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Special Issue
Affective Computing: Technology and Application

Edited by
Dr. Andrea Generosi and Prof. Dr. Maura Mengoni

MDPI

https://doi.org/10.3390/app15010256

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Evaluating the Role of Interactive Encouragement Prompts for Parents in Parent–Child Stress Management

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Abstract: Parental involvement is crucial for children's stress management, and co-regulation of stress can have a positive effect. To facilitate parental involvement in children's stress management in learning, we proposed an embodied connected system, which provides stress detection, stress information feedback, and encouragement prompts, aiming to help parents better understand and engage in children's stress-regulation process. This article focuses on the impact of interactive encouragement prompts provided to parents on children's stress management. The within-group experiment was used to collect stress data and scales from 36 parent–child groups during a controlled learning experiment, and semi-structured interviews were conducted with parents and children. The results indicate that the encouragement prompts provided to the parents enhance the effectiveness of stress relief in children facilitated by parental involvement. In particular, the psychological stress was reduced, and the communication between parents and children became more effective. In addition, active parental involvement and timely encouragement prompts can improve children's stress-coping abilities, providing an interactive intervention approach for learning stress management.

Keywords: stress management; parent–child interaction; learning stress; embodied technology; connected system

Academic Editors: Maura Mengoni and Andrea Generosi

Received: 11 December 2024
Revised: 25 December 2024
Accepted: 26 December 2024
Published: 30 December 2024

Citation: Wang, P.; Huang, L.; Dai, G.; Li, J.; Hu, J.; Barakova, E.; Yao, C.; Ying, F. Evaluating the Role of Interactive Encouragement Prompts for Parents in Parent–Child Stress Management. *Appl. Sci.* **2025**, *15*, 256. https://doi.org/10.3390/app15010256

1. Introduction

Stress management is essential to help children in elementary school to recognize and regulate stress. Asian children commonly encounter stress when preparing homework [1], which has a negative impact on their well-being and development. Performance, intolerance of failure, and expectations from parents and friends are the main stress factors. Meanwhile, limited coping skills and lack of stress awareness constrain children's ability to manage stress [2]. Among the various factors contributing to improving children's stress status, parental involvement has proven to be an effective strategy [3,4]. Children's vulnerability in stressful learning situations also highlights the necessity of active parental support [5]. Schools and teachers often encourage parental involvement in homework activities to enhance educational outcomes [6]. Children aged 5–12 often struggle with timely emotional self-regulation in task performance [7]. As a result, seeking social support or care is an essential approach. In home environments, positive emotional feedback from parents benefits children in regulating their emotions during stressful times [8]. Parental involvement encompasses a wide range of behaviors, from direct participation in children's learning activities to emotional and psychological support. Parent–child interaction is beneficial in addressing learning and developmental challenges, including fostering children's adaptability to social environments. Children with high levels of parental involvement in learning often exhibit lower stress levels, underscoring the positive influence of parents on their emotional well-being [2]. Compared to secondary school students, primary school students tend to seek connection and validation from their parents [9], offering potential opportunities for parents to assist in managing learning stress. On average, children spend 1.5 h daily on homework, and their ability to effectively regulate stress is not innate but cultivated through supportive relationships and positive environmental factors [10]. However, children's self-regulation or external support mechanisms are not always feasible or sufficient in real-time stressful situations, particularly for those facing academic pressure [11]. To bridge this gap, our research explores the potential role of human–computer interaction (HCI) in enhancing children's awareness and regulation of stress. By creating a real-time, context-sensitive stress management support system, we aim to improve the effectiveness of stress-coping strategies.

The concept of co-regulation of stress, where parents and children collaboratively manage stress, holds the potential for fostering positive dynamics in parent–child relationships. This approach not only alleviates immediate stress but also equips children with long-term coping mechanisms. Traditional stress interventions are often reactive, occurring long after stress has already manifested. However, there is growing recognition of the importance of addressing stress in real time. Timely intervention ensures that children maintain an optimal state for learning and development [12]. The emergence of interactive technologies has introduced valuable tools for stress management [13]. Integrating embodied technologies into home learning environments represents an innovative approach [13]. These technologies, ranging from simple applications to advanced interactive devices, serve as mediums for stress detection and enable effective parental engagement through intuitive feedback mechanisms. By transforming stress management into an engaging and interactive process, these tools have the potential to create interactive learning stress management systems in everyday settings, thereby enhancing children's learning experiences [14]. Advances in biofeedback technology, combining biosensors, computing platforms, and human–computer interaction, also offer new pathways for stress regulation and relaxation training [15]. Stress regulation plays a pivotal role, as self-awareness of stress enables reflection and adjustment [16]. Biofeedback systems not only enhance user's self-awareness of their physiological states but also help develop stress-regulation skills [17]. However, the application of biofeedback systems in everyday home environments remains underexplored.

This study introduces an integrated stress management system comprising three components: stress detection via a wearable device based on a PPG sensor, stress information feedback provided by a vaporizer on the desk for children, and encouragement prompts displayed on a laptop screen for parents. The system aims to support parents in more effectively engaging in their children's learning stress management. In particular, the encouragement prompt is designed to facilitate open communication about stress between parents and children, exploring its role in supporting stress regulation and parent–child interaction during learning. Encouragement prompts may serve as a key mechanism for strengthening parent–child relationships. Preliminary findings indicate that a stress feedback system can act as a proxy for children's stress states, encouraging open expression of stress. The encouragement prompt system demonstrates potential benefits in mitigating stress during learning when parents are actively involved. The study collected data on heart rate variability (HRV) as an indicator of stress, stress scale assessments, process records, and semi-structured interviews with children and parents. It aims to elucidate the role of embodied technology-based stress management tools in regulating children's stress during learning. Additionally, it explores the impact of interactive encouragement prompts within the context of parental involvement. The findings offer insights into designing stress interventions grounded in parent–child interaction mechanisms.

The main contributions of this article are as follows:

1. We proposed a connected system for home learning environments, which provides a management strategy based on encouragement prompts and stress information to assist parental involvement in children's stress management;
2. We investigated the impact of the encouragement prompt component of this system on parental involvement in children's stress management through user studies using a mixed-methods experimental design. The results demonstrate that the system helps reduce children's psychological stress during learning, enhances parental engagement, and fosters parent–child connection;
3. We provide insights for designing systems for parent–child collaborative stress management.

2. Related Work

2.1. Stress Management in Children

Children are more susceptible to stressors [18], which can hinder social learning, empathy, and constructive interaction. The results highlight the importance of managing stress during childhood. Traditional stress management methods include mindfulness practices [19,20], guided breathing [21,22], body scanning [23], and sensory exercises [24]. Additionally, guided imagery [25], which focuses on awareness itself, aims to internally enhance children's ability to direct their stress levels [26]. However, traditional stress-coping techniques, while helpful, do not systematically manage children's stress during the learning process.

