Measuring the stress of autistic people with the help of a smartwatch, Internet of Things Technology

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Abstract

This paper presents the outcomes of a research study that aimed to evaluate the anxiety levels of 10 individuals with autism using Internet of Things (IoT) technology, specifically a wireless smart watch. The incorporation of technology into daily life underscores the significance of recognizing its advantages in enhancing the well-being of individuals. The research study was carried out subsequent to an extensive review of the available literature, which explored various approaches to detecting stress utilizing sensors embedded in smart devices through IoT technology. The research was conducted on 10 adults with autism who were instructed to wear the smart watch, which provided measurements of their anxiety levels both in a calm state of mind and when exposed to loud music. The measurements were obtained during periods when the autistic individuals were relaxed, as well as when they were exposed to high volumes of music. The findings are presented in statistical charts after meticulous data analysis and are noteworthy as they validate previous studies on measuring and identifying anxiety in individuals with autism, as well as the disparities found in comparison to neurotypical individuals.

Keywords: internet of things, Autism, ASD, stress, sensors, heart rate sensor, smartwatch, ICTs, new technologies.

Medindo o estresse em pessoas autistas com a ajuda de um relógio inteligente e o uso da tecnologia da 'Internet das coisas'

Resumo

Este artigo apresenta os resultados de uma pesquisa que teve como objetivo avaliar os níveis de ansiedade de 10 indivíduos autistas utilizando a tecnologia da Internet das Coisas (IoT), especificamente um relógio inteligente online. A integração da tecnologia na vida quotidiana das pessoas realça a importância de reconhecer os seus benefícios para a capacitação e o bem-estar dos indivíduos. A pesquisa foi realizada após uma extensa revisão da literatura disponível, que explorou diversas abordagens para detecção de estresse por sensores incorporados em dispositivos inteligentes. Os resultados da pesquisa envolveram medições de 10 adultos autistas e registraram seus escores de ansiedade quando os sujeitos estavam em um estado mental calmo e quando foram expostos a música alta. Os resultados são apresentados em gráficos de análise estatística após um exame detalhado dos dados, alguns dos quais confirmam estudos anteriores sobre a medição e localização da ansiedade em indivíduos com autismo, bem como as diferenças registadas em comparação com indivíduos neurotípicos.

Palavras-chave: internet das coisas, Autismo, DAS, ansiedade, sensores, sensor de frequência cardíaca, relógio inteligente, STIIs, novas tecnologias.

1. Introduction

The present study utilized quantitative research methods to investigate the effectiveness of Internet of Things (IoT) technology, specifically using sensors, in detecting stress levels in individuals. The research initially explores the concepts of IoT, its architectural framework, and its application in stress detection. Additionally, the study examines the impact of stress and anxiety on the human body, the hormones associated with stress, and various stress management techniques. Furthermore, the investigation focuses on how individuals with autism can utilize low-processing power sensors and processors in IoT devices to gather information about their stress levels. The study addresses the following research questions: (i) Can sensors in IoT devices, such as those found in smartwatches, accurately detect stress in individuals. (ii) Can low-cost, low-processing power sensors provide reliable data for stress detection? (iii) Which specific sensors offer a reliable method for stress detection with minimal user interaction? (iv) What are the findings related to stress levels in autistic adults, as measured by a smart device with heart rate sensors during periods of rest and while listening to loud music?

This thesis presents the collected data and compares the results with relevant research published in the last two decades. The research findings are intended for researchers for further investigation, as well as autistic individuals who struggle to express their emotions. By utilizing IoT devices equipped with sensors, these individuals can benefit from technology and effectively identify and manage moments of stress. Anxiety is characterized as a feeling of pressure (Mitra, 2008). Several studies have demonstrated a relationship between stress and various illnesses, including cardiovascular diseases, diabetes (Steptoe; Kivimäki, 2013), and asthma (Oh et al., 2013). Stress has been found to significantly impact the progression of these illnesses, with lifestyle playing a common role. According to the World Health Organization, stress-related disorders are the primary cause of death in Europe.

