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Develop a Model to Assist People Suffering from Transient Global Amnesia Using a Smart Location System

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ABSTRACT

Transient Global Amnesia (TGA) is a neurological disorder characterized by the sudden, transitory development of amnesia. It is an amnestic episode not linked to a common neurological cause, such as a seizure or stroke. During the attack, the patient can forget recent events or fail to form new memories. This study aimed to evaluate the viability of a smart location system that can be helpful to TGA patients during the episodes. It also measures the engagement of the system in uncontrolled environments versus controlled environments, and also user time interacting with the application, frequency of errors, and satisfaction level. A hybrid research approach was applied to collect both qualitative and quantitative data on response time, geographical location, and physiological indications. The findings indicate that response time to alerts in real settings is faster than that achieved in simulated settings. Suburban areas showed higher location accuracy, while TGA patients engaged with stimuli had a mean of 15.3 seconds. Error rates were reduced from 12% to 5% over four weeks. The study therefore, advocates for the use of mobile applications and systems to improve TGA management, reducing anxiety, and enhancing coping styles.

1. INTRODUCTION

Over the years, the increased use of mobile applications and systems that aid human memory in daily activities has impacted many lives in society [1]. Such applications can effectively recognize, organize and plan various aspects of daily life, and have gradually become an integral aspect of routine activities [2]. Moreover, human beings tend to enjoy using such applications, in particular their ability to undertake many processes simultaneously, which can save both time and effort [3]. However, memory remains a significant aspect of human experience, capable of developing behavior and improving the accuracy of responses and actions [4]. In addition, modern machine learning and data analysis can also predict recommended responses, particularly when it comes to the use of mobile phones [5]. It is notable that reliance on such devices has increased exponentially over previous years, with over 8.58 billion users globally in 2022, now forecast to increase to approximately 17.26 billion by 2025 [6]. Smart phones have become more convenient and versatile, and an indispensable part of modern life, with a variety of applications for capturing data, including weather conditions (i.e., humidity and temperature); physiological body status (i.e., heart rate, physical activity and nutritional status); along with close friends, preferable movies and songs, news and traffic conditions [7].

Among neurological conditions, Transient Global Amnesia (TGA) pauses a significant problem, marked by a sudden onset amnesia, in which patients experience difficulties in both accessing old memories and also retrieving new memories. This indicates that the hippocampus system is not functioning properly [8].

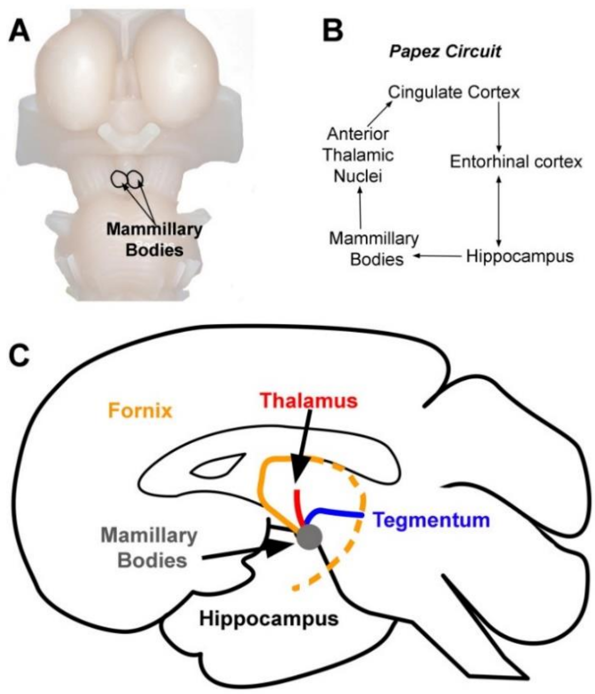

Figure 1. The memory circuit [9]

Figure 1 illustrates the circuitry of short-term memory, which is predominantly activated under stress. Initially, each hippocampus sends impulses to the septal area via the fornix. These signals are then relayed to the mammillary bodies and subsequently to the anterior nucleus of the thalamus. From there, the impulses progress to the cingulate gyrus of the frontal lobe before finally returning to the hippocampus [9]. TGA is the most common type of acute-onset amnesia, characterized by severe anterograde and retrograde amnesia that typically resolves within 24 hours [10]. Possible triggers for TGA include posterior circulation strokes, transient epileptic amnesia, psychogenic amnesia, post-traumatic amnesia, and toxic or drug-related amnesia. Although TGA's presentation is highly distinctive, its exact cause remains unestablished [11]. Globally, TGA affects approximately 5.2-10 per 100,000 people each year [12, 13], with incidence rates increasing to 23.5 to 32 per 100,000 among those over 50 years of age. The majority of documented cases occur in individuals aged between 50 and 80, with no significant differences observed between genders.

