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4

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Digital exercise prescription for hypertension: design of an integrated platform with wearable devices for real-time monitoring and patient support

Prescripción digital de ejercicios para la hipertensión: diseño de una plataforma integrada con dispositivos vestibles para monitoreo en tiempo real y apoyo al paciente

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ABSTRACT

This study addressed the development of an integrated platform that combines web, mobile, and wearable device technologies for real-time collection, transmission, and analysis of health data, with the specific goal of improving monitoring and communication between patients and physicians in the treatment of hypertension. Using a descriptive research methodology and data collection techniques such as interviews and questionnaires aimed at health professionals and patients, the study identified key needs. Subsequently, the design and development of the proposed solution were carried out using agile methodologies. Results highlighted the successful integration of a Garmin smartwatch with a mobile app and web system, which facilitated patient adherence to prescribed exercise regimens and improved real-time monitoring of vital signs. This research concludes that the developed platform significantly enhances the management of hypertension treatment, offering an effective tool for the continuous monitoring of patient health. This finding underscores the importance of incorporating digital technologies in healthcare to optimize the treatment and monitoring of chronic diseases, representing a significant advance in hypertension care and illustrating the potential of technological solutions to transform health management.

Palabra clave: health applications, hypertension, real-time monitoring, integrated platform, wearable technologies

RESUMEN

Este estudio abordó el desarrollo de una plataforma integrada que combinó tecnologías web, móviles y de dispositivos vestibles para la recopilación, transmisión y análisis en tiempo real de datos de salud, con el objetivo específico de mejorar el monitoreo y la comunicación entre pacientes y médicos en el tratamiento de la hipertensión. Utilizando una metodología de investigación descriptiva y técnicas de recolección de datos como entrevistas y cuestionarios dirigidos a profesionales de la salud y pacientes, se identificaron las necesidades clave y se procedió a realizar en el diseño y desarrollo de la solución propuesta mediante el uso de metodologías ágiles. Los resultados destacaron la exitosa integración de un smartwatch Garmin con una aplicación móvil y un sistema web, lo cual facilitó el cumplimiento de los pacientes con los regímenes de ejercicios prescritos y mejoró el seguimiento en tiempo real de los signos vitales. Esta investigación concluye que la plataforma desarrollada mejora significativamente la gestión del tratamiento de la hipertensión, ofreciendo una herramienta eficaz para el monitoreo continuo de la salud del paciente. Este hallazgo resalta la importancia de incorporar tecnologías digitales en la atención médica para optimizar el tratamiento y seguimiento de enfermedades crónicas, representando un avance significativo en la atención de la hipertensión y destacando el potencial de las soluciones tecnológicas para transformar la gestión de la salud.

Keywords: aplicaciones para la Salud, hipertensión, monitoreo en tiempo real, plataforma integrada, tecnologías vestibles

INTRODUCTION

Hypertension is a prevalent chronic non-communicable disease that poses significant challenges to global public health. Physical inactivity and inadequate diet are well-recognized risk factors that significantly contribute to the prevalence of hypertension (World Health Organization [WHO], 2010). In Ecuador, the Ministry of Public Health has identified these risk behaviors as predominant among the adult population, underscoring the need for effective interventions to control and prevent hypertension (Ministerio de Salud Pública del Ecuador, 2019).

Current literature supports regular physical exercise as an essential component in the prevention and treatment of hypertension, noting that it can be as effective as pharmacological treatments in certain cases (Ghadieh & Saab, 2015). However, monitoring and adherence to prescribed exercise regimens remain challenging, highlighting the need for innovative technological solutions that facilitate real-time monitoring and enhance communication between patients and healthcare providers.

Recent advances in wearable technologies and mobile applications have enabled the effective integration of health monitoring into patients' daily lives. Devices such as smartwatches and mobile apps have shown promise as tools in the management of chronic diseases, including hypertension (Deepak et al., 2023). However, widespread adoption of these solutions is hindered by issues related to usability, interoperability, and lack of personalization in treatment regimens.

Studies such as Dias and Cunha (2018) have explored the potential of wearable devices for continuous vital sign monitoring, highlighting their medical applications, although their use is mostly limited to research settings. Moreover, recent investigations have identified a lack of integrated platforms that effectively combine web, mobile, and wearable technologies for hypertension management (Cusack et al., 2024).

