environmental data such as air quality [18] for supporting stress detection, and 2 studies tracked eye movement.

The interaction medium provides different approaches to stress intervention and can be integrated with embodied technologies such as robots, wearables, and connected objects. In the selected studies, interactions are scaffolded through light, sounds, and haptic interfaces with multi-sensorial feedback. In total, 25 studies explored providing interactive feedback in stress management solutions. The most popular modality is haptic feedback which was reported in 13 out of 25 studies using vibration or gentle pressure on children to communicate information or provide relaxation. Light was used in 5 studies, sound in 7 studies, video games in 4 studies, and thermal feedback in 1 study.

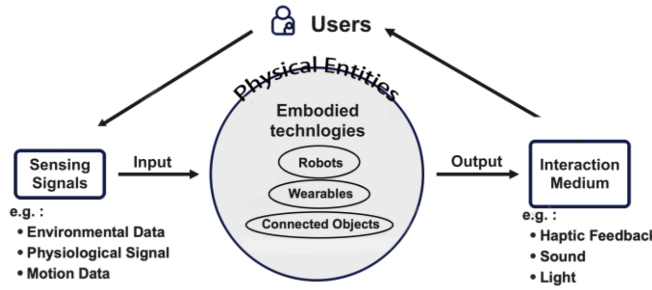


Figure 3. A diagram of a typical stress management system with applied embodied technologies

C. Studies Focused on different groups of children

Our analysis showed a clear difference in stress management between neurotypical children and children with ASD, ADHD, OCD, and mood disorders. Only 27 studies were performed for neurotypical children, with the remaining 64 studies focusing on various kinds of neurological developmental or mood disorders. Children with ASD got the most attention, accounting for 47 studies which is more than half of the total number of reviewed studies.

D. Main issues and challenges in utilizing technologies in stress management for children

We carried out a thematic analysis, which showed six challenges, listed in Table I. The most frequent difficulties mentioned in 37 articles were related to therapy delivery, clinical training, and daily care. There are many time and effort constraints in offering traditional therapy or training without the support of emerging technologies. The second most common issue is the lack of reliable data. Currently, poor reliability in stress prediction occurs due to a lack of contextual data inputs, intelligent predicting models, and difficulties in interpreting stress states in children. This challenge was reported in 26 studies, addressing the concerns of the data source, data type, data quality, and decision-making accuracy. The problem of limited interactivity was addressed in 17 studies. In particular, physical items provide limited tangible contact, and there is a lack of engagement between caregivers/therapists and children during human-machine interaction. Six papers looked at the effectiveness of embodied technologies in stress management due to a lack of clinical validation and clinical strategy guidance. Furthermore, 5 studies found that the diverse characteristics of how children react to stressors, particularly children with ASD, necessitate a certain degree of personalization in the design. There are also some shortfalls of the passive monitoring system, such as privacy concerns and poor product usability, which were addressed in 5 studies.

TABLE I. THEMATICAL ANALYSIS RESULTS OF MAIN ISSUES AND CHALLENGES

Main issues and Challenges themes	Number of studies	Detailed aspects
Delivering therapy /clinical training /daily care	37	- Professional therapy is inaccessible for all children (e.g.,[8], [19], [20]) - Low efficaciousness of treatment (e.g.,[21], [22]) -lack of emerging technologies support(e.g.,[23])
Low reliability of stress prediction or decision making	26	-Lack of data source(such as contextual data) (e.g.,[18], [24], [25]) -Lack of / low accuracy of stress prediction system(e.g.,[26], [27]) - Hard to interpret and perceive stress/emotion states and low-self awareness(e.g.,[28], [29])
Limited Interaction	17	-Limited embedded outputs capabilities (e.g., [30], [31]) -limited interaction with tangible objects (e.g.,[20]) -Robot lack of social and emotional interaction (e.g.,[32], [33]) - limited technology-enabled interaction between caregivers and children (e.g.,[34])
Heterogeneous feature of children	5	-Different sensory requirements and different preferences of emotion/communication expression(e.g., [3], [35]) -Different spectrum profiles (e.g.,[36])
The efficiency of applying embodied technologies in stress intervention	6	-Lack of integration of prediction and intervention in solution(e.g.,[30], [37]) -Lack of integration with clinical strategies(e.g.,[38])
Shortfalls of the passive monitoring system	5	-Missing connectivity to collect and communicate through physical objects(e.g.,[39]) -Privacy concern(e.g.,[40]) -Product usability (e.g., [41], [42])

