An IoT-based solution for monitoring young people with Emotional Behavioral Disorders in a Residential Childcare setting

Bharat Paudyal
DMT Lab
Birmingham City University
Birmingham, UK
bharat.paudyal@bcu.ac.uk

Chris Creed
DMT Lab
Birmingham City University
Birmingham, UK
chris.creed@bcu.ac.uk

Sherelle Knowles
Sherlock Healthcare Services
Birmingham, UK
sherelle@sherlockhealthcare.co.uk

Hilton Mutariswa
Sherlock Healthcare Services
Birmingham, UK
hilton@sherlockhealthcare.co.uk

Ian Williams
DMT Lab
Birmingham City University
Birmingham, UK
ian.williams@bcu.ac.uk

Abstract*— This paper focuses on the design, development and preliminary evaluation of cloud-based Internet of Things (IoT) system that utilises wearable sensors to remotely monitor the physiological patterns of young person with Emotional Behavioral Disorder (EBD). We report on an exploratory study with caregivers to understand the challenges exhibited by young people with EBD. This informed the design of cloud-based IoT system that retrieves real-time physiological parameters such as Heart Rate, Body Temperature through non-invasive wearable sensors, which enables caregivers to monitor the activity of young person remotely and provide enhanced support based on the collected parameters. To validate system's feasibility, an initial pilot study within a healthcare environment involving children with EBD was conducted. The study confirms the system's viability and identifies important areas for future improvements. By utilizing IoT technology, our work aims to enhance the healthcare sector's ability to support individuals with EBD and improve their overall well-being.

***Keywords* – Wearable sensor, young person with EBD, residential childcare, Internet of Things, eHealth**

INTRODUCTION

The advancement of affordable devices which form the Internet of Things (IoT) is uplifting the healthcare sector by making unobstructed health monitoring much more valid, practical and accessible for many sectors of society [3, 13, 29]. The use of non-invasive and unobtrusive IoT-based sensors (e.g., wearable devices, smartphones, ambient sensors) is becoming a viable diagnostic tool to monitor physical activities and health conditions and has been commonly implemented within the healthcare environment [9, 18, 23, 27]. Ambient sensors such as light, motion, and wearable sensors such as an activityband or smartwatch, can continuously measure real-time physiological signals such as Heart Rate (HR), Heart Rate Variability (HRV), Oxygen saturation (SpO2), and body temperature (BT) without the direct intervention of users [5, 11]. Studies have highlighted that monitoring an individual's physical activities can help to detect abnormal changes in behaviour via the acquisition of continuous real-time information about the environment (i.e., temperature, humidity), the users (i.e., daily routine activities), the health (i.e., heart rate, blood pressure) [19, 20], can identify a potential change in health status [27]. This can also alert a third person, i.e., a caregiver or healthcare professional to intervene and could help alleviate both the caregiver burden and reduce pressure on the service users. It can also empower a user to be more actively involved in managing and improving their own health [18, 28], thus having wider impacts on both users and society as a whole.

Prior studies have explored the potential of these sensors in healthcare and the management of activities and chronic diseases of older adults [6, 10, 15], with researchers highlighting that elderly people living independently in their homes can encounter issues that might affect their wellbeing and may suffer from age-related diseases such as Dementia, Alzheimer's and other unforeseen circumstances, so are often taken in consideration when conducting these kinds of studies [9, 13, 24, 27]. Whilst few studies utilised young people [1, 12, 16] within the age ranges of 8 through 18 as part of medical studies in a supervised lab-based environment, no studies have been conducted to measure the physiological parameters of a young person living in a residential childcare environment. Additionally, no work has been conducted to date using a young person with EBD. In this work, we set out to address the limitations of developing a continuous physiological monitoring system targeted at those user groups within the healthcare/childcare context.

This paper, therefore, provides an overview of work-in-progress that explores the potential of wearable sensors to monitor the physiological variables of young people. An exploratory study with caregivers in a residential childcare setting in the UK is initially presented to understand the challenges and issues that exist within a managed home and healthcare environment. Findings from this exploratory study were used to inform the development of an IoT-based monitoring system that retrieves sensor data from a wearable device of the young person and transfers it to a cloud server to enable caregivers to monitor the young person's data remotely. We focused on a pilot study conducted using young people with EBD residing within the residential childcare environment to measure the feasibility and validity of the developed system. We illustrate key findings from this study alongside future pathways that will be conducted with follow-on work in a residential childcare environment.