Over the past decade, the HCI field has studied methods to externalize stress. In personal informatics, self-tracking technologies have been used to collect behavioral or physiological data [27], simplifying stress into data representations [28]. Designers have experimented with various expressive forms, such as statistical graphs [29], natural language, and graphical metaphors [30,31], to better support user reflection and self-awareness. Other studies have proposed intuitive physiological feedback to represent individual stress levels [32], enabling more effective stress management strategies. For example, aSpire, a mobile pneumatic haptic device, provides subtle tactile feedback to help users regulate their breathing frequency, promoting relaxation [33]. Recently, HCI researchers have shown growing interest in children's stress regulation [13], especially for those with developmental disorders such as autism spectrum disorder (ASD) and attention deficit hyperactivity disorder (ADHD) [34]. Embodied technologies, including robots, smart wearables, and Internet of Things (IoT) devices, have emerged as effective tools for managing children's stress. For instance, robots like RETMAN [35] teach children RE&CBT principles to manage test anxiety. Abbas and colleagues used a crowd-powered robot to regulate the stress of students [36]. Similarly, Porrble [37] simulated the heartbeat to encourage interaction through touch and stroking to support in-the-moment emotion regulation. Grounded in Gross' Process Model [38], Porrble employs a three-tiered intervention strategy: offering immediate comfort during emotional arousal, fostering continued interaction with the tool, and promoting children's emotional control. Real-time interventions, such as biofeedback and virtual reality environments, and social robots emphasize learning-by-doing and immediate application of skills, yet their integration into daily routines remains challenging. In situ mechanisms bridge this gap by providing wearable technologies and mobile applications for immediate contextual support, guidance, and reminders [39,40]. However, HCI has yet to deeply explore stress management during learning, particularly within home environments.

2.2. Parent–Child Co-Regulation

Children aged 6–12 are developing cognitive strategies for constructive stress management, with cognitive flexibility being essential for coping with daily stress. Children seeking support from parents during this period is a critical strategy for coping with stress. Despite the benefits of parental involvement, the dynamics of parental involvement are influenced by factors such as parenting stress and motivational beliefs. Semke et al. [14] investigated how parenting stress affects family involvement in children with disruptive behaviors, highlighting the importance of addressing motivational and stress-related factors for effective parental engagement strategies. Other studies have revealed nuanced ways in which parental stress and engagement strategies influence children's educational and psychological outcomes [10]. Positive emotional responses and effective communication from parents provide the foundation for successful parent–child interaction [4,41]. When parents demonstrate understanding, patience, and empathy, they create a supportive environment conducive to stress resolution for both parties. Many studies emphasize enhancing parent–child relationships from an emotional perspective, including empathy strategies, understanding emotional dynamics, and utilizing technological tools to foster deeper connections [42,43]. For instance, Kim et al., [44] designed Dyadic Mirror, a tool that offers a second-person perspective to help parents enhance perspective-taking and self-awareness during face-to-face interactions with their children. While the literature highlights the critical role of parental involvement in children's stress management and overall well-being, this study further explores how embodied technology can support parents' involvement in managing children's stress.

2.3. Embodied Technology for Creating Connected Systems

With the rapid development of educational technology, integrating embodied technology into home learning environments offers opportunities for parents to engage in managing children's learning stress. Embodied technologies blend physical interaction with digital information, transforming everyday objects into stress management tools that support parental involvement. The concept of embodied cognition posits that cognitive processes are grounded in bodily interactions with the world, serving as the foundation for designing embodied technologies for educational purposes [13]. By leveraging this principle, embodied technologies such as robots, smart wearables [45], and IoT devices can be designed to respond to and influence users' states, promoting positive learning processes. In stress management, these technologies serve as mediums to detect and respond to stress signals while encouraging parental participation through intuitive feedback mechanisms. For example, wearable sensors can collect and analyze children's physiological signals (e.g., heart rate variability and respiration rate). Wearable devices for stress management have been extensively studied in HCI [46], providing a direct and personalized approach to tracking children's well-being. These devices enhance stress awareness [47], enable more accurate stress monitoring [39,40], and facilitate timely or long-term stress regulation [48].

Recent reviews emphasize the potential of embodied technologies in managing children's stress, highlighting key design opportunities and challenges [13], particularly in home settings. However, only a few studies [49–51] recognize the correlation between caregiver involvement and children's emotional coping and regulation. Embedded systems can adapt various feedback and intervention strategies based on assessed stress levels [52]. While many studies focus on digital applications as stress intervention mediums, embodied technologies offer a more seamless way to reflect children's stress states and support co-regulation in home learning environments. For instance, serious games like Mindlight employ neurofeedback and CBT techniques to train children in anxiety and depression prevention [53], while RAGE-Control integrates heart rate monitoring to train children to manage emotions in fast-paced and high-stress scenarios [54]. Based on this, by designing an integrated system for stress management (including stress detection, information feedback, and encouragement prompts), this article explores the mechanisms of parent–child interactions supported by the provision of encouragement prompts and their impact on alleviating stress during the learning process. The study further investigates how embodied technologies can transform objects in home environments into connected tools to promote parental involvement in managing children's learning stress.

3. Methodology

3.1. Experimental Hypothesis

To investigate children's stress management during learning, we propose a system-supported encouragement strategy provided by prompts to the parents. We designed a system that converts detected children's stress into visualized feedback to both children and parents, promoting awareness-based stress regulation. The representation of children's stress manifests in both physiological and psychological dimensions, with self-awareness and parental involvement serving as key approaches to stress management. We hypothesize that a system providing encouragement prompts can facilitate better parental involvement in managing children's stress, leading to reductions in both physiological and psychological stress levels.

H1: *The encouragement prompts provided by the system when stress in children is detected will help parents effectively engage in stress management.*

H2: *Children's physiological and psychological stress will decrease under the condition of encouragement prompts provided by the system.*

3.2. Participant Recruitment

To test the hypothesis, we contacted primary school principals to reach students and their parents. We selected children and their parents who were willing to participate in the experiment and obtained consent from all participants. A total of 53 children aged 6–12 years and their parents were recruited from Yiwu Art Primary School and Nanchang Third Primary School after completing an initial recruitment survey that included questions about their ethnicity, the children's grade levels, ages, gender identities, and parental education levels. To control variables and respect the will of the child, children should accept the testing device, consider that the device itself did not cause additional discomfort or stress, and be willing to present their stress through the stress feedback device. Children should be physically healthy without significant chronic illnesses, psychological disorders, or abnormal behaviors. Those who do not meet these criteria will be excluded. When exploring the bias of willingness to participate on outcomes, we found that almost all parents contacted by teachers at the time of recruitment showed willingness to participate, except for a few who were unable to attend due to time. A total of 36 children and their parents were finally selected to participate in the experiment. Each child was accompanied by a parent. At the start of the study, a researcher reviewed the consent forms with the families, addressing any questions they had. Both the children and their families were required to sign individual consent forms before proceeding. The study protocol and data collection process were reviewed and approved by the Research Ethics Committee of Tai Zhou Rehabilitation Hospital (IRB Protocol Approval #K20240331). Data collected through the system were accessible exclusively to the family members and the research team. All data were recorded and analyzed with parental consent. Upon study completion, all data were removed from Cloud storage, encrypted, and restricted to the research team for analysis. See in Table 1. Finally, the participants and their parents were compensated with a souvenir worth USD 12.

Table 1. Information statistics of participants.