Thus, there is a need for non-intrusive and non-disruptive methods to automatically detect daily stress levels in individuals. This can be accomplished by utilizing data from various sensors. By automatically detecting stress without adding additional stress to individuals, it can directly assist in managing stressful situations and be used in medical intelligence applications, such as improving blood glucose predictions for diabetics under stress. Extensive research has shown the effectiveness of technology in reducing and managing stress. Additionally, numerous mental health apps have been developed for stress management (Carissoli et al., 2015). One of the most significant technological advancements of the 20th century is Internet of Things (IoT) technology. IoT combines computing and technology with internet-connected devices that possess sensors. By integrating data collected from these sensors, IoT provides valuable insights. IoT is increasingly becoming a part of people's everyday lives, offering solutions to various needs.

One area where IoT technology is particularly prevalent is in smart homes, where internet-connected devices can control lighting, temperature, appliances, and provide security and energy savings. Furthermore, sensors can be used to assist elderly individuals by allowing their caregivers to monitor their well-being and intervene when necessary. Besides smart home applications, IoT technology is also beneficial in areas such as transportation, energy, health, agriculture, and education. In the context of special education, IoT offers numerous products and services that can enhance the daily lives of students with special needs. For example, gloves and tablets can convert sign language into spoken language, aiding hearing-impaired students. IoT systems can also convert sound to written language and provide accessible infrastructure in schools. Research has shown that the use of IoT applications, such as memory enhancement, attention improvement, self-regulation, and self-observation, can enhance cognitive and metacognitive functions (Moraiti et al., 2022).

This study aimed to measure stress in autistic people with the help of a smart watch and the use of 'Internet of Things' technology.

2. Materials and Methods

The research maintains a constant factor, which is the diagnosis of autism in the adult participants and utilizes the Fitbit Sense 2 smartwatch to measure both stress levels and heart rate. The continuous fluctuations in sympathetic and parasympathetic nerve activity directly impact heart rate variability (HRV), causing oscillations in the R-R interval around its average value. To assess HRV, various advanced calculations have been devised. One commonly used and straightforward measure is the standard deviation of the mean R-R interval (SDRR). When individuals experience acute stress, their heart rate increases while SDRR temporarily decreases. The objective of this study is to investigate the association between measurements obtained from a smart device, such as a smartwatch equipped with sensors, and the outward manifestation of an individual's stress levels.

The study focuses on the following variables: the independent variable of age (15-39 years old) of the subjects, the dependent variables of heart rate during a calm mental state and while listening to loud music, and the dependent variables of stress scores in these two conditions. All variables in the study are quantifiable and measurable. Exposure to chronic stress has been identified as a significant predictor of cardiovascular disease. Prolonged unresolved negative emotional states, such as anger and anxiety, disrupt the balance between the sympathetic and parasympathetic branches of the autonomic nervous system, leading to an increased sympathetic to parasympathetic ratio. This imbalance has been linked to higher rates of cardiovascular morbidity and mortality, as supported by several studies (Piccirillo et al., 1997; Gorman and Sloan, 2000; Rozanski and Kubzansky, 2005).

2.1 The practical significance of research refers to its real-world relevance and application, beyond its theoretical implications

The Fitbit Sense 2 smartwatch was selected due to its specialization in health applications. It provides programming interfaces, such as a web application programming interface and a software development kit, enabling developers to access user data with their consent through the auth2 protocol. Developers can also create apps for the smartwatch and web/server-based applications. It is important for parents and therapists to acquire the knowledge that applications, games and gamification techniques and practices in general and special education improve emotional educational processes and environments, making them more friendly and pleasant (Drigas et al., 2014; Doulou et al., 2022; Chaidi et al., 2021; Kefalis et al., 2020; Papoutsi et al., 2018).

Moving forward, the next step in our analysis could involve developing an application that continuously monitors an individual's stress levels in real-time, including during sleep. We propose the implementation of an online application that alerts family members and teachers when the individual is experiencing higher-than-usual stress levels, indicating that it is not an appropriate time for skill transfer or knowledge acquisition. Additionally, this application will provide the individual with more information about their own emotional state and suggest appropriate strategies for managing their feelings. The diagram below depicts the overall concept of utilizing Fitbit's capabilities in the development of the Feelbit app.