In light of this literature review, the following research question arises: Can an integrated platform combining web, mobile, and wearable technologies significantly improve adherence to prescribed exercise regimens and the monitoring of vital signs in hypertensive patients compared to existing technologies?

The underlying hypothesis of this study is that implementing an integrated technological platform will facilitate patient adherence to exercise regimens, improve the accuracy of vital sign monitoring, and ultimately optimize hypertension management. This optimization is expected to be achieved through personalized treatment, enhanced communication between patients and healthcare providers, and the integration of technologies enabling continuous, real-time monitoring.

Unlike existing technologies that focus solely on monitoring or intervention, the platform proposed in this study integrates multiple critical aspects of hypertension management. Current applications often lack interoperability and personalization; the proposed solution seeks to overcome these limitations through a holistic approach that includes personalized exercise regimens, continuous vital sign monitoring, and seamless communication between patients and healthcare providers. Therefore, this platform offers not only a tool for passive monitoring but also serves as an active means to improve adherence and long-term health management.

METHODOLOGY

This study employed a mixed-methods approach, combining quantitative and qualitative analyses to evaluate the impact of an integrated digital platform on hypertension management. Initially, in-depth interviews were conducted with medical specialists, including an endocrinologist from the Social Security Hospital, a cardiologist from Luis Vernaza Hospital, and a neurologist from the Naval Hospital in Guayaquil. These experts contributed to the collection of vital sign data—such as blood pressure, pulse, and heart rate—from volunteers and assisted in identifying the specific needs and functionalities required for the application. Interviews with hypertensive patients were also conducted to gain deeper insights into their specific needs and challenges.

The specialists identified key parameters crucial to the hypertension process. These included patient age, sex, height, hip and waist circumference, systolic and diastolic blood pressure before and after the intervention, and qualitative parameters related to the patient's physical activity level and current hypertensive status (Chuka et al., 2020). These biometric and qualitative parameters were consolidated into eight independent variables (X1 to X8) for incorporation into the analytical model.

Participants were selected based on inclusion criteria that required a confirmed diagnosis of hypertension, informed consent to participate in the study and use wearable devices, and access to a compatible mobile device for the application. Exclusion criteria encompassed severe comorbidities that could interfere with physical activity and non-compliance with the device usage protocol.

Quantitative data collected from the participants were analyzed using advanced statistical techniques. Linear regression models were employed to assess the relationship between exercise routines and changes in vital signs. An analysis of variance (ANOVA) was also conducted to compare the effects of different physical activity levels on the monitored health parameters. Statistical software, including R and Python, was utilized for data management and analysis.

Qualitative data from the transcribed interviews were subjected to thematic coding using NVivo software. This process facilitated the identification of patterns and trends in users' perceptions of the platform's effectiveness and usability, providing valuable insights into user experience and areas for improvement.

The platform was developed iteratively, with continuous reviews ensuring alignment with the initial requirements gathered from the interviews. The development process involved simulating the application's functionality using test data for vital signs and incorporating load and performance tests. These tests simulated multiple users accessing the application concurrently and performing data-intensive operations to evaluate the system’s capacity to handle high volumes of traffic without degrading performance or user experience (Rivera Villagra, 2018).

Upon completion of the design and development phase, the application was implemented following best practices to ensure data integrity and security. Updated security protocols were employed to protect sensitive health data (Cruz Rodríguez, 2023). Integration with tracking devices, such as Garmin smartwatches, facilitated continuous and reliable collection of vital sign data. Extensive testing—including unit tests, integration tests, and user acceptance testing—was conducted to ensure the application’s functionality and usability.

Based on statistical analyses of the collected data and feedback obtained during testing, enhancements were made to refine the user experience and improve the accuracy and effectiveness of exercise routine tracking and vital sign monitoring. The development tools used included Java for mobile application development and Python for backend development and data analysis. Android Studio served as the primary environment for building the mobile application, while Django was utilized for the web system. Hardware components comprised Garmin smartwatches for data collection and compatible smartphones for running the application. Cloud-based servers were employed to securely store and process the collected data.

Implementation testing involved load and performance tests that simulated interactions of multiple simultaneous users with the application, enabling the identification and correction of potential bottlenecks. Security tests were also conducted to ensure data integrity and confidentiality, adhering to relevant data protection regulations.

Platform requirements

To satisfy user demands, functional and non-functional requirements were carefully defined, these are essential for the optimal performance of the system which is aimed at doctors (or specialists) and patients (Pereda Lévano, 2022). The precise identification of these requirements are essentials to guarantee the effectiveness, efficiency, and adaptability of the system to the specific needs of different users.