Basic Information	Category	Number	Age (M ± SD)	Percentage
Gender	Male	21	10.02 ± 0.53	58.33%
	Female	15	9.94 ± 0.85	41.67%
	All	36	9.99 ± 0.68	100%
Grade	Third	6	9	16.7%
	Fourth	24	9.94	66.7%
	Fifth	3	11	8.3%
	Sixth	3	11.33	8.3%
Parents	Father	5	39.8 ± 3.9	13.9%
	Mother	31	39.0 ± 4.75	86.1%
	All	36	39.11 ± 4.6	100%

To control for the effects of individual differences, such as stress response, in this experiment, a within-group experiment was conducted to validate two hypotheses. Each group of children and their parents participated in two experiments: one using only the stress detection and feedback device and another using the stress detection, feedback, and encouragement prompt devices. The experimental design allowed each group to experience both conditions, providing a more comprehensive understanding of their own stress management. All recruited children were right-handed, and all parents had at least a high school education.

3.3. System Design

We designed CoManager, an integrated system for stress management, deployed on the child's desktop. The system consists of a stress detection device (based on a PPG sensor), a vapor generator (child's side), and a screen interface (parent's side). The child wears the stress detection device on their left hand and completes the given learning tasks. Parents accompanied their children during the learning process. Real-time stress data from the child are processed by a computer and transmitted to the information feedback device.

The information feedback device consists of two parts: a vaporizer that informs the child about their current stress level and a user interface on the computer that informs the parent of the child's stress state. When stress levels rise, the system triggers corresponding real-time changes in the feedback device. The parent-side user interface displays the child's stress status and, when stress is elevated, prompts the parent to provide supportive interactions. The interface generates encouraging phrases such as "Try a different approach; I believe you can find the answer" or "It's normal (for child) to face challenges; let's think of other ways together" [55]. The system workflow is presented in Figure 1.

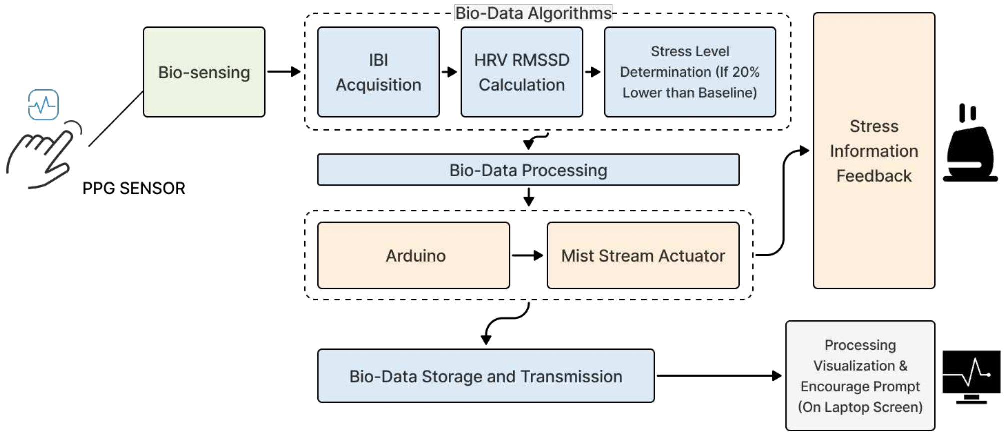


Figure 1. The working principle of the CoManager system.

3.3.1. Stress Detection

The researchers used a proven photoplethysmogram (PPG) sensor (MDL0025, 3.3 V, 10 mA) [56] to detect the heart rate of children during the task. The PPG sensor was placed tightly against the child's left-hand index finger and secured with skin-friendly paper tape. The PPG sensor was connected to the Arduino UNO R3 mainboard via Dupont wires. The detected heart rate data were transmitted to the Arduino mainboard, where an algorithm was processed to derive Inter-Beat Interval (IBI) and Heart Rate Variability (HRV) data. We chose the Root Mean Square of Successive Differences (RMSSD), a statistical measure used in HRV analysis, as the HRV parameter for its widespread use in short-term stress assessment [57]. It reflects the child's stress levels during the process. Higher RMSSD values indicate lower stress, while lower RMSSD values indicate higher stress.

3.3.2. Stress Information Feedback

In the CoManager system, stress information is presented through two devices, one for the child and one for the parent. As shown in Figure 2, a vaporizer device (based on atomizer plates: 5 V, 300 mA, 110 KHz, 2 W) that presents information for children in a subtle manner during the learning process, minimizing distractions while allowing the child to be aware of their stress levels. The vaporizer uses pure water without additives, which is converted into fine mist vapor. This process does not involve any chemical reactions or generate new substances. The vaporizer has two outlets: one operates when the stress level is relatively low, and both operate when the stress level is high, providing an increased level of alerts. Each outlet is connected to the Arduino NANO ATMEGA (Zhangzhuo Technology, Shenzhen, China) via Dupont wires. NANO ATMEGA boards are connected to the Arduino UNO R3 mainboard. The Arduino UNO R3 (Emakefun, Shenzhen, China) mainboard is powered by an external battery pack (9 V, PKCELL) to ensure adequate power supply for all modules. The Arduino UNO R3 is connected to a computer via a USB interface. After the heart rate data are collected by the PPG sensor and transmitted to the computer, they are processed through an algorithm to generate stress values, which then control the vaporizer and user graphical interface for stress information display. A graphical interface for parents, developed using the PROCESSING program on the computer, allows the parent to view the baseline stress value (measured before the experiment and not changing during the process), real-time stress data, and stress status interpretation.

Figure 2. (**a**) Homework session settings. The system is in its default state and provides encouragement prompts on the screen for parents when the stress level is high. (**b**) Children do homework with parent involvement during the experiment.

3.3.3. Encouragement Prompt

We categorize stress levels into four tiers: Stressful (BaseRMSSD $*$ 0.5 > RMSSD), Normal (BaseRMSSD $*$ 0.50 < RMSSD $\leq$ BaseRMSSD $*$ 0.80), Good (RMSSD > BaseRMSSD $*$ 0.80), and Relaxed (BaseRMSSD = 0). When RMSSD falls below 0.8 $*$ BaseRMSSD, the vaporizer in front of the child starts working, and the parent-side user interface displays the corresponding stress status along with encouraging prompts in Chinese. The system will guide parents to further know and confirm their children's stress status by using sentences like "You can observe whether the child exhibits many extra movements, such as scratching their head, biting their hands, or other restless behaviors", "You can try asking the child how they feel, such as whether they are encountering a difficult problem". If the child is struggling to solve the current difficulty, the system will prompt the parent with suggestions derived from a database of similar statements originally sourced from previous research on encouragement: "I know you are nervous about the test, but you 've studied hard. No matter how it turns out, you've done your best" or "It's normal to face challenges, I believe you can find the answer" [58].