In addition, despite the lack of any identified specific risk factors, the condition has been observed more frequently in individuals with a history of ischemic heart disease and hyperlipidemia. Although many experience TGA as a single episode, estimates of recurrence have ranged from 2.9 to 26.3% [14]. Until recently, there has been no treatment for this condition, leaving the individual unable to create new memories or recall current occurrences. Additionally, the patient can be unaware of his or her location, his or her purpose, or the date. It is, however, a truly critical situation, which may last for 24 hours and therefore requires urgent rescue from an external source.

Currently, TGA management strategies are largely passive, involving observation and reassurance during attacks [15]. However, these contribute little to assisting those suffering from recurrent TGA attacks cope with the day-to-day impact, such as becoming disoriented in unfamiliar surroundings. Furthermore, it is insufficient for sufferers to keep written notes or rely on a career, as these methods offer little help during an attack. This highlights the need for a more proactive approach, particularly due to the increase in technological assistance for health management.

1.1 Research contribution

This paper therefore, introduces a new model, which uses a smart location system for guiding real-time assistance for patients with TGA. It employs location-based services capable of guiding an individual through an episode of TGA to a safe location or, if required, to alert caregivers, in order to reduce disorientation and anxiety. Through this, the paper aims to make a unique contribute to the fusion of next-generation location-tracking technologies into user-friendly mobile interfaces, thus providing a seamless and automated solution for managing TGA. In addition, it has the potential to significantly improve a TGA patient's quality of life by filling the gap in existing research to offer a practical application for this approach.

1.2 Summary of paper organization

This paper is organized as follows: the theoretical foundations section describes previous methods of location tracking and their use in nursing patients with memory impairments. It also points out the shortcomings of today's systems and distinct requirements of TGA patients. The Methodology describes how the presented smart location system has been designed and developed, along with the model and the integration of the location-based services.The Results provide the evaluation of the effectiveness of the proposed system based on the statistical data verification of the system's impact on decreasing the patient disorientation. In the Discussion section, the author proceeds with the elaboration of the relevance of the outcomes and speaks about the advantages and the weaknesses of the introduced model. Finally, the last section of the paper provides the conclusion highlighting the paper's main contributions and potential enhancements for the system, as well as its potential in applying memory disorder management. It is in this vein that this paper will submit practicality and scalability ideas towards addressing memory loss that affect TGA patients . This organization therefore, helps in understanding theoretical aspect of the proposed smart location-based system, the manner in which it can be implemented, and the likely challenges that may be faced in its usage in managing memory loss in TGA patients.

2. LITERATURE REVIEW

2.1 TGA and memory loss

TGA has been studied over several decades, primarily its etiology, symptoms, and prognosis [16]. Nevertheless, the cause of TGA remains unknown, although it is often connected with conditions such as stress, physical stress, and migraines. During a TGA episode, patients experience anterograde amnesia, an inability to form new memories, and sometimes retrograde amnesia, which leads to a temporary loss of memories [17]. Although TGA is generally benign and self-limiting, its sudden onset, alongside the profoundness of the amnesia, demand the development of strategies for its effective management, so as to reduce the psychological impact on the patient and individuals involved, along with facilitating the patient's safety during episodes.

2.2 Technological interventions

There has recently been a general acceptance of the role of technology in managing neurological disorders, in particular mobile applications and wearable devices. For memory-related disorders like Alzheimer's disease, the technologies that have been found to improve patients' outcomes include GPS tracking, reminder applications, and cognitive training games [18]. However, there has been little application of such technologies in the management of TGA. Existing tools focus on supporting long-term memory but are unable to intervene in real-time within the context of an amnesia episode. For example, existing GPS devices can identify an individual's location, but cannot offer the immediate guidance and alerts required by TGA patients. This opens up an opportunity for the development of a more specialized solution for tackling TGA's intricacies.

2.3 Gaps in research

Despite neurological research advances in technology, it is vital to continue to develop tools designed for TGA. Most existing solutions consist of generic memory aids, or passive monitoring systems, which lack the real-time dynamic assistance required during a TGA episode [19]. Furthermore, it is vital more research is conducted on integrating smart location systems and mobile technology for managing TGA. This current research addresses these gaps with a comprehensive model that not only tracks a location in an advanced manner, but also offers a user-friendly interface to provide real-time support for TGA patients and their careers.