The system architecture is articulated around two main roles:

Physician or Specialist: This user profile is designed to empower healthcare professionals with the ability to verify patient assignment and proceed with detailed documentation of each patient's Clinical History. The purpose of this process is to collect exhaustive information about the Pathological, Non-Pathological and Family Inherited History, including the patient's current conditions. Additionally, this role enables the doctor to monitor the patient's vital signs in real time and prescribe adapted physical exercise routines, with the aim of promoting a healthy lifestyle and preventing fluctuations in the patient's health indicators (George, Shahul, & George, 2023).

Patient: This role is designed for users (Guevara Alban, 2020) who require medical monitoring, including those subjects who have been prescribed physical exercise routines by their doctor. The intention behind this role is to encourage the adoption of healthy habits and the prevention of alterations in vital signs through adherence to medical recommendations.

This role-based approach promotes an efficient and focused interaction dynamic between doctors and patients, allowing rigorous monitoring of health and the implementation of personalized measures for the care and improvement of the patient's quality of life. The system structure reflects a careful integration of the functionalities necessary to support health monitoring activities and personalized treatment management, essential in the context of modern healthcare.

Figure 1.
Roles and Functionalities of the Platform.

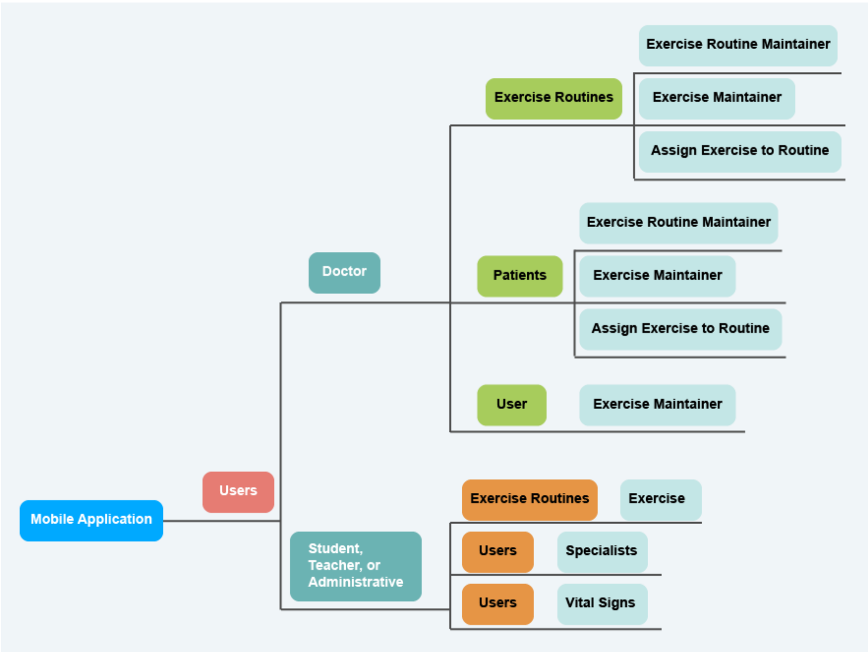

Figure 1 schematizes the distribution of tasks and interactions between users and system capabilities, facilitating the understanding of the essential functional requirements for the management and monitoring of patients with arterial hypertension.

César Alcívar Aray
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Web tokens significantly enhance data security and user authentication, creating a clear hierarchy among system roles including Physician or Specialist and Patients. They protect every client-server query, guaranteeing secure and dependable data transactions. Access to the application is secured through a rigorous user registration system for both roles. When data is transmitted to the server, it generates a unique token to validate the information before delivery to the application. To bolster security further, the server issues random access tokens at each login, refreshing these tokens with every session to enhance security measures. This strict security measure requires the use of a specific user’s token for all transactions, greatly strengthening authentication processes and maintaining data integrity. The system also incorporates safeguards to prevent access by potentially malicious users, thereby enhancing overall security.

Functional Requirements:

The specialists in endocrinology, cardiology, and neurology interviewed suggested the following requirements, which are considered functional requirements, at the beginning of the experiment. The functional requirements, derived from the analysis of the provided diagram and the context of the platform for the management and monitoring of patients with arterial hypertension, can be specified as follows (The Fifth Joint Task Force of the European Society of Cardiology and Other Societies on Cardiovascular Disease Prevention in The Fifth Joint Task Force of the European Society of Cardiology and Other Societies on Cardiovascular Disease Prevention in Clini, 2012):

1. User Authentication: Ability to register and authenticate users, distinguishing between doctor and patient roles

2. Patient Management: Functionality for doctors to consult and manage the patients in their care, including the approval of pending patients.