To study stress levels in both neurotypical and autistic individuals, we utilized the Fitbit Sense 2 smartwatch, which is designed specifically for stress management through the monitoring of electrodermal activity (EDA), heart rate, heart rate variability, and skin temperature. Once the watch collects data from these sensors, it offers recommendations for stress management techniques. These techniques include maintaining a balanced diet, preferably following a Mediterranean diet, practicing mindfulness, engaging in physical exercise, and ensuring sufficient sleep. The data collected by the sensors is transmitted via Bluetooth technology to a secondary device, such as a smartphone or tablet, for further analysis of the user's data history.

The application allows users to assess their readiness for studying or skill acquisition. By granting authorization, the user submits their information to the application's server. Subsequently, the application requests data from the Fitbit server, including HR, HRV, ECG*, BR, BRV, SPO2, and temperature values. The Fitbit server collects this data through Bluetooth technology from the user's watch and analyzes it to provide relevant information. The system identifies potential increases in stress levels by monitoring changes in emotional state, body temperature, heart rate, and sweat on the palms.

A specialized algorithm, developed by the team, combines heart rate, heart rate variability, skin temperature, and electrodermal activity to generate a stress score, indicating physical signs of stress referred to as body responses. This algorithm continuously operates throughout the day to detect real-time instances of stress. The information helps users reflect on their feelings, identify potential triggers, and take steps to manage their stress. Additionally, the smartwatch can detect positive stress, such as excitement before a game or during a promotion. By monitoring these metrics, users are alerted to assess their emotional responses and effectively manage stress over time. Overall, IoT devices offer a cost-effective and user-friendly solution for stress management and detection (Figure 1).

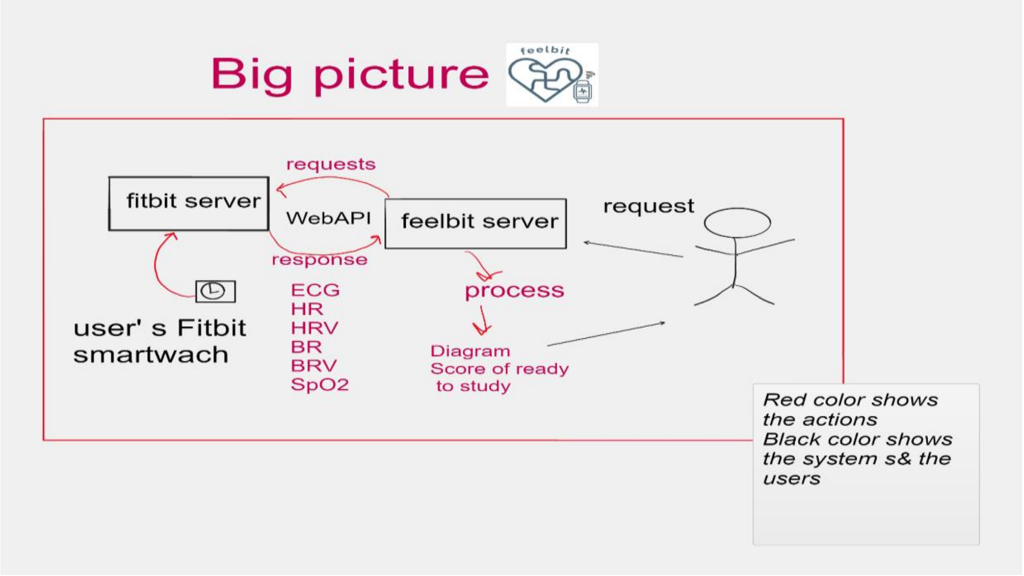

Figure 1. The architecture for implementing a web application for monitoring stress in individuals with a smartwatch. Source: Authors, 2023.

2.2 The research aims to test various hypotheses that have been formulated based on prior research and theoretical frameworks

There is a correlation between an elevation in heart rate and an augmentation in stress levels. Additionally, our research has identified a correlation between an escalation in stress levels and exposure to stress-inducing stimuli, such as listening to loud music. The validation of our research hypotheses has the potential to enhance the mental and psychological well-being of individuals with autism and their family members. Furthermore, it can instill confidence in them by providing valuable insights into their emotional state without necessitating significant effort on their part.