3. METHODOLOGY

3.1 Architecture overview

The proposed smart location system (see Appendix B1) supports individuals with TGA by providing location-based real-time guidance and alerts [20]. This involves hardware and software set up to work together for the smooth operation of the system. On the hardware side, a GPS module inside a smartphone continuously tracks the user's location. This component integrates a mobile application into the smartphone's operating system to access GPS data, process user inputs, and initiate predefined actions [21]. The system's backend is provided on a cloud platform, allowing for scalable data processing and storage. Such an approach ensures the system's performance will not degrade when several users connect simultaneously.

3.2 System design

The system's workflow is simple and effective (Appendix B2) (Figure 2). It has three main options, which can be personalized according to individual preferences. The first option places an automatic call to a preregistered emergency contact when the algorithm detects a TGA episode. The second option provides a point of reference by means of the last location where the user has spent a significant amount of time [22]. The third option returns the user to a preselected home location. These are all managed through three system variables, v1, v2, and v3, which relate to the three separate modes of location determination. These options can all be toggled through the smartphone's voice recognition facility [23].

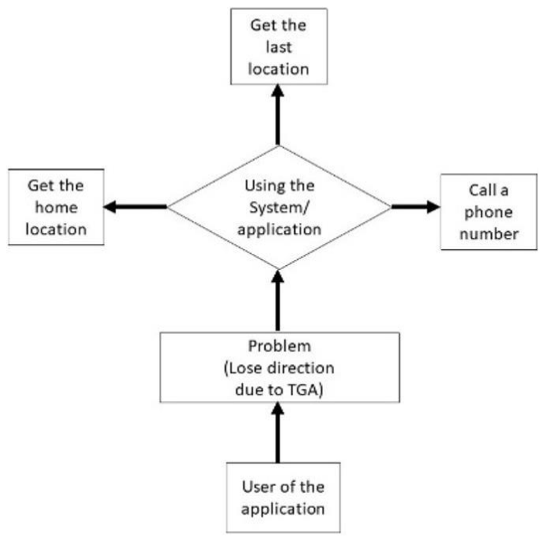

Figure 2. System design [24]

3.3 Smart app design and implementation key features

The smart app for TGA patients has five notable support features for amnesic episodes. Firstly, Location Tracking continuously monitors the position of the user with the help of GPS, aiding in real-time assistance and safety monitoring [24, 25]. Secondly, the Emergency Contact Alert is sent to pre-set trusted contacts, automatically sending the location and status of the patient upon demand, or the detection of an episode. Thirdly, the Last Known Location Retrieval establishes the user's orientation by displaying his or her most recent location, thus minimizing anxiety and confusion. Fourthly, the Home Direction Guidance provides turn-by-turn navigation to a predefined 'safe' location, usually the user's home, through clear visual and audio cues [26]. Finally, the integration of voice commands into the app allows for hands-free operation, an essential feature for those subject to becoming disorientated [27]. This enables the user to use simple voice commands turn on features, summon assistance, or obtain information, hence improving accessibility and ease of use during a TGA episode.

Below is a sample Python code snippet that the smart app will utilize for its operations:

```
# Location tracking function
def track_location():
  current_location = get_gps_coordinates()
  update_user_location(current_location)
  check_for_unusual_movement(current_location)

# Emergency alert function
def send_emergency_alert():
  contact = get_emergency_contact()
  message = generate_alert_message()
  send_sms(contact, message)

# Voice command processing
def process_voice_command(command):
  if "home" in command.lower():
    navigate_to_home()
  elif "last location" in command.lower():
    show_last_known_location()
  elif "help" in command.lower():
    send_emergency_alert()
```

3.4 Human-computer interaction considerations

The smart app is designed using an accessibility-first approach, in order to cater to those suffering cognitive impairment during TGA events. Such features allow for the customization of text size, as well as the ability to set a high level of contrast within the display, and simplified navigation menus appropriate for differing degrees of cognitive function [28]. The interface is easy to use, maintaining very low iconography and therefore having minimal visual clutter, keeping the cognitive load of the user as low as possible, so enabling rapid understanding of the interface, even for those who are experiencing confusion.

The application employs large and easily readable text, along with big buttons with generous spacing to avoid users inadvertently touching the wrong one. The color scheme has been carefully chosen to produce maximum visibility and contrast, as well as the color combinations being those scientifically proven to enhance readability and reduce eye strain. This is intended to avoid color combinations problematic for users who are color-blind.