3. Clinical History Record: Tool for doctors to document and access the complete clinical history of patients, recording pathological, non-pathological and family history.

4. Exercise Routine Management: A module to create, assign and maintain exercise routines, as well as to associate specific exercises with said routines.

5. Vital Signs Monitoring: Function for doctors to monitor patients' vital signs, allowing real-time view and traceability of health conditions.

6. Execution of Exercise Routines: Interface for patients, including teachers and students, to perform the prescribed physical exercise routines and record their compliance.

7. Traceability of Exercises and Vital Signs: Ability of the system to track and present the progression and effectiveness of exercise routines in relation to the patient's vital signs and general health condition.

These functional requirements are essential to ensure that the platform fulfills its purpose of offering comprehensive management and detailed health monitoring of patients with hypertension, thereby improving the quality of treatment and preventive care.

Non-Functional Requirements:

Non-functional requirements, adapted from “Desarrollo de una aplicación web que permita registrar los datos de las rutinas de ejercicios físicos prescritos a los pacientes, historial clínico y la trazabilidad de los ejercicios realizados con los signos vitales del paciente en tiempo real” by Cynthia E. Coello P., 2022, regarding communication between platform components, can be specified as follows:

1. Bluetooth Communication: The smartwatch collects vital signs and sends them to the patient's mobile application via a secure and stable Bluetooth connection, ensuring efficient and real-time data transmission.

2. WebSocket Transmission: Once the vital signs data is collected by the mobile application, it is transmitted to a central server using the WebSocket protocol. This ensures real-time two-way communication between the mobile app and the server, which is crucial for immediate monitoring of vital signs by doctors.

3. Real-Time Data Replication: The server uses subscription mechanisms to distribute vital signs information to the corresponding doctors' applications. This functionality allows multiple doctors to view real-time data simultaneously, facilitating a rapid response if any anomaly or need for medical intervention is detected.

These non-functional requirements are vital to ensuring that the platform functions cohesively, reliably, and securely, facilitating continuous interaction between patients and their doctors through technology and improving healthcare management.

Volunteer Sample Size Calculation

The volunteers were obtained from the Faculty of Industrial Engineering of the University of Guayaquil. The Faculty of Industrial Engineering at Guayaquil University is situated at the intersection of Juan Tanca Marengo and Benjamin Carrion Avenue in Guayaquil. The faculty employs 144 teachers and 187 administrative staff and enrolls 4,678 students. To determine the sample size for a finite population, the next formula was applied (Lind, Marchal, & Wathen, 2012), utilizing data from Table 1:

$$n = \frac{N \cdot \left(t_{n-1;\alpha} \cdot s\right)^2}{\left(t_{n-1;\alpha} \cdot s\right)^2 + (N-1) \cdot E_{max}^2}$$

Table 1. *Values Used in the Sample Size Calculation for a Finite Population*

Data	***Value***
Teachers	144
Administrative Staff	187
Students	4678
N	5009
t	2.093
α	0.05
s	720
n	20
$Emax$	342

Consequently, a sample size of 20 individuals was chosen for the experiment. These participants gave their informed consent to partake in the study and to share data collected from their smartwatches for research associated with the Competitive Research Fund (FCI).

RESULTS

An integrated platform has been developed consisting of an application on a Garmin smartwatch, a mobile application, and a web system, all interconnected through the Internet. Figure 2 details the communications architecture of the platform and the data exchange flow between its components. This scheme demonstrates how vital signs collected by the smartwatch are transmitted via Bluetooth to the user's mobile application. The data is then sent to the server using the HTTP protocol and distributed in real time to doctors' applications using WebSocket, allowing for continuous, real-time monitoring.

Figure 2.
Communication Architecture of the Platform and Data Flow.