3.4. Experimental Design

To assess the impact of specific interventions on the same participants, i.e., the difference in performance under different conditions and minimize the effects of individual differences, the experiment employed a within-subject design. To facilitate easier participation for students and parents, the researchers set up a room in a primary school equipped with desks and chairs to simulate a home learning environment. The room was quiet and comfortable, without any external distractions. Once the experiment began, only the parent and child were present in the room. The positions of the experimental equipment were fixed. The child's stress sources came from completing a school assignment within a limited time, and no additional stress sources were introduced. The homework tasks were designed to be in line with the child's current learning stage, but the difficulty was set slightly higher. Teachers help to select and assign the homework. To control the variables, the integrity and consistency of the stress detection and feedback equipment were maintained. Before the experiment, a class of students with similar study performance rankings was selected, excluding those with exceptionally high or low academic performance. All the children came from medium-to-high-level education, and the class was positioned in the upper-middle range within the school. One group of children and their parents participated in two experiments in sequence, with the same stress detection and feedback equipment used in both. The difference between the two experiments was the presence of the encouragement prompts system. Stage 1 does not provide encouragement prompts, while Stage 2 does. The researchers had previously asked about the participants' feelings toward the equipment, and only those parents and children who believed that the equipment would not induce stress were selected. To eliminate the effects of participant fatigue, a 3 min break was provided between the two experiments to help the children regain focus.

3.5. Study Procedure

The researchers invited a group of children and parents into a prepared room, which was equipped with desks, chairs, a CoManager system, and video recording equipment. Since the children wrote with their right hands and wore the PPG sensor on their left hands, the children sat on the left while the parents sat on the right. Before the experiment began, the parents signed an informed consent form, and the children verbally expressed their consent, agreeing to the recording of the experiment. Once seated, the researchers explained the overall experimental process, the tasks to be completed, the questionnaire, and the equipment's working principle to the parents. The same content was explained to the children using simpler and more understandable language. The researchers attached the PPG sensor to the child's left hand and secured it with skin-friendly paper tape. The experiment lasted 1.5 h in total, including the semi-structured interview: a 5 min baseline measurement [57,59], followed by 20 min for the first stage, 20 min for the second stage, and a 3 min break in between. During the baseline measurement, the parent guided the child to stay calm and try to read the homework questions. The purpose of the baseline measurement was to assess the child's stress state based on real-time HRV values collected during the experiment. After the baseline measurement, the HRV value was displayed on the parent's computer interface, and the experiment began. After each stage of the experiment, the child completed the State-Trait Anxiety Inventory (STAI-C), and the parent completed the STAI and STAI-P [55,60,61]. These anxiety scales are validated by previous research and are often used in short-term stress analysis. During the filling out of the questionnaires, the researchers observed the participants' responses and aided but did not guide or influence the answers. Finally, the researchers conducted a semi-structured interview with both the children and the parents. See Figures 2 and 3.

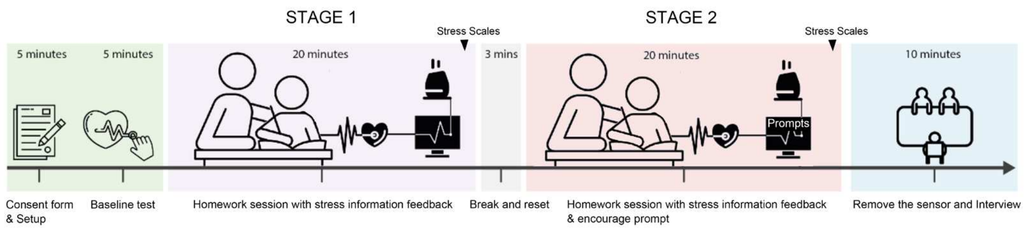


Figure 3. The experiment procedure.

4. Results

The PPG sensor collected the children's heart rate (HR) signals throughout the experiment. Each group of participants was assigned an ID, ranging from C1 to C36, representing their order of participation in the study. We conducted a quantitative analysis and correlation comparison of the heart rate variability (HRV_RMSSD) data, as well as the scores from STAI, STAI-C, and STAI-P scales for 36 children. Figure 4 shows the heart rate variability data for all children. Qualitative analysis was then performed on the video and interview data. This included annotating stress-related behaviors, dialogue data, and interactions in the video recordings using the children's stress data (HRV) according to the timeline of each experiment. After transcribing all types of data, one author generated an initial codebook using thematic analysis (TA) [62] based on their understanding of the data. The initial coding scheme was then reviewed and adjusted by another author. The two authors discussed these adjustments and reached a consensus on the final codebook.

Preliminary results showed that, compared with STAGE 1, the overall trend of RMSSD data and scale scores was consistent in STAGE 2, meaning that RMSSD increased while STAI scores decreased, indicating a reduction in stress. The changes in RMSSD data were not significant, while the changes in most categories of the STAI scale scores were significant. This suggests that the physiological and psychological representations of stress in children do not always align. After introducing the encouragement prompt system, the overall stress of the children was lower, and the conclusions from the semi-structured interviews supported this result.

4.1. Physiological Data Analysis

As shown in Figure 4 and Table 2, we collected HRV data from two experimental stages and plotted them on the same chart. We measured and recorded heart rate (HR) signals using a proven photoplethysmogram (PPG) sensor (MDL0025, 3.3 V, 10 mA) [56] attached to the child's index finger. The HR signals are then transmitted to the system and processed to derive Inter-Beat Interval (IBI) and Heart Rate Variability (HRV) data. Root Mean Square of Successive Differences (RMSSD) is a statistical measure used in HRV analysis and as the HRV parameter for its widespread use in short-term stress assessment [57]. Lower RMSSD values indicate higher stress levels. The RMSSD values for each participant, along with their baseline RMSSD (BaseRMSSD), were recorded in a TXT file in chronological order.

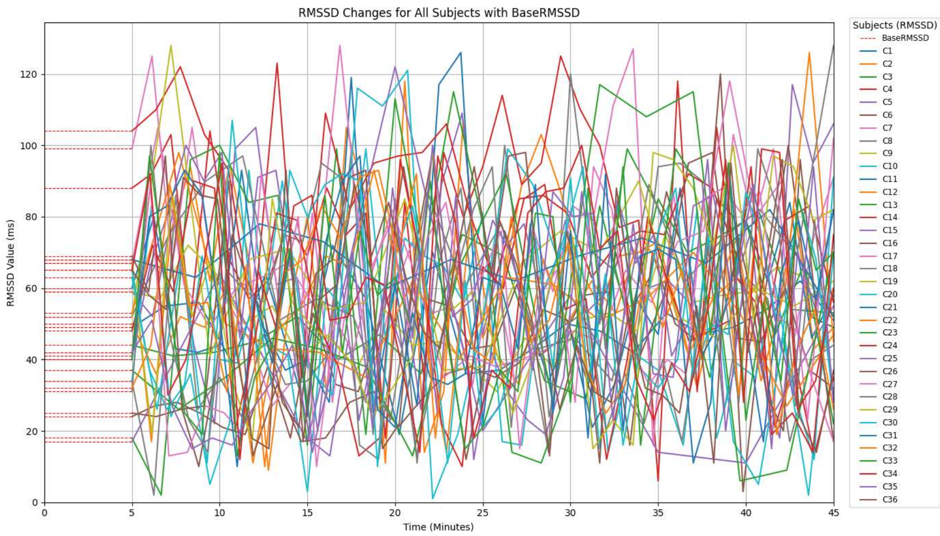


Figure 4. HRV data at two stages for all children.

Table 2. Statistics of HRV data, including mean value and standard deviation.