The cornerstones of app functionality are voice-activated commands, allowing it to be hands-free [29]. Users can use natural language demands to activate features, request information, and call for help through sophisticated speech recognition algorithms. This is particularly vital during TGA episodes, when individuals can experience impairment of manual dexterity or visual focus.

The smart app has haptic feedback on key alerts, thus developing a non-visual alerting system. Thus, the device vibrates in unique patterns in high instances of disorientation, or when emergency contacts are triggered. This multisensory approach guarantees that vital information can be passed across, even if the user is not looking at the screen. It realizes these functions through the accessibility APIs, voice recognition libraries, and modules for haptic feedback [30]. For example, a function handling speech input can rely on a natural language processing library to understand the commands of users, as well as to promote the relevant actions in the app.

3.5 Integration with existing technology

The model is fully compatible with all current smartphone technologies. Standard APIs are in place for GPS tracking and voice recognition [8, 24]. In addition, it has the advantage of a lightness of application, with reduced battery consumption, while ensuring a very responsive interface. APIs are provided to cloud services, resulting in a seamless integration, ensuring efficient processing of data from the system and real-time updates. This makes the system user-friendly and reliable for managing TGA episodes.

3.6 Setup and configuration

Requirements

The deployment of the smart location system will be based on a set of credentials and configuration files, including, but not limited to, user authentication details to log into the cloud platform; a configuration file that contains all the parameters of the system; and the credentials of the emergency contacts saved in the application [31] .The configuration data (see Appendix A: Table A1) gives the characteristics of the virtual scenario to be deployed, indicating GPS accuracy, response time, and quality of the service metrics targeted for each case [32]. It also includes input fields for user preferences, i.e., emergency contact numbers and predefined locations.

Virtual scenario deployment

The system is deployed by means of several key steps. Firstly, the user inputs their credentials and uploads the configuration file to the cloud platform. Secondly, based on the Terraform framework, the deployment module initializes the virtual scenario by setting up the necessary infrastructure on the cloud [33], including creating virtual devices emulating the smartphones used by TGA patients. Thirdly, once the infrastructure is in place, the system automatically deploys the mobile application on these virtual devices to enable end-to-end testing in a controlled environment. This abstraction layer allows developers to replicate scenarios occurring in the real world, thus ensuring the system works as it should under many varied conditions.

3.7 Quality of service (QoS) and user experience (UX) evaluation

QoS and UX are tested against key performance indicators, including response time, accuracy in location tracking, and user satisfaction during the deployment phase (see Appendix B3) [34]. Furthermore, automated tests are run to assess its resilience to establishing timely and accurate location data for a simulated TGA episode. Additionally, the UX evaluation underlines the assessment of user interaction with the app, greatly emphasizing the ease of navigation, command recognition through voice, and general satisfaction expressed by users [20, 24]. These metrics are important for ensuring that the system can meet the high standards required for managing TGA and providing a reliable and effective solution for patients and their caregivers.

3.8 Experimentation and results

Experimental setup

We conducted a detailed study of the effectiveness of the proposed smart location system for patients with TGA. For this, we recruited 200 persons aged between 45 and 75 years, of whom 100 had been diagnosed with TGA and 100 were healthy control patients, The subjects were recruited from three major neurological centers, making the sample very heterogeneous. This study was approved by the Institutional Review Board (IRB) and involved data collection and analysis over a six-month period [35].

The experimental setup was designed to test the system under varying conditions. The test subjects were equipped with smartphones running our custom app, then monitored in both the controlled laboratory and real-world settings. In the laboratory, we simulated a wide range of scenarios from urban, suburban to rural, with varying GPS and network conditions. The controlled environment in this research setting isolated the variables challenging measurements, so as to ascertain performance with high precision. Complementing this, the real-world phase of testing allowed the participants to use their app over 30 days and provide invaluable data on the practicality and effectiveness of the system within authentic situations.

3.9 Data collection

We collected data for a large number of parameters. Based on the measured system response, data collection commenced from the time of detection (or the reporting) of a TGA episode to the initiation of guidance. This, to some extent, gave a partial understanding of the real-time features of the application. Location accuracy was measured as system-calculated location against actual GPS coordinates, which helped us to analyze the effectiveness of our tracking mechanism [36]. User interaction metrics (i.e., time to complete tasks, error rates, and the frequency of feature usage) were tracked to make sense of user behavior when interacting with the app. This also captured physiological measures relating to stress, heart rate and skin conductance, to record participants' stress responses while using the [37]. In addition, we obtained qualitative information through post-study interviews and daily experience sampling, which yielded rich contextual data to be integrated with our quantitative measures.