RELATED WORK

Initial work has begun to investigate the potential of sensor-driven technologies to monitor the activities and health of users. In terms of monitoring activities, Lee et al. [18] utilized Pyroelectric Infrared (PIR) sensor to remotely monitor the activities of 9 elderly people living alone. The initial experimental results highlighted the possibility of estimating the behavioural patterns of elders. A web-based tool was provided to the caregivers to monitor the sensing data of each elder. Similarly, Aloulou et al. [4] implemented an ambient assistive living solution utilizing multiple sensors (PIR, Pressure, Shake) to detect the activities of dementia patients – with the system sending notifications to the caregivers on their smartphone based on the activities (e.g. notifications sent to a caregiver in conditions such as the patient not in the bed during the night, showering too long, forget to turn off the tap, among others). Whilst the results demonstrated the ability of the system to detect abnormal behaviour, issues (e.g. battery life, sensor removal, network connections) were highlighted during the deployment, affecting the effectiveness of the system. To record and document any activities and events, the study utilized a log sheet, where caregivers have to fill out on hourly basis. Moreover, Pais et al [22] utilized a combination of ambient and wearable sensors to monitor the activities (e.g. mobility, fridge visits, door events) and health-related activities (e.g. heart rate, skin temperature) of older adults living alone at home. Semi-structured interviews with caregivers, nurses, older adults, and families highlighted that using sensors helped elders stay at home, improved home care, prevented domestic accidents and reduced family stress. The study did not implement any logging mechanism, but email alerts were sent to nurses in case of deviations in activities (e.g. change in mobility).

In another approach, studies have highlighted that using sensors can help identify an individual's health condition, measure the stress level and predict the early warning of diseases [2, 6, 8, 12]. For example, Ghosh et al. [10] utilized multiple sensors (accelerometer, light, touch, body temperature, and ECG sensors) to allow doctors to remotely monitor the general health conditions of patients. The results of the experimental study were perceived positively by the participants. A desktop-based application was used to collect health data and was displayed through a web interface. Similarly, Kumar et al. [17] implemented a wristwatch-based IoT health monitoring application to measure SpO2 and HR of a user– with the results of clinical trial confirming the potential of developed sensor platform in future wearable health monitoring IoT applications, however, no logging mechanism was implemented in the system.

Whilst the existing literature can help inform the development of a cloud-based IoT system, there remain several areas where little or no work has been conducted. For instance, it remains unclear about the issues and challenges that exist within a children's home. Additional study is also needed to understand how caregivers identify, monitor and manage children with EBD living within a residential childcare environment. Additionally, it remains unclear how IoT based monitoring systems can be implemented and embedded within a residential childcare environment to monitor children with EBD. Moreover, many of the studies involving young people have been implemented within a lab-based environment, so further work is therefore needed to explore the usability and feasibility of this type of system within a real-world healthcare environment.

EXPLORATORY STUDY

Due to the limited work around the behavioural issues exhibited by young people with EBD and within a residential care home, it is unclear how caregivers currently identify and manage these. Additionally, less work has been conducted to understand how caregivers record and document the daily activities, events and any occurrences related to the home and a young people. Identifying the challenges, including managing and documenting processes within a reliable system is essential to identify intuitive and appropriate approaches to help balance the workload of a caregiver and support the young person. An online survey with the manager, and caregivers of a residential childcare setting was therefore conducted to gain an understanding of such challenges and issues that exist within this environment.

Methods

An online survey was created and sent to the employees of a residential childcare setting in the UK. The survey consisted of 63 questions of which 19 were open-ended questions, and the rest (44) were closed-ended questions (6 multiple choices, 7 Yes/No and 31 rating scale). The survey was completed by 13 participants (homes manager/ deputy manager and 11 caregivers) working within the home. On average, all participants had at least 2 years of experience within the childcare industry. As requested by the manager of the home, demographic information such as the age and gender of caregivers was not included in the survey. The initial questions focused on their experience working with young people who have EBD. Previous studies have highlighted that a young person living within a residential carehome exhibits behavioural issues such as aggressivity, delinquency, and attention problems, arising from their tangled family histories and psychological distress [14, 26],therefore, the questions focused on identifying these lived experiences.