BaseRMSSD (M ± SD)	Stage 1 RMSSD (M ± SD)	Stage 2 RMSSD (M ± SD)
51.97 ± 20.4	56.62 ± 29.96	57.24 ± 26.73

For later comparison, the RMSSD data were kept in their original sequence, with duplicate, outlier, and zero values removed, retaining only the unique BaseRMSSD. The chart shows significant variations in RMSSD changes across different participants, with considerable individual differences. Some children (e.g., C16, C18, and C22) exhibited lower stress levels in both stages and showed further reduction in stress over time. In contrast, some children (e.g., C7) remained in a higher stress state throughout the experiment. We performed a t-test on HRV data from Stage 1 and Stage 2 (mean value per stage and dynamic data) to compare differences. The Shapiro–Wilk test was used to assess whether the data followed a normal distribution. The result showed a p-value less than 0.05, indicating that the data significantly deviated from normal distribution. Then, the Wilcoxon signed-rank test was applied. The result yielded a p-value of 0.4799 (>0.05), suggesting that the RMSSD difference before and after the introduction of the encouragement prompt system was not significant. We also conducted a non-parametric method (Mann–Whitney U test) to statistically analyze the differences in stage means. The result yielded a p-value of 0.5384 (>0.05), suggesting the encourage prompt for parents did not cause a significant change in children's RMSSD. Therefore, Hypothesis 2 is rejected, as there is no significant stress relief at the physiological level. The means and median RMSSD values for Stage 2 were slightly higher than those in Stage 1, with most participants showing a slight upward trend in RMSSD during the experiment. Compared to Stage 1, Stage 2 RMSSD data were more concentrated and stable.

Additionally, the feedback device itself may have induced a placebo effect, leading children to feel "helped" or "the device can help them," which could have contributed to relaxation and a subsequent increase in HRV. Parental verbal or emotional support, combined with the information feedback from the device, might have provided dual feedback—both behavioral and physiological—helping children regulate themselves and maintain higher HRV.

4.2. Stress Scales Data Analysis

As shown in Table 3 and Figure 5, the results indicate that the mean scores of the STAI, STAI-C, and STAI-P scales decreased to varying degrees, with these changes being statistically significant. This suggests that the overall reduction in stress levels is not attributable to random fluctuations. The findings demonstrate that the encouragement prompt system alleviates children's stress with parental involvement while also improving parents' awareness of their children's stress and slightly reducing parents' own stress levels.

Table 3. Statistical metrics on participants' scores of stress scales, where p-values are reported. A total of 36 children filled in STAI-C forms, and 36 parents filled in STAI and STAI-P forms.

Stress Scale		Mean Score (M ± SD) (Stage 1	Stage 2)	Distribution (Stage 1	Stage 2)	t	p
STAI	S	35.06 ± 8.63	33.67 ± 8.05	35.06 ± 8.63	33.67 ± 8.05	1.4675	0.151
STAI	T	40.5 ± 10.31	38.75 ± 11.15	40.5 ± 10.31	38.75 ± 11.15	2.9389	0.006 **
STAI	TOTAL	75.56 ± 17.31	72.42 ± 16.75	75.56 ± 17.31	72.42 ± 16.75	2.6926	0.010 **
STAI-C	S	33.53 ± 7.06	31.64 ± 6.8	33.53 ± 7.06	31.64 ± 6.8	2.4425	0.020 *
STAI-C	T	34.17 ± 8.91	32.81 ± 8.32	34.17 ± 8.91	32.81 ± 8.32	2.5596	0.015 *
STAI-C	TOTAL	67.69 ± 12.48	64.44 ± 12.02	67.69 ± 12.48	64.44 ± 12.02	2.9183	0.006 **
STAI-P		37.08 ± 9.41	34.58 ± 9.87	37.08 ± 9.41	34.58 ± 9.87	2.6599	0.012 *

* Significant differences. (* $p < 0.050$, ** $p < 0.010$).

As shown in Figure 6, combined with physiological RMSSD data, we preliminarily infer that learning-related stress manifests not only on a physiological level but also on a psychological level. Although the system showed limited effects on reducing physiological stress, it had a more pronounced impact on alleviating psychological stress. In Stage 2, the standard deviations of most scale scores slightly decreased, which may indicate a consistent intervention effect. Additionally, the intervention might have reduced individual differences and score fluctuations caused by randomness, leading to more stable responses to stress across participants. Combined with individual data analysis, we observed that the intervention was particularly effective for high-stress groups, as evidenced by larger reductions in post-test scale scores, contributing to the decrease in standard deviation. However, changes were not significant for some individuals, suggesting variability in the intervention's effectiveness across different participants.

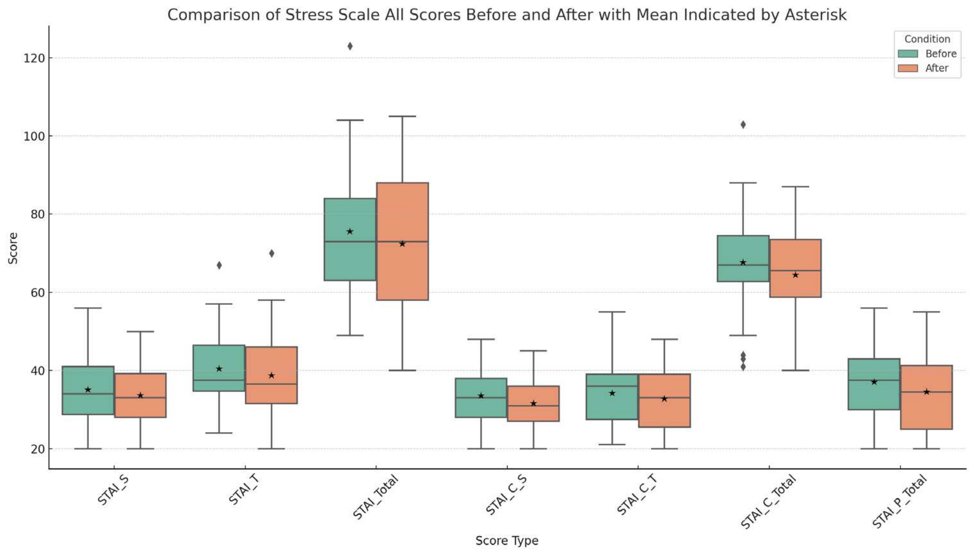


Figure 5. Box plot illustrates stress scales at Stage 1 (before) and Stage 2 (after).