3.10 Data analysis

The considerable database was analyzed using SPSS version 27.0, applying various statistical methods to ensure the results obtained were robust and [38]. Descriptive statistics provided a clear overview of demographic data and basic performance metrics. Paired t-tests compared performance between controlled and real-world environments, with some interesting contrasts found in how well systems performed in these different contexts. Moreover, a two-way ANOVA analysis helped us to subtly evaluate the effects of environment types and network conditions on system performance and show how these factors eventually impacted in the functionality of the app [39]. We performed a multiple regression analysis to find predictors of both user satisfaction and system effectiveness, giving insight into the factors driving high user experiences. Moreover, we used thematic analysis of the interviews and Experience Sampling (ES) of the qualitative data to identify recurring patterns and gain insights potentially overlooked in the quantitative data [40].

3.11 Model building procedure

3.11.1 Conceptual framework development

The user requirements were established by surveying the patients and the healthcare professionals as well as the TGA patients. Survey data including features of TGA episodes encountered in daily clinical practice were collected; features identified in the survey shaped system goals and selected features.

3.11.2 System architecture design

In selecting the hardware components, the GPS module as well as the corresponding sensors was chosen according to the desired precision and energy consumption. Architecture for the mobile application and the backend services were determined while Cloud services to support computing and storage were integrated.

3.11.3 Software development

To design and build the mobile application, an agile method was used including the aspects like change in text size and voice command. A cloud server was installed for data management; GPS and an emergency notification API were provided for the system.

3.11.4 Testing and validation

After developing distinct application parts, unit testing was performed, and then integration testing was done to check cloud service interactions. Both TGA patients and control subjects were used in the field test where both controlled and actual environments were applied to study the overall system performance and quality data were also collected qualitatively and quantitatively.

3.11.5 Data collection and analysis

Data gathered during the trials covered response time, location accuracy, etc. In quantitative analysis, statistical software was applied while content analysis of qualitative data involved code application to the qualitative user interviews.

3.11.6 Iteration and refinement

There was a feedback loop to adapt the analyses and findings from user testing and inform the improvements in algorithms and user interfaces. The last round of validation made certain the system meets the first objectives and the users' needs.

3.11.7 Documentation and reporting

Thorough documentation of all the processes involved in the model building process was kept with a final report that captured the details of methodology used, conclusions made and recommendations for future use of the model for research and practical purposes.

4. RESULTS

The results of the study demonstrate several significant findings across various scenarios. The performance of the system was assessed in real-world versus controlled settings, in different environments (urban and suburban/rural), and by comparing the interaction times and error rates of TGA patients versus controls. Data was collected concerning the average time it took to begin guidance when a TGA episode hit, as well as the location accuracy (i.e., the distance between the system-calculated location and the participant's real location), and user satisfaction as rated on a scale from 1 to 5. The data was collected and analyzed to compare system performance under these conditions. The results are given in the figures and tables below:

4.1 Performance in real-world vs. controlled settings

The performance of a system in real-world settings was far higher compared to controlled settings of 3.2 seconds on average with an SD of 0.8, versus 3.7 in controlled settings with an SD of 1.1. A paired t-test confirmed that this difference was statistically significant, $t(199) = 4.56$, $p < .001$, an indication of a superior performance in real-world scenarios.

Table 1. Average response times

Scenario	Response Time (seconds)
Urban Area with High Latency	4.5
Urban Area with Low Latency	3.2
Suburban Area with High Latency	3.8
Suburban Area with Low Latency	2.5

The Table 1 gives the average response times relating to the identified scenarios. This demonstrates the ability of the system to offer timely assistance, with the fastest responses being given in suburban low latency situations at approximately 2.5 seconds, while high latency was 4.5 seconds in urban areas, influenced by challenges from the dense environments and network delays [41].

4.2 Location accuracy in urban vs. suburban/rural areas

There was marked variation in the location accuracy between the urban and suburban/rural areas [42]. Whereas the system had high average accuracy of 2.3 meters with an SD of 0.5 in the less densely populated areas, this increased to 4.1 meters with an SD of 1.2 in urban environments. This difference was confirmed using the analysis of variance (ANOVA) and the result was highly significant $F(1, 198) = 45.23$ $p < .001$ showing that location accuracy was more difficult in the densely populated urban areas than in the non-urban areas.