E. *Design opportunities created by embodied technologies in stress management for children*

The thematic analysis revealed 8 design opportunities that were elaborated upon in Table II. The potential of using IoT and robots for different aspects of stress management has been widely discussed. The opportunities of applying IoT for mobile health and exploiting robots to complement existing interventions were reported in 28 and 24 studies, respectively. 25 studies have explored and suggested extending the means of interaction, especially tangible interactions through connected objects. 23 studies saw the potential of using physiological signals as stress indications, and 14 studies suggested using contextual data such as speech and environmental data to improve the accuracy of the stress detection system.

Furthermore, 4 studies designed active monitoring systems based on human and connected objects interaction that indicated a great potential to detect stress. 10 studies emphasized the importance of engaging caregivers and therapists in children-object interaction, which has been proven to have a positive impact on stress regulation for children. In addition, personalization (7 studies) refers to the opportunity to design adaptable or intelligent solutions that meet the heterogeneous feature of children. As a result, to be more precise in decision making and effective in stress intervention. Implementing ML/AI models can also help achieve this objective. According to 13 studies, ML/AI allowed a reliable system to detect stress and adapt to individual preferences.

TABLE II. THEMATICAL ANALYSIS RESULTS OF DESIGN OPPORTUNITIES

Opportunity themes	Number of studies	Detailed aspects
IoT for Mhealth	28	- Detecting stress state and delivering in-time intervention(e.g.,[43], [44]) -Remote supervision and therapy(e.g.,[24], [45]) -Connectivity for connecting multi-stakeholders(e.g.,[40], [46])
Robots as complement to existing interventions	24	-Robot-assisted intervention(e.g.,[47], [48]) -Animal-like robots(e.g.,[49], [50])
Extend the means of interaction	25	-Extend interaction medium and have more embodied tangible interaction(e.g.,[30], [51], [52]) -Active monitoring by providing natural interaction (e.g.,[39], [42])
Physiological signals as stress indications	23	- It is feasible that use physiological data to indicate stress(e.g., [53])
Context data for stress indication	14	-Integrating context data for validating stress states(e.g.,[25], [54])
ML/AI models for supporting stress prediction and regulation	13	-Improve accuracy in detecting stress state(e.g.,[40], [44]) -Learn individual preference for a personalized intervention(e.g., [33])
Caregiver and therapist involvement	10	-Engage caregiver in the interaction by using connected objects(e.g.,[17], [55]) - Robot or objects facilitate caregiver/therapist-children interaction(e.g.,[8], [34]) - Caregiver strategies, annotation, and decision(e.g.,[23], [56])
Personalization	7	-Personalized stress detection system(e.g.,[57]) -Personalized stress intervention techniques (e.g.,[15], [35])

IV. DISCUSSION

Based on the findings, we identified several research trends as well as under-explored but intriguing research directions. We see them as research opportunities and discuss them from four viewpoints.

A. *Stress management in children with ASD: Embodied and Connected solutions*

More than half of the reviewed studies (52%) focused on designing embodied technologies that can be used to aid in the diagnosis, stress detection, stress regulation, and clinical treatment of children with ASD. Compared to typical children, children with ASD often experience high anxiety and stress levels. Many children with ASD are not aware of their stress or have difficulties communicating distress to family and caregivers [3]. In response to this challenge, many wearable sensors [30], [58] were developed to passively monitor physiological changes [59] and track body motion [60]. AI algorithms were further trained to predict stress states. However, it is still challenging for caregivers to manage the stress of children with ASD without experts' support. With the development of network technologies in recent years, several studies [43], [61] proposed exploiting IoT systems as an

M-health solution for providing real-time stress detection and interventions in various daily life settings. Robots play a vital role in stress intervention for children with ASD. Twenty-one studies provided robot solutions, mostly with the purpose of supporting therapy training [49], [62] by observing children's motivation, anxiety and providing interaction with SAR [4]. Most robotic interventions are stand-alone solutions. Only two studies connected robots with other objects [25] or included robots into IoT systems [41] for stress management aid in children with ASD. These studies indicate the potential of connectivity that enables information exchanges and expands the competencies of robots, other connected objects, and users in stress management.