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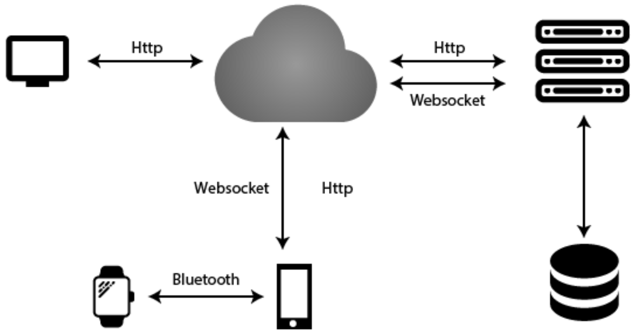


In the development of the proposed platform, three key components were successfully implemented, designed to improve the interaction between patients and doctors, as well as to facilitate the monitoring and tracking of patient health. The results obtained for each of the platform components are described below.

Garmin Smartwatch Software

Garmin smartwatch software was successfully developed with the platform, allowing the device to collect and send relevant information, such as vital signs and compliance with prescribed exercises, to the mobile system and the web system. The Bluetooth connection between the smartwatch and the patient's mobile device was effectively established, ensuring continuous real-time data synchronization. Figure 3 illustrates the exercises specified by the health professional for the patient, which are obtained through a web service.

Figure 3.
Application showing the exercises prescribed by the specialist to the patient.

Mobile Application

Mobile Application focused on making it easier for health professionals to meticulously monitor their patients' vital indicators in real time. Designed specifically for the medical environment, this tool captures critical data such as heart rate, number of steps, body temperature among other vital signs, through Bluetooth connectivity with wearable monitoring devices, in this case, a smartwatch. focused on making it easier for health professionals to meticulously monitor their patients' vital indicators in real time. Designed specifically for the medical environment, this tool captures critical data such as heart rate, number of steps, body temperature among other vital signs, through Bluetooth connectivity with wearable monitoring devices, in this case, a smartwatch. The process shown in Figure 4, begins when a patient sends a system access request to the doctor or specialist, who reviews the request and either approves or declines it. Once approved, the patient is selected for treatment from the doctor or specialist's list of assigned patients. Through the application, they can access and send various treatment options -such as exercise routines and medications- based on the patient's diagnosis. The doctor or specialist then prescribes the daily activities, which are communicated to the patient via the mobile app. The patient reviews these activities, starts the exercise routines, and follows the dietary recommendations given by the doctor. During the exercise, the patient's vital signs and activities are transmitted to the doctor in real-time, who monitors these vitals, takes necessary precautions, and provides feedback on any specific issues or satisfactory progress. In Figure 5, it is shown as the mobile application that monitors the vital signs of patients in real time.

Figure 4.
Use Case Context Diagram for Mobile application. Information adapted from (Cabrera, 2020).

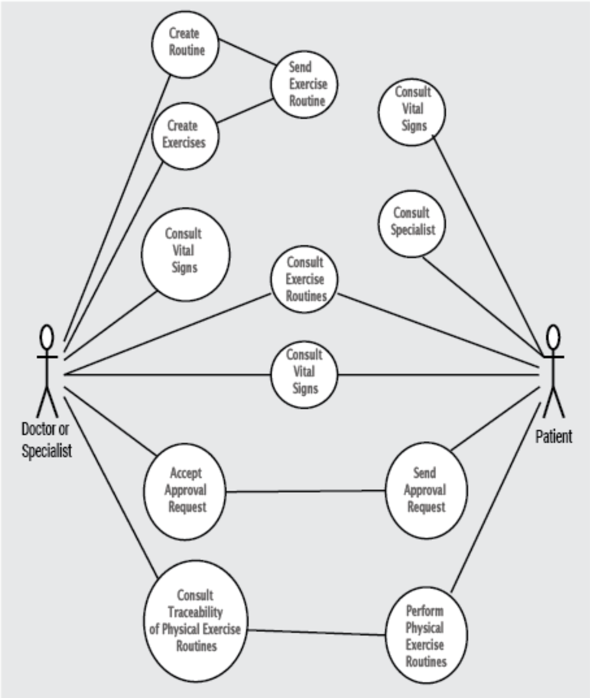
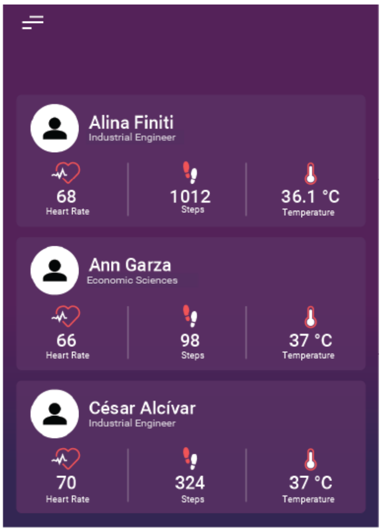


Figure 5.
Mobile application for real-time monitoring of patient vital signs.