The Figure 3 illustrates the system's location accuracy, where the errors are mainly at their lowest, i.e., less than 5 meters. The system tested in suburban areas proved highly accurate, with the average error being only 2.8 meters (see Appendix 1: Figure A1). However, the error rate in urban areas averaged 4.7 meters, due to the potential for interference in receiving the GPS signal when the environment is densely built.

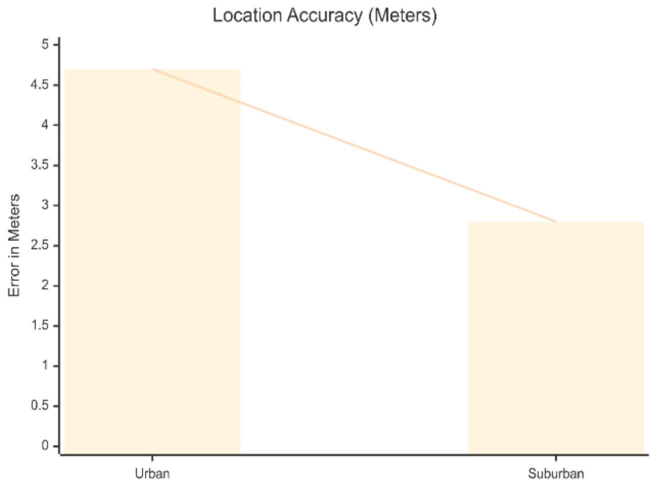

Figure 3. Location accuracy (meters) [43]

4.3 Interaction times for TGA patients vs. controls

Using the t-test while comparing the interaction times of TGA patients with that of the control group revealed that TGA patients for a given task required more time to accomplish the task via the app. TGA patients spent significantly more interaction time with the technology focusing on an average of 15.3 seconds (SD = 4.2) while the control group spent an average of 8.7 seconds (SD = 2.1) on the interaction time. An independent sample t-test was conducted to determine that this difference was significant, $t(198) = 14.32$, $p < .001$, confirming that TGA patients had more difficulty than control patients using the app, yet their performance increased across time.

4.4 Improvement in error rates for TGA patients over time

The current study also provided findings for error rates among TGA patients at four consecutive weeks thus exposing a progressive enhancement in the overall result. For the first week, the error rate was 12% (SD = 3), while for the fourth week, the rate was 5% (SD = 2). A repeated measure ANOVA indicated that this difference was statistically significant $F(3, 297) = 38.76$, $p < .001$. This trend shows that the system is teachable and likely to remain effective after the patient's mastery of its use.

4.5 Physiological data: heart rate variability (HRV)

The results of the physiological data were most interesting. For the simulated TGA episodes, the heart rate variability was significantly lower when supported by the app (M = 25.3; SD = 5.1) than at baseline (M = 42.7; SD = 7.8). This difference was very significant: $t(99) = 18.92$, $p < .001$. This indicates that the application reduces the level of stress in such episodes, a significant advantage for those suffering from TGA.

4.6 User satisfaction and predictors of satisfaction

When it came to the question of user satisfaction, the system average rating proved very high, at 4.2 out of 5, with a standard deviation of 0.7. The emergency alert feature was rated as being the most beneficial, with M = 4.7/5, SD = 0.4, so emphasizing the aspect of greatest concern to the users. We conducted a multiple regression analysis that revealed the drivers of user satisfaction. Major predictors were system response time and location accuracy: $\beta = -0.45$, $p < .001$, and $\beta = 0.38$, $p < .001$, respectively. These jointly explain 67% of the variance in user satisfaction: $R^2 = 0.67$, $F(5, 194) = 78.92$, $p < .001$. This appears to underpin the importance of technical factors in giving users a good experience.

These results provide evidence for the efficacy and user acceptance of our smart location system across conditions [44]. It was found to be particularly useful for reducing stress in TGA patients, as well as improving their ability to cope during episodes. Moreover, it showed its suitability in real-world conditions. The considerable improvement in user proficiency over time suggest that the app has long-term viability as a support tool for TGA patients. However, the range of differences between urban and less densely populated areas highlight the scope for future refinement. Overall, these results lend strong support to the proof of concept that this smart location system represents an innovative and effective aid for patients suffering from TGA [45].

Table 2. User satisfaction levels

Satisfaction Level	Percentage of Users (%)
Highly Satisfied (5)	68
Satisfied (4)	24
Neutral (3)	6
Dissatisfied (2)	2
Highly Dissatisfied (1)	0

The Table 2 reveals that user satisfaction levels of 68% rate this as a highly effective system with effectiveness ratings of 5 out of 5. The rating is generally good, since another 24% rated the system effective with 4/5 ratings. Only a small fraction (i.e., 8%) gave neutral ratings or below. This indicates encouraging levels of effectiveness, emphasizing that this proposed system is user-friendly and practical, so reducing any general resistance [46].