The next set of questions focused on the staff member's role in managing young people in a state of distress, and the survey concluded with questions around the logging and documentation system which is an essential requirement of young people's care management and is commonly utilized in this type of setting.

Findings

Responses from all the participants were obtained for analysis. A thematic analysis [7] was employed, where codes were derived from retrieved data to identify initial themes and concepts. These themes were then analysed iteratively and were collated into four key themes:

Identification of behavioural challenges in young people

All participants highlighted that they have experience working with young people who have EBD and stated that they could easily identify the signs including the physical changes when a young person is becoming distressed. The majority (10) found that a young person between the ages of 12-15 years old displays the most challenging behaviour. One theme to emerge from five participants was the young person's struggle to manage their emotions: "*Very energetic, have a mind not of their age, do not have a settled mind and can't express their emotions well* "(P6)

Three participants commented that young people are goal-oriented and focused but struggle to follow the routine:

"*some children may be very tunnel visioned. You have to give clear instructions and break it down when explaining"* (P3).

Three participants also highlighted that young people are impatient and need to meet their demands immediately. Participants also highlighted the types of physical changes or the behaviour when young people are distressed or becoming distressed with 12 participants commenting that they appear to be agitated. 11 participants highlighted that young people also change their facial expressions (i.e., frowning or scowling) and also move around frequently: "*They seem to be annoyed and behave aggressively towards staff*"(P6).

"Some children become clingy and have nightmares or bully other children" (P11).

Several caregivers (N=9) described the increase in body temperature and heavy and exaggerated breathing as a sign to spot distress. Similarly, other attributes include sweaty hands, increased heart rate, and rapid eye moment. Three participants also highlighted the change in voice: "*Sometime when they want to say any word, they stutter and also there is change in their vocal levels*" (P8).

Behavioural challenges during different time intervals

Most of the participants (N=8) highlighted that young people exhibit the most challenging behaviour during the evening – with the key challenge being the refusal to take medication (N=10). Additional evening challenges include the young person refusing to do personal chores, excessive eating, hyperactivity, and being angry: "*Supporting with dinner and can eat excessively due to medication. Struggling with routines and settling, hyper-focused"* (P1).

"Wanting to do an activity when everyone is trying to wind down" (P4).

Similarly, 10 participants highlighted excessive eating or snacking as a significant challenge during the afternoon. In addition to that challenging or rude to staff, refusing to engage with staff, and over-excitement are also some of the afternoon issues of the young person: "*Supporting children with their routines and them being hyper-focused on something, or zoning out*" (P7).

Not returning home on time is the biggest night challenge highlighted by the participants (N=10). In addition to that, refusing to take medication and engage in bedtime routine are other challenges encountered by staff during the night: "*Not settling to sleep and being disruptive throughout the night*" (P2).

Lastly, refusing to take medications and engaging in personal hygiene (e.g. washing) are some of the biggest challenges encountered in the morning (highlighted by 12 participants). Similarly, struggling to wake up in the morning, refusing to take breakfast, and refusing to go to school are also some of the morning challenges: *"Struggling with a routine, such as can wake at 3am and want to get ready for the day. But this not being appropriate*" (P9).

Managing the behaviour

Seven participants expressed that they find it easy to support a young person who is distressed – with five participants highlighting staff engagement and allowing the young person to sit calmly as the support approach. Eight participants expressed that engaging a distressed person in a planned activity can be more challenging, while three found it to be easier. Similarly, five participants found engaging distressed young people in an unplanned activity to be easier as opposed to six.

Only three participants said that engaging distressed people in education and daily routines (hygiene, chores) was easy, while eight participants found it to be harder. Similarly, eight participants found it difficult to offer emotional support and advice to a distressed young person: "*They can often go on a tangent when expressing what's wrong with them they can go off track and ramble a little bit*" (P6).

Documentation system

The majority (N=10) highlighted that they spent most of their working hours recording the activities and events related to young people using a web-based system - with eight participants commenting that it has made their job easier. Seven participants highlighted that despite the benefits, the current system does suffer from issues such as data duplication, form repetition, randomly deleting data, and data loss: "*It's easy to use although it's not very reliable as there are constant problems occurring*" (P2).

The majority of participants expressed their interest in automating the process which would allow them to spend more time with young people: "*Condensing the amount of work into less documents i.e. daily summary about a child should have all information such as individual meetings etc"* (P13).