Data regarding patients' vital signs and exercise routines are transmitted from the mobile app to the web system.

César Alcívar Aray
Mariuxi Toapanta Bernabé
David Ramos Tomalá

The following quantitative variables were collected from both the Mobile Application and the Web System as part of the experiment: X1 through X8, kilocalories, steps taken, and distance traveled. These findings are detailed in Table 2.

Table 2.
Quantitative Variables in Research

Variable	*Name*	*Value*
X_1	Sex	Male=0 Female=1
X_2	Age	18 min-75 max
X_3	Physical Activity Level	Sedentary=0 Medium Active=1 Very Active=2
X_4	Hypertensive Risk	Low=0 Medium=1 High=2
X_5	Body Mass Index	weight/height^2
X_6	Waist/Hips Index	Waist/Hips
X_7	Body Fat Index	%
X_8	Decrease in Mean Arterial Pressure	Mean Pressure Before-Mean Pressure After

Table 3.
Kilocalories: Sample Data for Research.

	Kilocalorie	*X1*	*X2*	*X3*	*X4*	*X5*	*X6*	*X7*	*X8*
0	9620	0	39	1	2	21.7	0.904255	24	1.3
1	7600	0	49	1	2	34.3	0.934959	30	18.0
2	11569	0	46	1	2	27.3	0.859649	25	2.7
3	10000	0	49	1	2	24.2	0.936170	24	8.3
4	6530	0	44	1	1	32.9	0.825688	26	1.0
5	8570	1	38	1	1	28.0	0.931373	28	1.0
6	9826	0	48	0	2	34.0	0.960000	35	5.3
7	9560	0	47	1	2	34.2	0.846154	32	6.3
8	9946	1	44	0	1	25.4	0.881818	44	4.0
9	9863	0	26	1	1	24.0	0.761905	22	5.0
10	10308	1	24	0	2	28.2	0.739130	40	12.3
11	10072	1	24	1	1	24.4	0.803922	36	0.7
12	10974	0	25	0	2	24.5	0.840000	14	4.3
13	9677	0	28	1	2	28.7	0.900000	30	6.7
14	10185	0	26	0	1	28.4	0.886957	28	1.7

César Alcívar Aray
Mariuxi Toapanta Bernabé
David Ramos Tomalá

15	9980	0	28	0	2	35.2	0.884615	36	10.0
16	11146	0	27	0	1	27.8	0.970297	27	5.0
17	10824	0	25	0	2	28.7	0.863248	27	5.3
18	10745	1	25	0	2	25.4	0.708333	43	10.3
19	9615	0	23	0	1	24.6	0.833333	25	4.0

Table 4.
Steps taken: Sample Data for Research.

	Steps	***X1***	***X2***	***X3***	***X4***	***X5***	***X6***	***X7***	***X8***
0	176130	0	39	1	2	21.7	0.904255	24	1.3
1	170882	0	49	1	2	34.3	0.934959	30	18.0
2	176719	0	46	1	2	27.3	0.859649	25	2.7
3	178350	0	49	1	2	24.2	0.936170	24	8.3
4	158759	0	44	1	1	32.9	0.825688	26	1.0
5	168000	1	38	1	1	28.0	0.931373	28	1.0
6	172528	0	48	0	2	34.0	0.960000	35	5.3
7	178510	0	47	1	2	34.2	0.846154	32	6.3
8	172913	1	44	0	1	25.4	0.881818	44	4.0
9	174362	0	26	1	1	24.0	0.761905	22	5.0
10	174648	1	24	0	2	28.2	0.739130	40	12.3
11	176576	1	24	1	1	24.4	0.803922	36	0.7
12	175337	0	25	0	2	24.5	0.840000	14	4.3
13	176724	0	28	1	2	28.7	0.900000	30	6.7
14	174526	0	26	0	1	28.4	0.886957	28	1.7
15	173923	0	28	0	2	35.2	0.884615	36	10.0
16	177358	0	27	0	1	27.8	0.970297	27	5.0
17	173731	0	25	0	2	28.7	0.863248	27	5.3
18	176232	1	25	0	2	25.4	0.708333	43	10.3
19	175082	0	23	0	1	24.6	0.833333	25	4.0

Table 5.
Distance Traveled in Kilometers: Sample Data for Research.