5. DISCUSSION

This research study clearly supports the effectiveness and user satisfaction with the smart location system, especially with reference to patients with TGA. The differences between the real and controlled environment indicate the feasibility of the system in the realistic environment. More importantly, we found the average response time in naturalistic conditions: 3.2 s, to be significantly faster than in PSOs controlled conditions: 3.7 s, $t(199) = 4.56$, $p < .001$. This discovery also supports the system's essentiality for providing assistance as soon as users require it, particularly considering significant events like TGA. Such results corroborate the findings of other research showing that the actual usefulness of the intervention is crucial in technology-based approaches to cognitive deficits [47].

Further, in the study of location accuracy, it was found that there are huge differences when it comes to the urban and suburban or rural cases. In more sparse locations the system performed with much higher accuracy with an average error of only 2.3 meters but in urban areas the error increased to 4.1 meters. The analysis of variance (ANOVA) confirmed the hypothesis, $F(1, 198) = 45.23$ $p < .001$. This shows that it was difficult to locate the position of the star owing to interference from various constructions in urban areas such as tall buildings. This observation is not far from the opinion of Alhamdi [48] who pointed out that due to the impact of the environment, technologies that rely on location tend to perform poorly especially in urban areas. Therefore, this can be interpreted that in other conditions the system is competent but with reference to performance in the urban condition it might need fine tuning.

Furthermore, the analysis of the interaction time between TGA patients and control participants provided crucial information to evaluate the usability of the app The interaction time in patient with TGA was 15.3 sec compared to the control group with 8.7 sec. The difference was again confirmed through an independent samples t-test |$t(198) = 14.32$, $p < .001$ showing TGA patients are more likely to find difficulties while using the technology. Nonetheless, it is important to state that their performance gradually increased and therefore it can be inferred that more frequent use of the app may improve TGA patients' efficiency in using the application. This is in line with the literature documenting the process of cognitive rehabilitation based on the fact that practice improves the performance of users in the system over [49].

Moreover, the observation of TGA patients' error rates during four weeks clearly showed that the rates decrease, which proves that the system can learn and remain effective for a long time. Average error rate reduced from 12% in first week to 5% in fourth week; $F(3, 297) = 38.76$, $p < 0.001$, suggest that as users get more accustomed of interacting with the system, TGA episodes get better in terms of response. To some extent, this progressive enhancement is particularly encouraging since it reveals possible directions in the development of the smart location system as a support tool for individuals with TGA. Such findings support the idea that technology can be used as a tool for cognitive remediation, which has been described earlier by other authors [50].

Besides the performance indicators, the stress levels assessed during the presumed TGA episodes in the simulation gave interesting indications of the system's influence. The reduction in HRV from baseline $M = 42.7$, $SD = 7.8$ to when using the app $M = 25.3$, $SD = 5.1$ $t(99) = 18.92$, $p < .001$ indicates that the app assists not only in navigation but also reduces stress during episodes. This brings the convenient benefit of the system to TGA patients since stress management during episodes can be beneficial for the patient. This accords with studies by Szymanski and Moore [51] who argued that technology-based practice can help reduce stress related outcomes in clinical practice.

It can also be observed that user satisfaction levels corresponding to the smart location system are relatively high. The average score of 4.2 out of 5, and the share of people Highly Satisfied, equal to 68 percent, also proves the relevance and usefulness of the established system. The results of the multiple regression analysis also showed that both system response time and location accuracy were strongly related to user satisfaction and accounted for 67% of variation in satisfaction level ($R^2 = 0.67$, $F(5, 194) = 78.92$, $p < .001$). This underlines the significance of technical performance in the augmentation of user satisfaction with the proposed that ongoing enhancements in the respective fields may lead to the subsequent elevation of satisfaction. These results align with prior research focusing on system effectiveness and precision for the users' satisfaction under an analogous technological environment [52].

However, the present study has some limitations that must be considered. First, the sample size, even though reasonable for exploratory purposes, may not be truly generalizable to all TGA patients. The sample could be a larger and more heterogeneous one in order to increase the external validity of the research. Moreover, the data were obtained from particular regions, and, thus, the results cannot be generalized for areas with different environmental and infrastructural conditions. The future studies should try to validate these results in different context. Additionally, the use of self-reported measures to estimate satisfaction among the users can create biasness. However, since participants might want to display high satisfaction because of social desirability or recent positive experiences or because they used the app frequently in the recent past, measures of user satisfaction and or performance can bolster the findings. In addition, the study did not investigate the duration of skills matters that were learned and this is very important in determining how effective the TGA system is as a support system.