ASD is a highly heterogeneous disorder. Heterogeneity refers to different degrees of severity, intelligence, and comorbidities [63]. There is no one-size-fits-all strategy to follow, and each approach should allow a certain level of personalization [36]. Embodied technologies with the embedment of various sensors and actuators enable diverse and flexible feedback and interaction. It allows designers and researchers to develop a personalized solution [35] for stress management in children with ASD.

Only a few of studies [67], [68] have incorporated embodiment and connectivity into a single system. We encourage researchers and designers to consider these research paths for developing a holistic mental healthcare system, from stress detection to stress interventions, by connecting multi-stakeholders and intelligent objects.

B. *Technology-mediated interaction between children and caregiver: foster caregivers' involvement*

Most of the stress interventions provided by embodied technologies are a closed loop where the interaction is restricted between the child and the machine, as Figure 3 shows. It neglects the critical role of caregivers and therapists that takes place in stress management for children. Caregivers and therapists are not only able to contribute to stress detection by annotating and validating the stress states, but also by providing guidance and strategies for relaxation [23], [68]. Existing robot intervention research shows that caregivers' involvement in emotion regulation for children relates directly to the child's emotional coping and regulatory skills [23]. Research from Rasouli et al., [8] encouraged alleviating stress for children with social anxiety through triadic social interaction between the child, robot, and caregiver or therapist. In addition to robots, embodied technologies, especially these smart and interactive everyday objects such as toys and wearables, have great potential to facilitate caregiver-child interaction in stress-related intervention practices. Some embodied tangible smart toys [34], [64] and robots [49], [67] engaged parents with the intervention and guided emotion-targeting parent-child interaction. Connecting these everyday objects through the internet with an IoT infrastructure is another approach to encourage caregiver involvement. Connected wearables [55] that provide affect regulation to children with ASD allow caregivers to customize the vibratile intervention, follow the effect on their own side, and make adjustments if needed.

However, caregivers' stress states can affect the quality of interaction between the caregiver and the child, and even influence the child's cognitive development [65]. Therefore, caregivers' stress reflection is indispensable for supporting and interacting with children. Dyadic Mirror concept [65] attempted to use a connected smart mirror to foster parental capacity in daily parent-child interaction. It helped parents reflect and be aware of their stress states, thereby avoiding increasing children's stress by improper parenting strategies.

C. *Passive Sensing and Active Sensing Through Connected Objects*

Stress monitoring through physiological, environmental, and behavioral signals requires sensors embedment in wearables and ubiquitous home health monitoring systems. These monitoring processes that don't require active input from the individual are so-called passive sensing. Most reviewed studies leveraged connected wearables for passive sensing of stress-related data to better estimate the stress level of users. However, there are many shortfalls regarding the passive monitoring system. For instance, measuring children's physiological signals by itself can bring additional stress, especially for children who are oversensitive to these wearable sensors [42]. Wearable devices are thus not the best choice for every child group. Therefore, wearables can be replaced by everyday objects as in the work of Li and colleagues [69]. Other active monitoring systems were proposed with the advantages of being non-invasive, highly interactive, and personalized. Studies leveraged connected robots [41], [67], connected toys [66], and connected everyday objects [39], [69] that collected stress-related data while providing interaction and real-time intervention to children. The technologies regarding connectivity and embodiment extended the possibilities and forms of active sensing systems, enabling stress detection and intervention through playful and natural interaction with objects around children's everyday life.

D. *Internet of Robotic Things*

Robots have shown promising results in providing stress-related therapeutic support [19] due to their embodiment and ability to engage patients in long-term relationships. IoRT is an IoT system when one intelligent object is a robot. Specifically, robots or robotic devices are connected to the internet, enabling them to exchange information with other internet-connected devices and users. IoRT in stress management extends robots' capability to receive and process stress-related information from various sources, including wearable sensors [67], connected toys, and other devices. In the meantime, IoRT enables a more sophisticated and advanced intervention system involving multi-stakeholders [25], like caregivers and domain experts, besides children. The use of IoRT in mental health is still an under-explored domain of applying embodied technologies. Only 3 studies found by our search explored connecting robots to the internet with the aim of engaging caregivers. The toy robot Tiglo [66] is one example. In another study, robot Kaspar was connected to wearable sensors for adapting interactive strategies depending on the received stress states of children [25]. A new study [67] that appeared after the search for this systematic review took place. It also reports a robot that gets information from a wearable about the stress and pain levels of a child during the interaction and responds in an emotionally appropriate way. IoRT as an integrated solution of connectivity and embodiment, has the potential to enrich the possibilities for empowering children with personalized and engaging systems for managing stress in their everyday life.