Despite the communication challenges faced by these individuals, their emotional condition can be accurately perceived, and tailored management strategies can be proposed when deemed necessary, all without incurring excessive costs or requiring any special interventions from the individuals themselves. Moreover, the device that will facilitate all of the aforementioned functionalities will be inconspicuous in size, lightweight, and user-friendly.

2.3 Null/Statistical hypotheses of research and research limitations

Based on the null hypothesis (H0), it is posited that there is no relationship between the variables of Heart Rate and Stress Score in autistic individuals during emotional state switching. Conversely, the alternative or experimental hypothesis (H1) suggests that there is a correlation between these variables, indicating the need for further investigation. This correlation is supported by statistical diagrams commonly used in research. The probability of error can be determined using Jamovi statistical analysis software, specifically through the t-test plot, which allows for acceptance or rejection of the null hypothesis H0.

The research was constrained to identifying a sample size of 10 individuals with functional autism, specifically between the ages of 25 and 39, consisting of an equal number of women and men. The study was conducted over a period of 10 weeks, during which the participants attended their scheduled sessions at a designated creative activity center as prescribed by their specialized intervention program. To facilitate the research, data was collected from adult students enrolled in a creative center situated in the northern suburbs of the Attica prefecture.

2.4 Operational definitions of the research and the methodology

Stress Score (Operational Definition): The stress score is determined on a scale of 1 to 100 using a measuring device. A higher score indicates a greater level of physical stress symptoms experienced by the individuals. This score is derived from monitoring over 10 different factors related to stress using the device. Heart Rate

(Operational Definition): This refers to individuals who are in good health and exhibit an average resting heart rate ranging from 60 to 100 beats per minute. These individuals do not have any underlying medical conditions and are not taking any medication.

The participants in this study were selected based on specific criteria. They were between the ages of 25 and 39 and had a body weight within the range of 78 to 126% (mean 101% ± 0.11) as determined by metropolitan standards. All individuals were normotensive, with blood pressure readings below 140/90 mmHg, as confirmed by three separate sitting measurements. A thorough history and physical examination ensured that the participants were in good health and did not have any medical conditions that could impact autonomic nervous system (ANS) activity. None of the participants were taking regular medication and none had a history of drug or alcohol abuse.

The selection of participants was conducted using quantitative sampling methods, specifically targeting individuals between the ages of 25 and 39 who had been diagnosed with functional autism. By restricting the sample to this specific subgroup, the amount of data that needed to be collected was reduced. Access to a Center for Creative Employment of Children and Adults with Disabilities in the region of Attica facilitated the identification of potential participants. In order to fulfill the requirements of the study, a total of 10 individuals diagnosed with autism, with ages ranging from 25 to 39, voluntarily participated. This group consisted of an equal number of men and women. The participants wore a smartwatch during periods of rest and stress, which involved exposure to intense noise. The heart rate measurements and stress scores of the subjects will be analyzed in the following sections.

2.5 Measuring instruments/Intervention programs

The data for this study was collected using the Fitbit Sense 2 smartwatch, a specialized tool designed to monitor various aspects of the wearer's daily activities, stress levels, and sleep patterns. The smartwatch can be synchronized with other devices through Bluetooth technology, and requires the user's internet connection and location authorization. Equipped with a range of sensors, including a multi-path optical heart rate sensor, EDA sensor, oxygen sensor, 3-axis accelerometer, and temperature sensor, the Fitbit Sense 2 smartwatch is capable of providing accurate measurements. Its user-friendly interface makes it accessible to individuals without specialized knowledge.

In this study, the smartwatch was utilized to measure the heart rate and stress levels of autistic individuals, shedding light on the potential applications of smart devices in addressing everyday needs. It is important to note that, as with any technology used for heart rate monitoring, the accuracy and reliability of measurements may be influenced by physiological factors, the positioning of the device, and the individual's movements. This particular smartwatch has not been employed in previous research studies.

2.6 Procedures

Participants were included in the study after obtaining their consent to provide personal data and have measurements taken from their wrists. Their daily routines were not disrupted, as data collection took place at the activity center where they were already scheduled to be. No preliminary instructions were given; instead, they followed verbal instructions from the researcher. Members of the activity center, with whom the participants had established relationships, were present to support and assist if needed. The sample consisted of individuals who met the age criteria and had a diagnosis of functional autism.