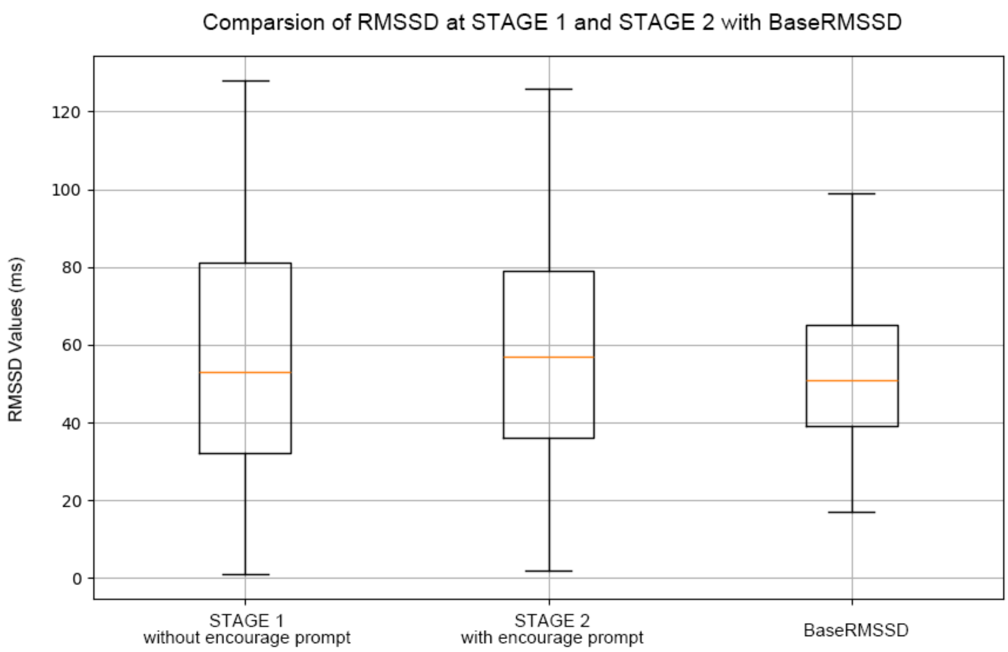


Figure 6. Box plot illustrates the HRV distribution, central tendency, and dispersion.

Figure 5 presents the changes in the three stress scales across the two stages. The mean and median values for each category showed varying degrees of decline in Stage 2. For instance, the mean STAI-C S score decreased from 33.53 to 31.64, the mean STAI-C T score decreased from 34.17 to 32.81, and the mean total STAI-C score decreased from 67.69 to 64.44. All changes were subjected to t-tests, with statistically significant differences observed in all measures except for STAI-S. This indicates that the encouragement prompt system further contributed to reducing children's stress in learning contexts. Moreover, the system also had a positive effect on alleviating parents' stress. Some parents reported that the encouragement prompt system effectively helped reduce their feelings of helplessness when addressing their children's stress.

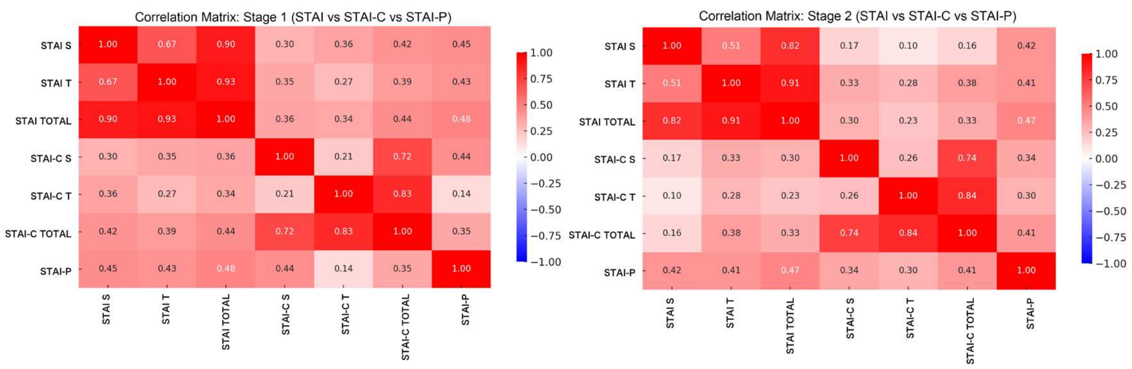
4.3. Correlation Analysis

4.3.1. Correlation Among STAI Subscales

As shown in Table 4 and Figure 7, in Stage 1, the correlations among the STAI subscales were generally high. For example, the correlation between STAI-S and STAI-T was 0.669, and the correlation between STAI-T and the total STAI score was 0.929, indicating a strong linear relationship among the subscale scores before the intervention (encouragement prompt system). However, after the intervention, most correlation coefficients decreased. For instance, the correlation between STAI-S and STAI-T dropped from 0.669 to 0.509, and the correlation between STAI-T and the total STAI score decreased from 0.929 to 0.910. This change may suggest that the intervention partially weakened the correlations among different dimensions of anxiety.

Table 4. Correlation among stress scales (STAI, STAI-C, and STAI-P).

STAGE 1	STAI-S	STAI-T	STAI	STAI-C S	STAI-C T	STAI-C	STAI-P
STAI-S	1.0	0.669	0.897	0.300	0.357	0.424	0.445
STAI-T	0.669	1.0	0.929	0.349	0.270	0.390	0.429
STAI	0.897	0.929	1.0	0.357	0.338	0.444	0.477
STAI-C S	0.300	0.349	0.357	1.0	0.211	0.716	0.435
STAI-C T	0.357	0.270	0.338	0.211	1.0	0.833	0.141
STAI-C	0.424	0.390	0.444	0.716	0.833	1.0	0.347
STAI-P	0.445	0.429	0.477	0.435	0.141	0.347	1.0
STAGE 2	**STAI-S**	**STAI-T**	**STAI**	**STAI-C S**	**STAI-C T**	**STAI-C**	**STAI-P**
STAI-S	1.0	0.509	0.819	0.167	0.095	0.160	0.417
STAI-T	0.509	1.0	0.910	0.326	0.277	0.377	0.407
STAI	0.819	0.910	1.0	0.298	0.231	0.328	0.471
STAI-C S	0.167	0.326	0.298	1.0	0.257	0.743	0.344
STAI-C T	0.095	0.277	0.231	0.257	1.0	0.837	0.304
STAI-C	0.160	0.377	0.328	0.743	0.837	1.0	0.405
STAI-P	0.417	0.407	0.471	0.344	0.304	0.405	1.0



(**a**) (**b**)

Figure 7. Correlation Matrix between STAI, STAI-C, and STAI-P: (**a**) Stage 1 (stress detection, stress information feedback); (**b**) Stage 2 (stress detection, stress information feedback, and encouragement prompts).

Regarding the correlations among the STAI-C subscales, the correlation between STAI-C_S and STAI-C_T in Stage 1 was relatively low at 0.211, indicating a weak association between children's state anxiety and trait anxiety before the intervention. In Stage 2, this correlation increased to 0.257, suggesting a slight enhancement of the relationship between these two dimensions after the intervention. The correlation between STAI-C S and the total STAI-C score increased slightly from 0.716 to 0.743, indicating that the association between trait anxiety and overall anxiety strengthened post-intervention. Additionally, the correlation between STAI-P and STAI-C S decreased from 0.435 to 0.344, while the correlation with STAI-C T increased significantly from 0.141 to 0.304, and the correlation with the total STAI-C score rose from 0.347 to 0.405. This suggests that parents' perception of children's stress became less correlated with children's state anxiety but had a more pronounced impact on their trait anxiety.

After the intervention, many correlation coefficients showed a decline, particularly between the total STAI score and other subscales. This may reflect the intervention's effect in independently improving different dimensions of anxiety, thereby reducing the interdependence among the scales.