"*Really helpful to have grouped information relating to children's pattern of behaviour in a chart"* (P1).

The key issues highlighted in the survey and possible recommendations are listed in Table 1.

Issues	Key challenges	Suggestions
Sleep Pattern	Young people struggle to sleep and disruptive through the night	-Able to monitor the sleep pattern and offer support
Physiological patterns	When young person is distressed, they display signs such as exaggerated breathing, increased heart rate and body temperature	- Monitoring the heart rate and body temperature and identifying possible early indicators that may require intervention
Out of the Home	It is hard to quantify the behaviour of a young person when they are out of the home	-Able to view the physiological pattern of a young person when they are out in the community.
Documentation system	The current documentation system is not user-friendly and suffers from data duplication, data being lost, only one staff member at a time can access a form.	-Automation of system to remove the issues and improve reporting accuracy and efficiency -Identification of patterns and trends to support more informed decision-making

Table 1: Key issues, challenges and possible suggestions

The findings from this exploratory study helped us to understand the issues and challenges that existed within a residential childcare environment. This also provided a solid starting foundation for the project and informed the technological requirements that are needed to support the caregivers to identify, monitor and manage young people with EBD living in a residential care home. Prior studies have highlighted that the utilization of sensors can support caregivers in monitoring the residents living within a healthcare environment. [2, 4, 22, 28] Therefore, an IoT-based monitoring system will be developed to address the issues highlighted in the study.

SYSTEM DEVELOPMENT

Drawing from the insights obtained from the exploratory study with caregivers, we developed a cloud-based monitoring system that measures physiological variables such as heart rate, body temperature, steps and sleep patterns through the utilisation of non-invasive wearable sensors. Prior studies have highlighted that wearable devices, in particular smartwatches and smartbands support multiple sensors, thus can detect continuous sensor data (e.g., when performing an activity, the wearable can detect heart rate, accelerometer, and calories) without the need for multiple ambient sensors [21, 25, 30]. It was therefore decided to utilise an off-the-shelf wearable smartwatch as a sensor device, alongside the system's hardware architecture as depicted in Figure 1.

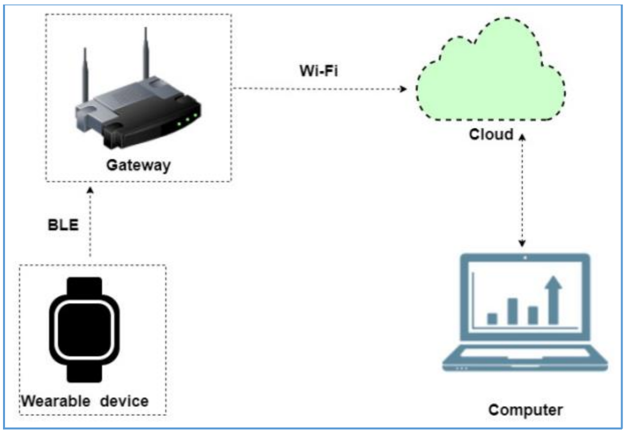

Figure 1: System architecture

The system encompasses a wearable device (wristwatch), a Bluetooth Low Energy (BLE) gateway, a cloud-based server and a computer. The wearable device incorporates Heart Rate (HR), Body Temperature (BT), Blood Pressure, SpO2, accelerometer and sleep sensors and has a long battery life (~six days). An Android-based BLE gateway was developed which retrieves sensor data from the watch using a Bluetooth connection and transfers the data to a cloud server using WI-FI connectivity. The gateway retrieves and transfers HR, BT and accelerometer data continuously (every second), while sleep data is retrieved and transferred periodically throughout 24 hours. Seven watches can be connected simultaneously in the BLE gateway, which can work within a range of up to 15 meters. The data is stored in the secure cloud server and is displayed on the computer through the Web App, a user interface (UI) developed using NodeJS, VueJS, HTML5 and CSS.

To support the monitoring of young people both within the home and outside of the home, the system supports offline activity monitoring. Therefore, when a user goes out of the Bluetooth range (offline), HR and BT data are stored locally within the watch, and when the connection is re-established (online), the data stored during the offline period is automatically retrieved and stored by the gateway. Feedback is provided to caregivers on the offline and online status of each watch worn by each young person. To allow caregivers to visualize each young person's data easily, the HR and BT data collected during both the online and offline periods is clearly differentiated by colour (red or green) as displayed in Figure 2.