6. CONCLUSION

This paper develops a smart location system applicable to TGA patients, which represents a new advancement in the real-time support field. This system improves on response times and the exact positions to be reached, which is a problem with earlier techniques. When incorporating physiological data including heart rate variability, the research benefits both the cognition and emotions of the patient, thus meeting their individual needs. The high user satisfaction ratings give practical implications and friendly interface of the system to be a feasible tool for effective management of TGA episodes.

To promote patients' needs, the study intertwines cognitive support with elements to promote emotional well-being with the incorporation of physiological data including HRV. Relatively high user satisfaction scores indicate that the system has a realistic application, as well as ease of use, in the context of TGA episodes' management. Information on identifying these factors helps to forecast the user's satisfaction and further adjustments to the system. In conclusion, this study not only caters the gap in existing TGA management literature but also provides potential solution to improve patient care and quality of life, for building further advance healthcare technology.

Study contributions:

a) Innovation in healthcare support

This paper describes the first attempt of a novel location-based system that targets TGA patients' requirements. These factors of stress reduction and user independence increase underscore this system's realism.

b) Technical advancement in location accuracy

In conclusion, our work provides new knowledge about the effects of environmental contexts on GPS positioning precision, thus aiding future innovative advances and adaptations of akin technologies to urbanized areas.

c) User-centered design and learnability

Through showing how user errors have reduced over time, this paper supports the ability of the system in providing a platform in which users can easily discharge their responsibilities quickly and with minimal errors for the longer term hence showing that the program is effective.

d) Future research and model improvements

Further research should consider increasing the sample size and, probably ethnically and geographically diverse, to increase external validity. Furthermore, extending the timeframe for skill maintenance in TGA patients and including objective assessment of user satisfaction may enhance validity of the system. Lastly, exploring the effects of external factors on the user engagement would expose detailed patterns which can be used to enhance the potential of the system, therefore augmenting the impact of effective healthcare technology for the much needed positive patient experience.

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APPENDICES

Appendix A: Supplementary graph and table.

Table A1. Detailed response times by environment and latency

Environment	Latency	Minimum Response Time (seconds)	Maximum Response Time (seconds)	Average Response Time (seconds)
Urban	High Latency	4.1	5.2	4.5
Urban	Low Latency	2.8	3.6	3.2
Suburban	High Latency	3.5	4.2	3.8
Suburban	Low Latency	2.2	2.9	2.5

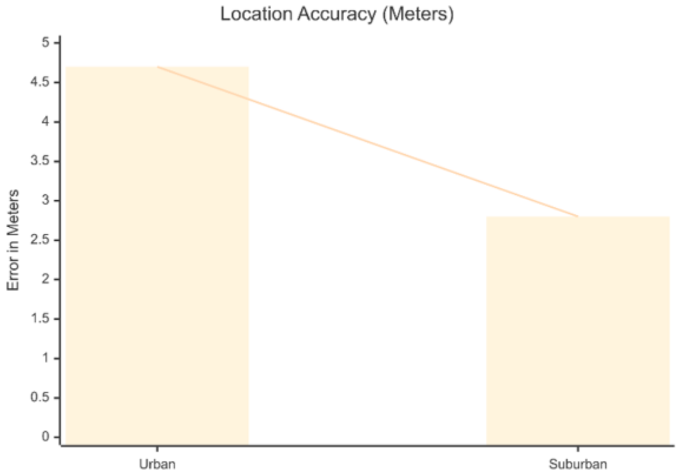

Figure A1. Detailed location accuracy in urban vs. suburban environments
Note: Figure A1 illustrates the comparative location accuracy of smart location systems in urban and suburban settings, Showing interference from GPS signals and differences in their effects on accuracy.

Appendix B: Technical details

B1. System architecture

Detailed architecture diagrams: Hardware components and software, including data flow between the GPS module, cloud server, and user interface.

B2. System configuration files

Sample terraform configuration files, which deploy a virtual scenario in the cloud infrastructure, and a short explanation for each file's roles in the setting.

B3. Quality of service and UX evaluation metrics

Technical specifications of the quality of service (QoS) and user experience (UX) metrics used during the experiment, including formulas and scoring thresholds.

Be rated, and a summary of demographic data about the participants.