V. Conclusion

Our review provided an overview of embodied technologies' stress-related applications, challenges, design, and research objectives. This review sought to identify potential design opportunities generated by embodied technologies for assisting children in dealing with stress in their everyday lives. The findings from the 91 articles show that children with ASD are an important target group that can benefit from stress management with the help of embodied technologies. Wearables for stress detection and robot-assisted therapy, in particular, are well-studied uses. We see opportunities in combining these technologies. However, there are many remaining issues, such as the reliability and efficiency of design, shortfalls of passive sensing, and limited interaction. These led to future opportunities to design a connected system that engages caregivers, connected objects, and robots to provide children with real-time and personalized stress management solutions.

Appendix

Summary Table of Reviewed Article is available at: https://drive.google.com/file/d/18iETM1nswbuX57CykZrlgDTrxe8BJe3x/view?usp=sharing

References

[1] N. Scientific Council, 'Excessive stress disrupts the development of brain architecture', *J. Child. Serv.*, vol. 9, no. 2, pp. 143–153, 2014.

[2] C. M. Kerns, C. J. Newschaffer, and S. J. Berkowitz, 'Traumatic Childhood Events and Autism Spectrum Disorder', *J. Autism Dev. Disord.*, vol. 45, no. 11, pp. 3475–3486, Nov. 2015.

[3] B. Blobel, P. Pharow, and L. Parv, *PHealth 2013: Proc. of the 10th Int. Conf. on Wearable Micro and Nano Technologies for Personalized Health*. IOS Press, 2013.

[4] R. B. Burns, H. Seifi, H. Lee, and K. J. Kuchenbecker, 'Getting in touch with children with autism: Specialist guidelines for a touch-perceiving robot', *Paladyn J. Behav. Robot.*, vol. 12, no. 1, pp. 115–135, Jan. 2021, doi: 10.1515/pjbr-2021-0010.

[5] F. Fioriello *et al.*, 'A wearable heart rate measurement device for children with autism spectrum disorder', *Sci. Rep.*, vol. 10, no. 1, Art. no. 1, Oct. 2020, doi: 10.1038/s41598-020-75768-1.

[6] B. A. Hickey *et al.*, 'Smart Devices and Wearable Technologies to Detect and Monitor Mental Health Conditions and Stress: A Systematic Review', *Sensors*, vol. 21, no. 10, p. 3461, 2021, doi: 10.3390/s21103461.

[7] V. Welch *et al.*, 'Use of Mobile and Wearable Artificial Intelligence in Child and Adolescent Psychiatry: Scoping Review', *J. Med. Internet Res.*, p. e33560, Mar. 2022, doi: 10.2196/33560.

[8] S. Rasouli, G. Gupta, E. Nilsen, and K. Dautenhahn, 'Potential Applications of Social Robots in Robot-Assisted Interventions for Social Anxiety', *Int. J. Soc. Robot.*, vol. 14, no. 5, pp. 1–32, Jul. 2022,

[9] K. Kabacińska, T. J. Prescott, and J. M. Robillard, 'Socially Assistive Robots as Mental Health Interventions for Children: A Scoping Review', *Int. J. Soc. Robot.*, vol. 13, no. 5, pp. 919–935, Aug. 2021,

[10] O. Sadka and A. Antle, 'Interactive Technologies for Emotion Regulation Training: A Scoping Review', *Int. J. Hum.-Comput. Stud.*, vol. 168, p. 102906, Dec. 2022, doi: 10.1016/j.ijhcs.2022.102906.

[11] H. Vahdat-Nejad *et al.*, 'Impact of the Internet of Things on Psychology: A Survey', *Smart Cities*, vol. 5, no. 3, pp. 1193–1207, Sep. 2022, doi: 10.3390/smartcities5030060.