To provide an accurate and scalable range within the home environment, multiple BLE gateways can be placed at multiple locations in the home. This allows the young person to freely walk around the home, and the watch will connect automatically to the nearest BT gateway based on signal strength. Additionally, battery levels are displayed in the UI to remove the issues around battery life, which will allow caregivers to charge the device if the battery goes below 10% capacity.

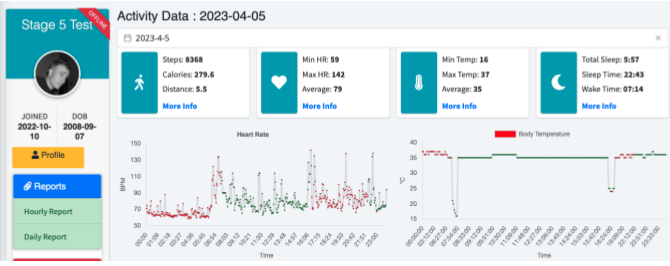

Figure 2: The UI displaying the sensor data. The red dots in the chart indicate the data retrieved during the offline period, while the green indicates the data retrieved during the online period.

PILOT STUDY

We conducted a pilot study on a young person with EBD in a residential childcare environment to gauge the validity of the developed system. The overarching aim of the study is to understand the system is able to retrieve the data of an unsupervised young person with EDS and to gain insights about the impact and any challenges associated with embedding the system within a residential care home environment. It was therefore felt that a study with a single young person with EDS at this stage would also help us tease out any deployment issues as highlighted in the previous study [4] that can be iteratively updated prior to conducting evaluations with wider participants.

Two BLE gateways were embedded and integrated into the house at two different locations - one in the staff sleep room on the first floor while another was placed in the office (ground floor). Both gateways were 20 meters apart from each other and had barriers such as walls and doors (Figure 3). The locations were also less active zone with no usable electric items nearby and were kept away from the sight of the children living within the house.

Participants

Two people, including one young person with EBD, volunteered for the study. The young person wore the watch continuously for a week, while the other user wore the watch only during the daytime periods of 9am and 5pm. A caregiver worked as a reviewer to log the sensor data being captured by the watch and displayed in the UI at key intervals (every hour from 9am to 8pm).

Apparatus

The system detailed in Figure 1 was embedded into the home. A standard laptop was used to monitor the data through the developed UI (Figure 2). Uninterrupted WI-FI connection and power supply were provided to the gateway.

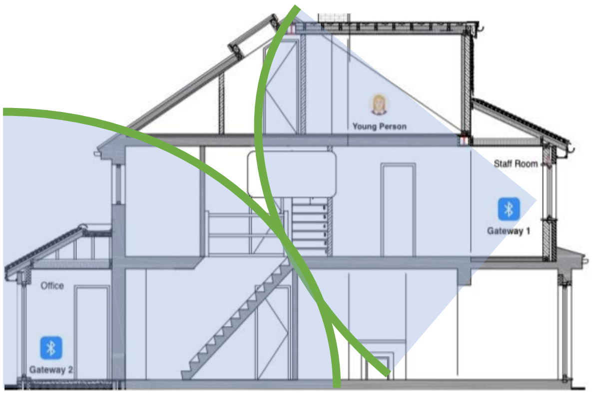

Figure 3: Architectural diagram displaying the location of two BLE gateways and their range coverage in the young person's home

Procedure

Institutional Review Board (IRB) approval was obtained for the study. Participants and the reviewer were briefed about the project, given an information sheet, and asked to provide informed consent. Participants were asked to wear the watch and continue with their normal daily activities. The reviewer was provided with training of the system and encouraged to ask any clarifying questions. Once training was complete the system was initiated.

For the duration of the study, each participant's data was retrieved and stored in the database and displayed in the UI dashboard (Figure 2). An hourly report was automatically generated at the end of each day which displays the heart rate, body temperature and activity (total steps, distance and calories). Additionally, total sleep time along with bedtime and waketime is also displayed in the daily report. A push notification appeared on the reviewer's laptop when a watch went out of range (i.e., out of the home) and reconnected (i.e., returning to the home). The reviewer had the option to manually check all automated reports report and input any supplementary data. Each morning a handover process was conducted with the care staff. As part of this process, the sleep pattern of the previous night obtained via the watch alongside the prior hourly and daily reports was discussed.