4.3.2. Pre-Test and Post-Test Correlation

As shown in Table 5, the pre-test and post-test stress scale data exhibit high correlations with statistical significance. In the Pearson correlation analysis of the same subscales in Stage 1 and Stage 2, STAI-S (r = 0.770), STAI-T (r = 0.948), and the total STAI score (r = 0.916) demonstrated strong correlations, indicating that changes in state anxiety (STAI-S), trait anxiety (STAI-T), and total scores were highly consistent. Similarly, children's state anxiety (STAI-C S, r = 0.776) and trait anxiety (STAI-C T, r = 0.934) also showed strong correlations, suggesting that children's state and trait anxiety exhibited consistent patterns of change before and after the intervention.

Table 5. Pearson correlation coefficient of each stress scale (Pearson's r).

Item	r	*p*-Value
STAI-S	0.770	3.98×10^{-8}
STAI-T	0.948	2.01×10^{-18}
STAI	0.916	4.65×10^{-15}
STAI-C S	0.776	2.60×10^{-8}
STAI-C T	0.934	1.00×10^{-16}
STAI-C	0.852	4.42×10^{-11}
STAI-P	0.830	3.90×10^{-10}

Notably, the highest correlations were observed between STAI-T and STAI-C T, at 0.948 and 0.934, respectively, indicating that post-intervention changes in trait anxiety were remarkably stable and closely aligned with pre-intervention measurements. In contrast, the correlations for state anxiety (STAI-S and STAI-C S) were relatively lower, possibly suggesting that state anxiety is more susceptible to short-term intervention effects, leading to less consistent changes between pre-test and post-test measurements.

Additionally, the statistical significance of the pre-test and post-test correlations further validates the reliability and consistency of the experimental data, demonstrating that the research design captured psychological state changes before and after the intervention, with minimal influence from random noise.

4.3.3. Correlation Between STAI Scales and RMSSD

As shown in Figures 8–11, correlation analysis revealed varying degrees of association between changes in the STAI-C subscale scores and RMSSD (as a physiological indicator of relaxation). The change in STAI-C state anxiety (STAI-C S) showed a weak positive correlation with RMSSD (r = 0.276, $p = 0.192$), suggesting a potential relationship, although it was not statistically significant, as shown in Table 6. Similarly, the correlation between changes in STAI-C trait anxiety (STAI-C T) and RMSSD was weak and negative (r = −0.095, $p = 0.507$), indicating little to no significant interaction between long-term trait anxiety changes and physiological relaxation. The correlation between changes in the STAI-C total score and RMSSD was also weak and positive (r = 0.146, $p = 0.559$) and did not reach statistical significance. Regression analysis further confirmed these weak correlations, with regression coefficients of 0.905 for STAI-C S, −0.693 for STAI-C T, and 0.288 for the STAI-C total score. However, none of these relationships were statistically significant. Overall, the data suggest that the psychological changes in stress levels show a limited association with the physiological relaxation measured by RMSSD, with state anxiety exhibiting a stronger association compared to trait anxiety or the total score.

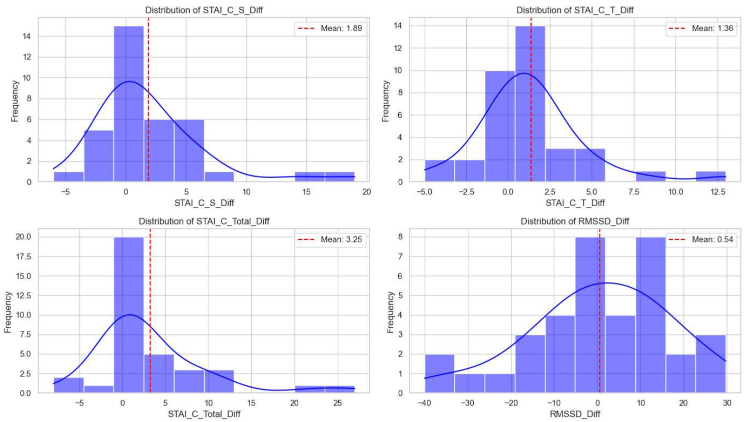


Figure 8. Distribution of stress scales (STAI-C) and RMSSD.

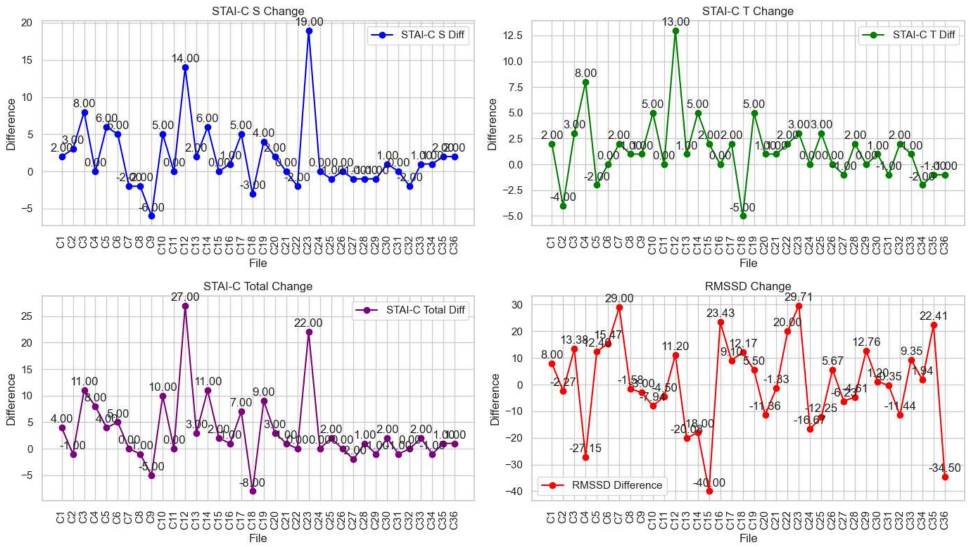


Figure 9. Scores and values change of STAI-C and RMSSD for each participant.

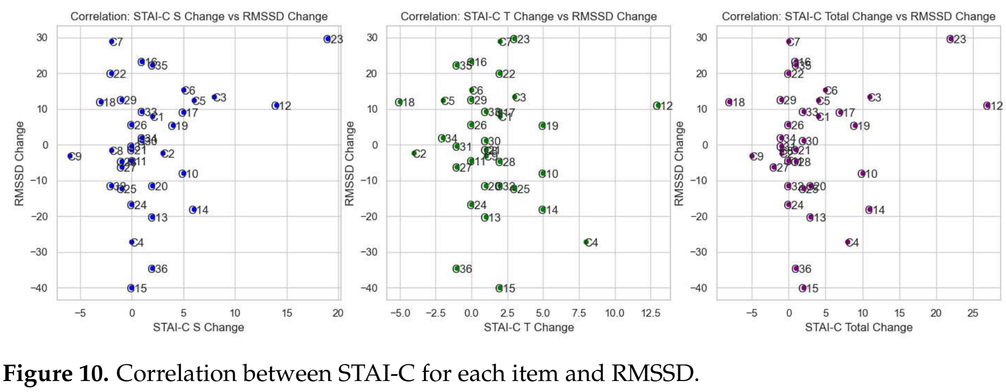


Figure 10. Correlation between STAI-C for each item and RMSSD.