	Kilometers	***X1***	***X2***	***X3***	***X4***	***X5***	***X6***	***X7***	***X8***
0	132.28	0	39	1	2	21.7	0.904255	24	1.3
1	143.75	0	49	1	2	34.3	0.934959	30	18.0

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2	148.89	0	46	1	2	27.3	0.859649	25	2.7
3	148.06	0	49	1	2	24.2	0.936170	24	8.3
4	106.38	0	44	1	1	32.9	0.825688	26	1.0
5	128.5	1	38	1	1	28.0	0.931373	28	1.0
6	146.29	0	48	0	2	34.0	0.960000	35	5.3
7	138.34	0	47	1	2	34.2	0.846154	32	6.3
8	133.93	1	44	0	1	25.4	0.881818	44	4.0
9	130.36	0	26	1	1	24.0	0.761905	22	5.0
10	132.65	1	24	0	2	28.2	0.739130	40	12.3
11	131.49	1	24	1	1	24.4	0.803922	36	0.7
12	136.19	0	25	0	2	24.5	0.840000	14	4.3
13	134.59	0	28	1	2	28.7	0.900000	30	6.7
14	134.48	0	26	0	1	28.4	0.886957	28	1.7
15	135.33	0	28	0	2	35.2	0.884615	36	10.0
16	137.41	0	27	0	1	27.8	0.970297	27	5.0
17	133.76	0	25	0	2	28.7	0.863248	27	5.3
18	136.08	1	25	0	2	25.4	0.708333	43	10.3
19	139.99	0	23	0	1	24.6	0.833333	25	4.0

On this platform, medical specialists can analyze metrics and observe trends that reflect the health progress of hypertensive patients. This essential information supports comprehensive trend analysis, clinical evaluations, and continuous monitoring of patient progress, as illustrated in Figures 6.

On this platform, medical specialists can assign exercise routines to their hypertensive patients, in addition to analyzing metrics and observing trends that reflect their health progress. This essential functionality supports comprehensive trend analysis, clinical evaluations, and continuous monitoring of patient progress, as illustrated in Figure 6.

Figure 6.
A medical specialist has assigned an exercise routine to their patient. Information adapted from (Cabrera, 2020).

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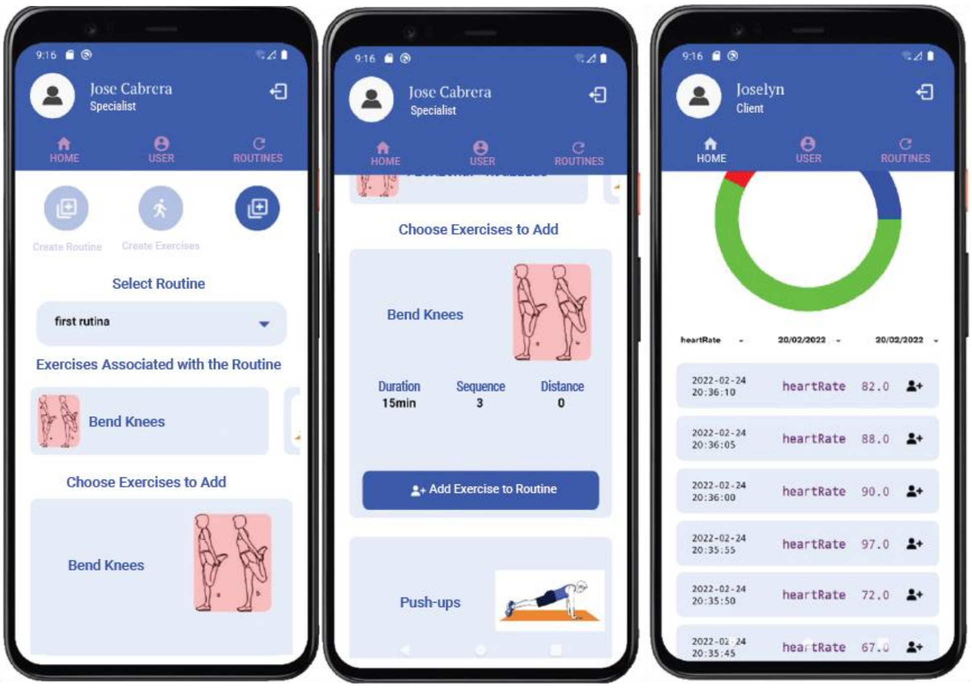

The mobile application designed for health monitoring requires a minimum internet connectivity of 2 Mbps to ensure effective data transmission, crucial for the management of real-time information such as vital data and other health parameters. Furthermore, it maintains a maximum latency tolerance of 100 ms to prevent performance degradation in its critical functions, ensuring fast processing necessary for timely medical response.