[12] 'Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement| Annals of Internal Medicine'. https://www.acpjournals.org/doi/full/10.7326/0003-4819-151-4-200908180-00135 .

[13] 'Home | Dedoose'. https://www.dedoose.com/

[14] J. Albo-Canals, D. Feerst, D. de Cordoba, and C. Rogers, 'A Cloud Robotic System based on Robot Companions for Children with Autism Spectrum Disorders to Perform Evaluations during LEGO Engineering Workshops', in *Proc. of the 10th ACM/IEEE Int. Conf. on Human-Robot Interaction Extended Abstracts*, New York, NY, USA, Mar. 2015, pp. 173–174.

[15] A. N. Antle, E. S. McLaren, H. Fiedler, and N. Johnson, 'Design for Mental Health: How Socio-Technological Processes Mediate Outcome Measures in a Field Study of a Wearable Anxiety App', in *Proc. of the 13 Int. Conf. on Tangible, Embedded, and Embodied Interaction*, New York, NY, USA, Mar. 2019, pp. 87–96.

[16] F. Garzotto, M. Gelsomini, A. Pappalardo, C. Sanna, E. Stella, and M. Zanella, 'Using Brain Signals in Adaptive Smart Spaces for Disabled Children', in *Proceedings of the 2016 CHI Conference Extended Abstracts on Human Factors in Computing Systems*, New York, NY, USA, May 2016, pp. 1684–1690. doi: 10.1145/2851581.2892533.

[17] F. Hamidi, M. Merino, I. Gomez, S. Lopez, A. Molina, and M. Baljko, 'A Wearable System for Multisensory Stimulation Therapy for Children', in *Proc. of the 2017 CHI Conference Extended Abstracts on Human Factors in Computing Systems*, NY, 2017, pp. 1655–1662.

[18] A. A. Schultz *et al.*, 'Investigating Cumulative Exposures among 3- to 4-Year-Old Children Using Wearable Ultrafine Particle Sensors and Language Environment Devices: A Pilot and Feasibility Study', *Int. J. Environ. Res. Public. Health*, vol. 17, no. 14, Art. no. 14, Jan. 2020.

[19] 'Emobie™: A robot companion for children with anxiety'.

[20] M. Alemi, A. Meghdari, and N. S. Haeri, 'Young EFL Learners' Attitude Towards RALL: An Observational Study Focusing on Motivation, Anxiety, and Interaction', in *Social Robotics*, Cham, 2017, pp. 252–261. doi: 10.1007/978-3-319-70022-9_25.

[21] H. Kumazaki *et al.*, 'An Intervention for Children with Social Anxiety and Autism Spectrum Disorders Using an Android Robot', in *New Frontiers in Artificial Intelligence*, Cham, 2017, pp. 470–477.

[22] N. Theofanopoulou, K. Isbister, J. Edbrooke-Childs, and P. Slovák, 'A Smart Toy Intervention to Promote Emotion Regulation in Middle Childhood: Feasibility Study', *JMIR Ment. Health*, vol. 6, no. 8, p. e14029, Aug. 2019.

[23] K. Isbister *et al.*, 'Design (Not) Lost in Translation: A Case Study of an Intimate-Space Socially Assistive robot; for Emotion Regulation', *ACM Trans. Comp..-Hum. Interact.*, vol. 29, no. 4, p. 32-36, Mar. 2022,

[24] J. Primbs *et al.*, 'The SSTeP-KiZ System—Secure Real-Time Communication Based on Open Web Standards for Multimodal Sensor-Assisted Tele-Psychotherapy', *Sensors*, vol. 22, no. 24, Art. no. 24, Jan. 2022, doi: 10.3390/s22249589.

[25] B. Coşkun *et al.*, 'Stress Detection of Children with Autism using Physiological Signals in Kaspar Robot-Based Intervention Studies', in *2022 9th IEEE RAS/EMBS Int. Conf. for Biomedical Robotics and Biomechatronics (BioRob)*, Aug. 2022, pp. 01–07.

[26] M. Kalanadhabhatta, A. M. Santana, D. Ganesan, T. Rahman, and A. Grabell, 'Extracting Multimodal Embeddings via Supervised Contrastive Learning for Psychological Screening', in *10th Int. Conf. on Affective Computing and Intelligent Interaction*,Oct.2022, pp. 1–8.