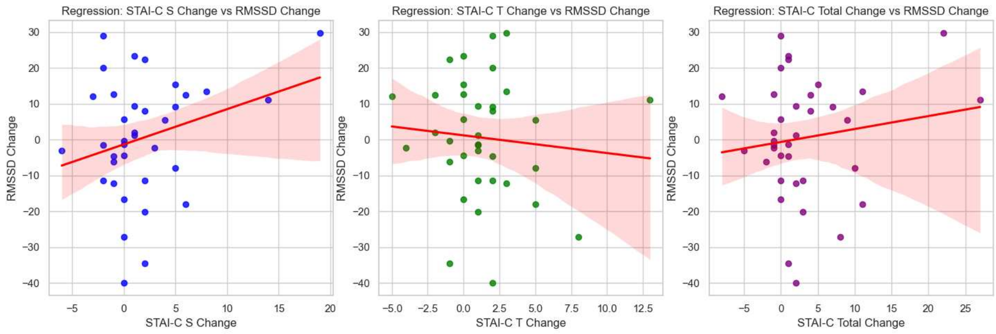


Figure 11. Regression analysis of STAI-C and RMSSD.

Table 6. Statistical metrics on participants' STAI-C and RMSSD data.

	STAI-C S Change vs. RMSSD	STAI-C T Change vs. RMSSD	STAI-C Change vs. RMSSD
Correlation	0.27585968	−0.0953948	0.146008
R-squared (R2)	0.080	0.021	0.017
Regression Coefficient	0.9051	−0.6927	0.2884
Statistical (P>∣t∣)	0.192	0.507	0.559

5. Discussion

In this article, we examined the role of a connected system incorporating stress information feedback and encouragement prompts in managing stress related to children's learning tasks. Based on RMSSD and STAI-C scores, our findings suggest that while physiological (RMSSD) and psychological (STAI-C) stress indicators are not always consistent, the intervention had a more pronounced effect on psychological stress, particularly on self-assessed anxiety, rather than directly influencing the physiological state measured by heart rate variability (HRV).

Our analysis revealed a weak positive correlation between changes in RMSSD and increases in anxiety scores (STAI-C S-state) across the first and second stages. However, this correlation was not statistically significant, with wide variability in the data and broad confidence intervals. These results indicate that, while there is a slight trend toward improvement in both physiological and psychological stress levels, the relationship between the two is not strong enough to establish a clear linear association. This could be attributed to the complexity of stress responses, where physiological changes in HRV may not directly reflect shifts in psychological states like anxiety. Nevertheless, the encouragement prompts provided by the interactive system showed some effectiveness in alleviating psychological stress, as reflected in improvements in STAI-C scores.

These findings support the hypothesis that involving parents in managing their children's learning stress can foster mutual understanding and a shared perspective on stress, thereby improving emotional outcomes. The results underscore the positive impact of parent–child interaction in stress management, with both parties benefiting from the encouragement prompts. Furthermore, the correlation observed between the anxiety levels of children and parents highlights the emotional connection between them, suggesting that family-based interventions may contribute to reducing overall family stress. The relatively low correlation with STAI-S scores implies that the intervention may have a more direct impact on short-term emotional states, such as stress experienced during learning tasks, rather than on long-term or chronic stress.

This study primarily focuses on quantitative data analysis, with the interview findings to be further refined. However, integrating preliminary qualitative insights with quantitative data reveals that the stress management system effectively facilitates direct communication between parents and children while providing valuable guidance for parental involvement. Participants, both children and parents, generally reported a strengthening of the parent–child connection.

Many parents mentioned during interviews that the feedback system enabled them to better understand their children's stress levels, which in turn prompted some to adjust their interactions with their children. Highly educated parents tended to engage more proactively in communication and interaction with their children, whereas less-educated parents often expressed difficulty in knowing how to communicate or assist their children, even when aware of their stress. Most parents believed that the encouragement prompts helped them learn effective communication strategies, thereby fostering healthier parent–child relationships. Similarly, most children reported feeling that their parents had gained a better understanding of their situations, making them more inclined to seek help from their parents. A minority of children, however, expressed a preference for resolving issues independently rather than through frequent communication with their parents. Nevertheless, these children acknowledged that parental support and companionship offered critical emotional encouragement and confidence during pivotal moments.

Future research should explore the augmented effects of biofeedback-based parent–child interactive media on the stress management system and evaluate its long-term efficacy in reducing learning stress and enhancing mechanisms of parent–child interaction. A wireless-connected stress management system is also one of the directions for future exploration. Additionally, there is significant potential to investigate the applicability of the system in various contexts (e.g., schools) and the feasibility of parental remote participation in stress management interventions. Currently, the stress management system has not yet adopted a wireless connection, and the wearing comfort of the sensor has not been explored in depth. In the future, the stress management system can incorporate more comfortable wearing designs and wireless connections, and the encryption of the data could be taken into consideration if applied to group stress management. Additionally, a more diverse group of participants from various backgrounds can be recruited to analyze the pervasive impact, and the system can be enhanced to become more portable and user-friendly, as well as include other physiological metrics (e.g., SDNN) to enable its application in long-term research studies.

6. Conclusions

Our study demonstrates that an interactive system integrating real-time stress feedback and parental encouragement prompts holds the potential for alleviating both psychological and physiological stress in children. By enhancing parent–child interaction, this intervention appears to effectively mitigate stress in learning contexts. These findings highlight the positive role of parental involvement, suggesting that this strategy can provide parents with more guidance and support in communication, thereby offering better emotional support to children and ultimately helping to manage learning-related stress.

Future research should focus on investigating the long-term effects of these interventions, exploring their applicability across diverse educational settings, and examining the underlying mechanisms behind the weak correlation between physiological and psychological stress responses.

Author Contributions: Conceptualization, P.W.; Methodology, P.W. and G.D.; Software, P.W., G.D. and L.H.; Validation, P.W., L.H. and G.D.; Formal analysis, P.W. and L.H.; Investigation, P.W. and G.D.; Resources, P.W., L.H., G.D. and J.L.; Writing—original draft preparation, P.W.; Writing—review

and editing, P.W., L.H. and G.D.; Visualization, P.W. and L.H.; Supervision, C.Y., F.Y., J.H. and E.B.; Project administration, P.W.; Funding acquisition, P.W. and C.Y. All authors have read and agreed to the published version of the manuscript.

Funding: This research was supported by the Fundamental Research Funds for the Central Universities (Grant No. 226-2024-00164), "Leading Goose" R&D Program of Zhejiang (Project No.2023C01216), Zhejiang Provincial Natural Science Foundation of China under Grant No. LR24F020001, Research Center of Computer Aided Product Innovation Design, Ministry of Education.

Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki and approved by the Institutional Review Board of Taizhou Rehabilitation Hospital (IRB Protocol Approval #K20240331, 14 March 2024).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The raw data supporting the conclusions of this article will be made available by the authors on request.

Acknowledgments: We express our gratitude for the collaboration between Zhejiang University and Eindhoven University of Technology. We appreciate all children and their parents who participated in this study. Our sincere thanks to the teachers and staff of Liantang Third Primary School and Yiwu Art Primary School. This project was achievable due to the full support they provided.

Conflicts of Interest: The authors declare no conflicts of interest.

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