The study was conducted for a week, and after the completion of the study, the reviewer was asked to complete an online questionnaire to gain insights around the experience of using the system. Informal interviews were also conducted with all the participants including the young person, the homes manager to understand their perceptions of using the system.

RESULTS

Qualitative feedback

The feedback obtained from the reviewer has been encouraging. The positive comments emphasized the system to be helpful and intuitive: *"I think the system is going to be useful to determine certain elements of changes within the body that may not be visible to the naked eye"*.

Additionally, the reviewer stated that they could understand the quality of a young person's sleep: *"It verifies what we were already thinking in terms of the young person's lack of sleep"*.

The reviewer also mentioned that use of charts and data displayed in the dashboard was user-friendly and easy to help them understand the behaviour of the young person: *"The dashboard makes you aware of little changes in the mood so that you are able to alter your approach when managing their care "*.

The manager of the home remarked that the use of the system helped the staff to be more proactive in responding to the young person. The comments tended to emphasize that monitoring the young person's activity pattern (such as heart rate, body temperature, and steps) during the offline period (e.g. during school time) helped them to understand the challenges and behavioural issues exhibited by the young person when they are not at home: *"The dashboard is making the staff more cautious on responding to the young person"*.

The manager further reiterated that using a watch has allowed the young person to engage with smart technology, thus improving the self -awareness and understanding.

The young person also provided positive feedback on using the watch – with the comments focused on the device helping them to understand their heart rate and steps: *"The watch is quite useful and I would like to use it on a longer-term basis"*.

The weeklong longitudinal study helped to validate the usability and feasibility of the developed IoT system by capturing the young person's physiological data such as heart rate, body temperature, and sleep pattern obtained during the online and offline period and displayed in the web app. The system addressed some of the issues encountered by the caregivers through the utilization of a live monitoring dashboard to identify early indications of crisis and be aware and more conscious. Whilst the system was perceived positively, participants also suggested potential improvements around the UI design by incorporating responsive design to make it compatible with different screen sizes. Additionally, the manager and reviewer also suggested incorporating the data within the documentation system to support the automation and efficiency of reporting.

DISCUSSION AND FURTHER WORK

This paper has presented a novel IoT-based system to support caregivers in remotely monitoring the physiological pattern of young people with EBD living within a residential childcare environment. The system allowed caregivers to continuously monitor the heart rate and body temperature of the young person obtained during the online period and offline period and to adopt appropriate measures to manage their well-being. Additionally, using sleep data can help analyze the sleep pattern of the children and implement approaches to improve sleep quality. Overall, the strengths of the study are mainly (1) the exploration of an online survey to understand the issues and challenges; (2) the development of a multi-sensory system; (3) embedding and integrating the system within the residential childcare setting (4) close collaboration between children, stakeholders, and caregivers. However, we acknowledge some limitations within our study – for instance, the study sample is very small. Whilst this is a pilot study, further evaluation with other young people with EBD living in the same types of setting will be conducted. Furthermore, the use of only one device (wearable watch in our case) can sometimes lead to the failure of the device, so might not be able to retrieve the data. Studies have highlighted that the use of both ambient and wearable sensors can yield a more accurate, effective and less error-prone [22, 27], therefore, future work is required to utilize both sensors (i.e. ambient and wearable). The current documentation system involves data duplication and repetition, so further iterative work is required to automate the documentation system. As highlighted by the participants, the system is incompatible with different screen sizes, so further work is needed to make the system more responsive by utilizing the grid approaches. Additionally, the collated data can be used to identify patterns and biomarkers associated with the behavioral disorder and develop predictive models to help forecast attention deficit hyperactivity disorder (ADHD)-related behaviors or symptoms.

CONCLUSION

We developed a cloud-based IoT system, which retrieves sensor parameters through the wearable and allows caregivers to monitor the data remotely. A pilot study with a young person with EBD within a residential childcare environment was perceived positively and demonstrated that the system can be a valuable approach for the continuous monitoring of sensor data. Insights obtained during the pilot study also helped to identify key areas where future research and development will be important to make the system more robust and effective in monitoring young people within a healthcare context.

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