[27] A. Puli and A. Kushki, 'Toward Automatic Anxiety Detection in Autism: A Real-Time Algorithm for Detecting Physiological Arousal in the Presence of Motion', *IEEE Trans. Biomed. Eng.*, vol. 67, no. 3, pp. 646–657, Mar. 2020, doi: 10.1109/TBME.2019.2919273.

[28] K. Takahashi, S. Matsuda, and K. Suzuki, 'A Smart Clothe for ECG Monitoring of Children with Autism Spectrum Disorders', in *Computers Helping People with Special Needs*, 2016, pp. 555–562.

[29] B. C. Loftness, J. Halvorson-Phelan, A. O'Leary, N. Cheney, E. W. McGinnis, and R. S. McGinnis, 'UVM KID Study: Identifying Multimodal Features and Optimizing Wearable Instrumentation to

Detect Child Anxiety', in *44th Conf. IEEE Engineering in Medicine & Biology Society (EMBC)*, Jul. 2022, pp. 1141–1144.

[30] G. Goncu-Berk, T. Halsted, R. Zhang, and T. Pan, 'Therapeutic Touch: Reactive Clothing for Anxiety', in *Proceedings of the 14th EAI International Conference on Pervasive Computing Technologies for Healthcare*, New York, NY, USA, Feb. 2021, pp. 239–242.

[31] F. Garzotto, M. Gelsomini, A. Pappalardo, C. Sanna, E. Stella, and M. Zanella, 'Using Brain Signals in Adaptive Smart Spaces for Disabled Children', in *Proc. of 2016 CHI Conference Extended Abstracts on Human Factors in Computing Systems*, NY, 2016, pp. 1684–1690.

[32] C. D. Wallbridge *et al.*, 'Using a Robot Peer to Encourage the Production of Spatial Concepts in a Second Language', in *Proceedings of 6th Int. Conf. on Human-Agent Interaction*, NY, 2018, pp. 54–60.

[33] C. H. Park, H. Javed, and M. Jeon, 'Consensus-Based Human-Agent Interaction Model for Emotion Regulation in ASD', in *HCI International 2019 - Posters*, Cham, 2019, pp. 295–301.

[34] N. Theofanopoulou and P. Slovak, 'Exploring Technology-Mediated Parental Socialization of Emotion: Leveraging an Embodied, In-situ Intervention for Child Emotion Regulation', in *Proc. of the 2022 CHI Conf. on Human Factors in Computing Systems*, New York, Apr. 2022.

[35] W. Simm *et al.*, 'Anxiety and Autism: Towards Personalized Digital Health', in *Proc. of the 2016 CHI Conference on Human Factors in Computing Systems*, New York, 2016, pp. 1270–1281.

[36] P. Parvin, M. Manca, C. Senette, M. C. Buzzi, M. Buzzi, and S. Pelagatti, 'Alexism: ALEXa supporting children with autISM in their oral care at home', in *Proc. of the 2022 International Conference on Advanced Visual Interfaces*, New York, NY, USA, Jun. 2022, pp. 1–5.

[37] S. Balaji, F. Sanfilippo, M. W. Gerdes, and D. Prattichizzo, 'A Perspective on Intervention Approaches for Children with Autism Spectrum Disorder', in *Intelligent Technologies and Applications*, 2022, pp. 132–143. doi: 10.1007/978-3-031-10525-8_11.

[38] M. H. J. Smakman *et al.*, 'A Trustworthy Robot Buddy for Primary School Children', *Multimodal Technol. Interact.*, vol. 6, no. 4, Art. no. 4, Apr. 2022, doi: 10.3390/mti6040029.

[39] T. Hosoi, K. Takashima, T. Adachi, Y. Itoh, and Y. Kitamura, 'A-blocks: recognizing and assessing child building processes during play with toy blocks', in *SIGGRAPH Asia 2014 Emerging Technologies*, New York, NY, USA, Nov. 2014, pp. 1–2. doi: 10.1145/2669047.2669061.

[40] Y. Choi, Y.-M. Jeon, L. Wang, and K. Kim, 'A Biological Signal-Based Stress Monitoring Framework for Children Using Wearable Devices', *Sensors*, vol. 17, no. 9, Art. no. 9, Sep. 2017, doi: 10.3390/s17091936..