The procedure involved wearing a smart watch on their wrist to measure heart rate, stress index (determined by pulses, oxygen levels, temperature, etc.), and repeating the process while listening to loud music through headphones. Each participant underwent the measurements for a duration of 20 minutes. Some participants had to undergo the data collection process multiple times due to their sensitivity to loud sounds and their preference for a quieter environment.

2.7 Statistical analysis

The statistical analysis of the collected data was conducted using the open software statistical platform Jamovi 2.2.5. The individuals in the sample wore smart watches to measure their heart rates in two different conditions: when they were calm and when they were listening to loud music through headphones (Figure 2).

	ID	Gender	Age	Heart Rate	Stress Score	Heart Rate with Noise	Stress_Score_with_Noise
1	autism1	F	27	72	73	95	93
2	autism2	F	25	77	75	106	95
3	autism3	F	29	75	71	89	79
4	autism4	F	31	79	81	103	92
5	autism5	F	33	82	80	105	90
6	autism6	M	33	81	83	109	99
7	autism7	M	25	79	87	86	90
8	autism8	M	29	85	80	102	94
9	autism9	M	30	81	85	103	99
10	autism10	M	35	77	81	100	85

Figure 2. Statistical analysis variables. Source: Authors, 2023.

3. Results and Discussion

The results of the measurements revealed that the latter condition caused agitation and a higher stress score, which indicates a greater manifestation of physical signs of stress on the body. The stress score values, ranging from 1 to 100, were determined based on over 10 factors monitored by the Fitbit device. One of the factors contributing to the increase in stress score was the rise in heart rate. The data collected from the smart watches were recorded in worksheets and subsequently analyzed using statistical software.

After recording the variables and their corresponding values obtained from the sample of participants, the subsequent step involved conducting a descriptive analysis on the Heart Rate and Stress Score variables. This analysis was conducted during two distinct states of mind for the participants: a calm state and while listening to loud music. The table below presents the computed measures of central tendency and dispersion, including the average, mean, standard deviation, minimum, and maximum values derived from the collected data.

Finally, the t-test diagram below confirms hypothesis H1, which suggests a relationship between increased heart rate when subjects listened to loud music and an increase in stress scores detected by the IoT device, as indicated by a *p*-value less than 0.05. The correlation heatmap of the data, generated using the statistical tool Jamovi, visually represents the relationships between the survey variables: Heart Rate, Stress Score, Heart Rate with Noise, and Stress Score with Noise. The heatmap color indicates the strength and direction of association, with greener colors indicating stronger correlations.

The histograms provided demonstrate a clear correlation between an individual's heart rate and their stress score. When the subjects listened to loud music through headphones, there was an initial increase in heart rate, which aligns with the findings of Danesh et al. (2021) and other studies on sound tolerance disorders in autistic individuals. Hyperacusis, which involves perceiving environmental sounds as excessively loud, was confirmed through the use of an IoT device. Additionally, as heart rates increased, stress scores of individuals also increased, supporting the research of Schuber et al. (2009), which suggests that exposure to stressors leads to elevated heart rates and vice versa. An elevated heart rate is one of the indicators of increased stress. The data was evaluated for internal consistency using Cronbach's α reliability analysis, which yielded an acceptable level of reliability with a value of $\alpha = .74$. Removing any variables would significantly reduce the scale's reliability.

Descriptives

	ID	Gender	Age	Heart Rate	Stress Score	Heart Rate with Noise	Stress_Score_with_Noise
N	10	10	10	10	10	10	10
Mean			29.7	78.8	79.6	99.8	91.6
Median			29.5	79.0	80.5	103	92.5
Standard deviation			3.40	3.74	5.15	7.50	6.11
Minimum			25	72	71	86	79
Maximum			35	85	87	109	99

Figure 3. Descriptive analysis of variables HR, Stress Score with/without noise. Athors, 2023.

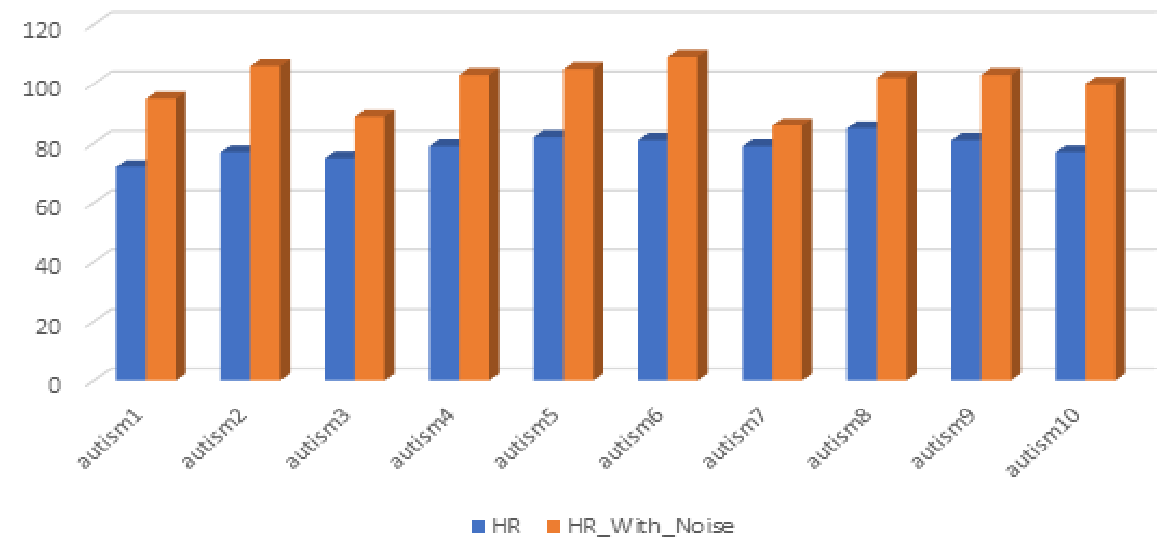

Figure 4. Histogram of heart rate measurements. Source: Authors, 2023.

Paired Samples T-Test

Paired Samples T-Test

			statistic	df	p
Heart Rate	Stress Score	Student's t	−0.625	9.00	0.548
Heart Rate With Noise	Stress Score with Noise	Student's t	4.351	9.00	0.002

Note. Hₐ μ Measure 1 - Measure 2 ≠ 0

Figure 5. Hypothesis testing using t-test. Source: Authors, 2023.

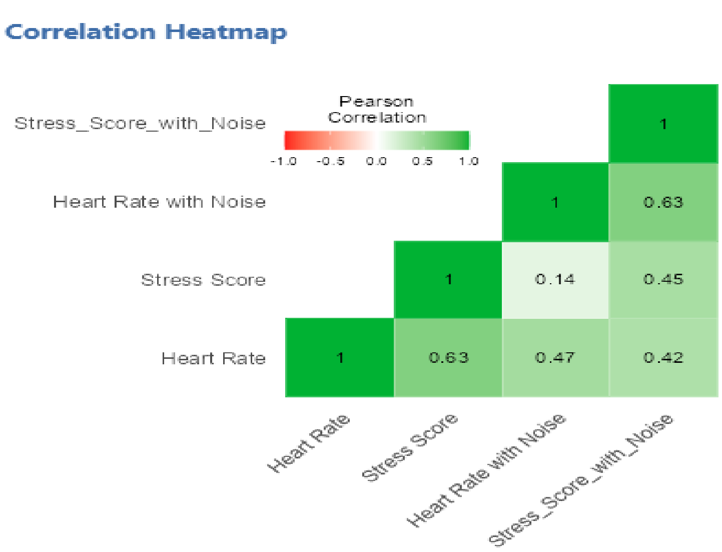

Figure 6. Correlation Heatmap. Source: Authors, 2023.

Item Reliability Statistics

	if item dropped
	Cronbach's α
Heart Rate	0.673
Stress Score	0.735
Heart Rate with Noise	0.719
Stress_Score_with_Noise	0.582

Figure 7. Cronbach’s reliability analysis. Source: Authors, 2023.