[41] J. Albo-Canals, D. Feerst, D. de Cordoba, and C. Rogers, 'A Cloud Robotic System based on Robot Companions for Children with Autism Spectrum Disorders to Perform Evaluations during LEGO Engineering Workshops', in *Proceedings of the Tenth Annual ACM/IEEE International Conference on Human-Robot Interaction Extended Abstracts*, New York, NY, USA, Mar. 2015, pp. 173–174.

[42] E. Vonach, M. Ternek, G. Gerstweiler, and H. Kaufmann, 'Design of a Health Monitoring Toy for Children', in *Proceedings of the The 15th International Conference on Interaction Design and Children*, New York, NY, USA, Jun. 2016, pp. 58–67. doi: 10.1145/2930674.2930694.

[43] Md. I. Mamun, A. Rahman, Md. A. Khaleque, Md. A. Hamid, and M. F. Mridha, 'AutiLife: A Healthcare Monitoring System for Autism Center in 5G Cellular Network using Machine Learning Approach', in *2019 IEEE 17th Int. Conf. on Industrial Informatics (INDIN)*, Jul. 2019, pp. 1501–1506.

[44] C. B. Redd *et al.*, 'Physiological Signal Monitoring for Identification of Emotional Dysregulation in Children', in *2020 42nd Annual International Conference of the IEEE Engineering in Medicine & Biology Society (EMBC)*, Jul. 2020, pp. 4273–4277.

[45] Y. Gizatdinova *et al.*, 'PigScape: An embodied video game for cognitive peer-training of impulse and behavior control in children with ADHD', in *Proceedings of the 24th International ACM SIGACCESS Conference on Computers and Accessibility*, NY, Oct. 2022, pp. 1–4.

[46] Y. Qian, D. Chang, and Y. Sun, 'BUDDY: A Companion Product Design for Alleviating Parent-Child Separation Anxiety', in *2022 IEEE 25th International Conference on Computer Supported Cooperative Work in Design (CSCWD)*, May 2022, pp. 221–226.

[47] Y. Xia, C. Wang, and S. S. Ge, 'Design and Development of Dew: An Emotional Social-Interactive Robot', in *ICSR* 2016, pp. 621–629.

[48] A. Taheri, A. Shariati, R. Heidari, M. Shahab, M. Alemi, and A. Meghdari, 'Impacts of using a social robot to teach music to children with low-functioning autism', *Paladyn J. Behav. Robot.*, vol. 12, no. 1, pp. 256–275, Jan. 2021, doi: 10.1515/pjbr-2021-0018.

[49] I. van den Berk-Smeekens, M.W.P. de Korte, M. van Dongen-Boomsma, *et al.* Pivotal Response Treatment with and without robot-assistance for children with autism: a randomized controlled trial. *Eur Child Adolesc Psychiatry* vol. 31, 2022, pp. 1871–1883.

[50] J. Bharatharaj, L. Huang, A. Al-Jumaily, R. E. Mohan, and C. Krägeloh, 'Sociopsychological and physiological effects of a robot-assisted therapy for children with autism', *Int. J. Adv. Robot. Syst.*, vol. 14, no. 5, p. Sep. 2017.

[51] K. Vitullo and M. Benitez, 'A wearable therapy and technology garment for kids: the underlying super hero', in *Proceedings of the 2019 ACM International Symposium on Wearable Computers*, New York, NY, USA, Sep. 2019, pp. 329–333. doi: 10.1145/3341163.3346933.

[52] M. Rocha *et al.*, 'Towards Enhancing the Multimodal Interaction of a Social Robot to Assist Children with Autism in Emotion Regulation', in *Pervasive Comp. Technol. for Healthcare*, 2022, pp. 398–415.

[53] J. Nguyen, R. E. Cardy, E. Anagnostou, J. Brian, and A. Kushki, 'Examining the effect of a wearable, anxiety detection technology on improving the awareness of anxiety signs in autism spectrum disorder: a pilot randomized controlled trial', *Mol. Autism*, vol. 12, no. 1, p. 72, 2021.

[54] A. Thierfelder *et al.*, 'Multimodal Sensor-Based Identification of Stress and Compulsive Actions in Children with Obsessive-Compulsive Disorder for Telemedical Treatment', in Proc. *44th IEEE Engineering in Medicine & Biology Society (EMBC)*, 2022, pp. 2976–2982.

[55] 'FAR: End-to-End Vibrotactile Distributed System Designed to Facilitate Affect Regulation in Children Diagnosed with Autism Spectrum Disorder Through Slow Breathing | Proc. of 2022 CHI Conference on Human Factors in Computing Systems'.

[56] A. Catala, H. Gijlers, and I. Visser, 'Guidance in storytelling tables supports emotional development in kindergartners', *Multimed. Tools Appl.*, Oct. 2022, doi: 10.1007/s11042-022-14049-7.

[57] N. I. Abbasi, M. Spitale, J. Anderson, T. Ford, P. B. Jones, and H. Gunes, 'Can Robots Help in the Evaluation of Mental Wellbeing in Children? An Empirical Study', in *2022 31st IEEE International Conference on Robot and Human Interactive Communication*, Aug. 2022, pp. 1459–1466. doi: 10.1109/RO-MAN53752.2022.9900843.

[58] A. J. Masino *et al.*, 'm-Health and Autism: Recognizing Stress and Anxiety with Machine Learning and Wearables Data', in *2019 IEEE 32nd International Symposium on Computer-Based Medical Systems (CBMS)*, Jun. 2019, pp. 714–719. doi: 10.1109/CBMS.2019.00144.

[59] A. Gul Airij, R. Bakhteri, and M. Khalil-Hani, 'Smart Wearable Stress Monitoring Device for Autistic Children', *J. Teknol.*, vol. 78, no. 7–5, Jul. 2016, doi: 10.11113/jt.v78.9453.

[60] E. W. McGinnis *et al.*, 'Wearable sensors detect childhood internalizing disorders during mood induction task', *PLOS ONE*, vol. 13, no. 4, p. e0195598, Apr. 2018, doi: 10.1371/journal.pone.0195598.

[61] T. Z. Fadhil and A. R. Mandeel, 'Live Monitoring System for Recognizing Varied Emotions of Autistic Children', in *2018 Int. Conf. on Advanced Science and Engineering*, Oct. 2018, pp. 151–155.

[62] C. Pop, B. Vanderborght, and D. David, 'Robot-Enhanced CBT for dysfunctional emotions in social situations for children with ASD', *J. Evid.-Based Psychother.*, vol. 17, pp. 119–132, Sep. 2017.

[63] 'DSM'. https://www.psychiatry.org:443/psychiatrists/practice/dsm.

[64] 'Toy Design for Emotion Regulation: Current and Potential Research Opportunities | Interaction Design and Children'.

[65] W. Kim *et al.*, 'Dyadic Mirror: Everyday Second-person Live-view for Empathetic Reflection upon Parent-child Interaction', *Proc. ACM Interact. Mob. Wearable Ubiquitous Technol.*, vol. 4, no. 3, p. 86:1-86:29, Sep. 2020, doi: 10.1145/3411815.

[66] C. V. Joseph, 'Tiglo: Inhabiting Toys Through Expression Mirroring', in *Proceedings of the Fourteenth International Conference on Tangible, Embedded, and Embodied Interaction*, New York, NY, USA, Feb. 2020, pp. 943–948.

[67] O. I. Ferrari, F. Zhang, A. A. Braam, J. A. van Gurp, F. Broz, and E. I. Barakova, "Design of child-robot interactions for comfort and

distraction from post-operative pain and distress," *Companion of the 2023 ACM/IEEE Int. Conf. on Human-Robot Interaction*, 2023.
[68] K. Frederiks, P. Sterkenburg, E. Barakova, and L. Feijs, "The effects of a bioresponse system on the joint attention behaviour of adults with visual and severe or profound intellectual disabilities and their affective mutuality with their caregivers," *Journal of Applied Research in Intellectual Disabilities*, vol. 32, no. 4, pp. 890–900, 2019.
[69] J. Li, E. Barakova, J. Hu, W. Staal, and M. van Dongen-Boomsma, "Apen: A stress-aware pen for children with autism spectrum disorder," *Artificial Intelligence in Neuroscience: Affective Analysis and Health Applications*, pp. 281–290, 2022.