8. Conclusions

There were some limitations to this research. The participants had not previously met the researcher, which may have caused temporary anxiety. Additionally, it was their first time wearing a smart watch, which could have been a source of distraction. To conduct this research, it was necessary to explore IoT technology, stress and its causes, as well as sensors that can be incorporated into smart devices to detect and manage stress. The focus of the study was on individuals with autism, but it does not exclude the possibility of a correlation between the variables and typically developing participants. Further investigation with a larger sample size will be required to validate or refute the findings.

The statistical analysis of collected data suggests that Internet of Things (IoT) devices have the potential to assist in measuring stress levels in individuals with autism. This technology, which is user-friendly and intelligent, can be utilized by educators, therapists, parents, and caregivers to assess and intervene in autism spectrum disorder. For instance, smart watches can provide valuable data for research purposes. The absence of participant-filled questionnaires in the research reduced the possibility of dishonesty or falsification of results.

The measurements obtained through the device were accurate and did not require any specialized technical or cognitive skills from the participants. The researcher provided the participants with pre-set device configurations to extract only the necessary data. During the study, it was observed that the heart rates of participants increased when they listened to loud music, compared to previous measurements taken while they were at rest. Additionally, the subjects' stress levels were found to be elevated. This increase in both variables was observed in all ten participants.

The New Technologies (NT) and more specifically Digital Technologies as the technology of IoT provide the tools for access, the analysis and transfer of information and for its management and utilization new knowledge. Information and Communication Technologies (ICT), unprecedented technological capabilities of man, have a catalytic effect, create the new social reality and shape the Information Society (Pappas; Drigas 2015; Bakola et al., 2020, 2022; Drigas; Politi-Georgousi, 2019; Karyotaki et al., 2022).

In conclusion, as this research presents, according to the number of tools it used, it is necessary to mention that the combination of ICT with theories and models of metacognition, mindfulness, meditation and the cultivation of emotional intelligence accelerates and improves educational, productive practices and the decision-making results (Drigas; Karyotaki, 2014; Drigas et al., 2017; Drigas; Papoutsi, 2018; Drigas; Karyotaki 2019; Pappas; Drigas, 2015; Papoutsi et al., 2018, 2021; Karyotaki; Drigas, 2016; et al., 2020, 2021; Chaidi; Drigas, 2022; Mitsea et al., 2020, 2022; Galitskaya et al., 2021; Bakola; Drigas, 2020; Bakola et al., 2022; Bamicha et al., 2022).

Finally, as the study by Papoutsi et al. (2018) suggests, it is crucial to develop more applications that cater to the specific needs of individuals with autism. Specifically, creating applications that focus on recognizing emotions can aid in developing emotional intelligence and enhancing social interaction skills. In recent decades, significant social changes have been observed, which are related to the role of ICT's and A.I. and technology in people's daily lives. The most important of them concern communication, diffusion and management information’s and in the ability to assimilate and utilize the produced new knowledge.

We have to underline that the role of Digital Technologies in emotional education domain and Sensory Integration Training, as well as in all the aspects of everyday life, are very productive and successful, facilitate and improve the assessment, the intervention, decision making, the educational procedures and all the scientific and productive procedures via Mobiles (Stathopoulou et al., 2019; Drigas et al., 2015, 2020, 2022, 2022; Vlachou et al., 2017; Papoutsi et al., 2018; Alexopoulou et al., 2020), various ICTs applications (Drigas et al., 2005, 2010, 2013, 2014, 2017, 2018, 2019, 2020, 2021, 2022; Pappas; Drigas, 2015; Papoutsiet et al., 2018, 2021; Karyotaki et al., 2016, 2022; Bravou et al., 2022; Lytra et al., 2021), via AI Robotics & STEM (Drigas et al., 2005, 2014; Lytra et al., 2021; Pappas; Drigas, 2016; Chaidi et al., 2021), and games (Chaidi et al., 2021; Drigas et al., 2021).

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10. Authors' Contributions

Ioanna Moraiti: study design, research, writing, scientific reading, submission and publication. *Athanasios Drigas*: scientific writing, textual review, contextualization and final writing.

11. Conflicts of Interest

No conflicts of interest.

12. Ethics Approval

Not applicable.

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