Regarding network requirements, the application needs at least a 4G LTE connection, though it is also compatible with 5G, which significantly enhances the efficiency of data synchronization and communication. This capability ensures that the application is prepared for future technological improvements in network infrastructure.

The platform supports both Wi-Fi and cellular connections, allowing it to operate in a wide range of environments and leverage the best available technology based on network coverage, thus enhancing accessibility and continuity in health monitoring.

To handle situations without internet connection, a local database using SQLite and Room is implemented, which allows secure data storage until the connection is restored. Equipped with Connectivity Manager, the application detects changes in connectivity, managing locally stored data and synchronizing it efficiently with the central server once the connection is recovered. This approach ensures that the application operates continuously and efficiently, maintaining the integrity of critical patient data at all times.

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Web System

A web interface has been developed that allows patients to register and submit their personal information. Within this system, medical specialists have the capability to approve patients and document their Clinical History, which includes medical history and allergies. The system enables real-time monitoring of patients' vital signs, as shown on the left side of Figures 10 and 11, gathering data from a server that receives inputs from a smartwatch worn by the patient. A specific section within the platform allows doctors to prescribe personalized exercises routines, as illustrated in Figure 9, which patients can readily access and follow. This streamlined process enhances the management of exercise routines, ensuring that patients adhere to the specific guidelines set by their doctors. Additionally, it allows doctors to monitor compliance and evaluate progress, facilitating tailored and effective care management. All available options for both the doctor or specialist and the patient are shown in Figure 8.

Figure 8.
Use Case Context Diagram for Web System. Information adapted from (Coello, 2022).

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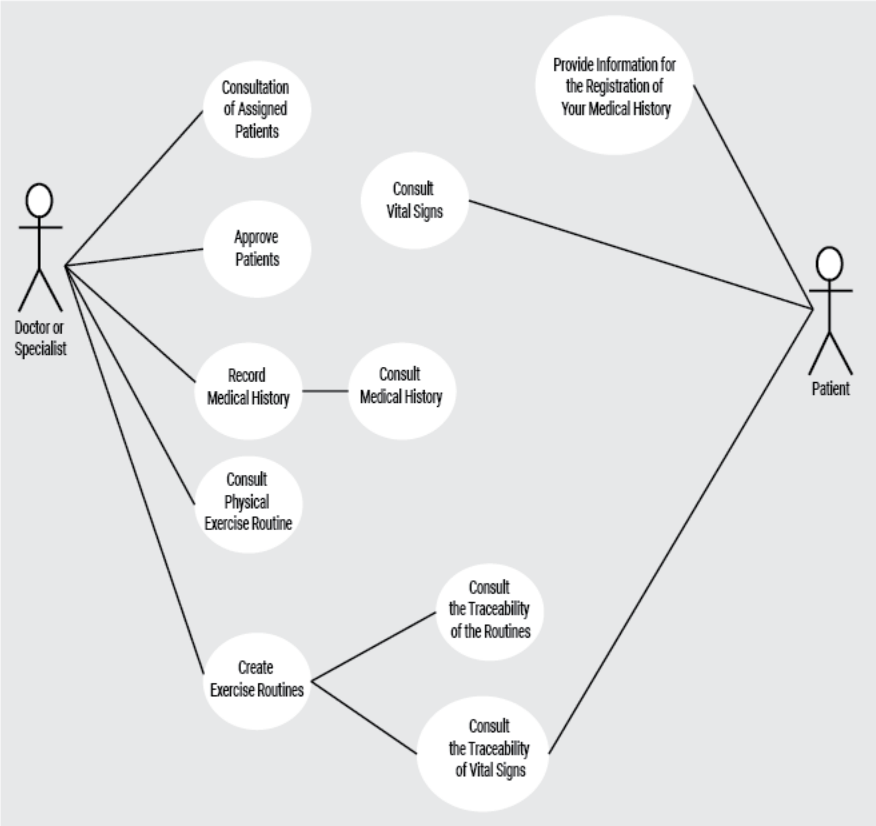

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Figure 9.
Exercise Assignment Interface on the Web Platform

César Alcívar Aray
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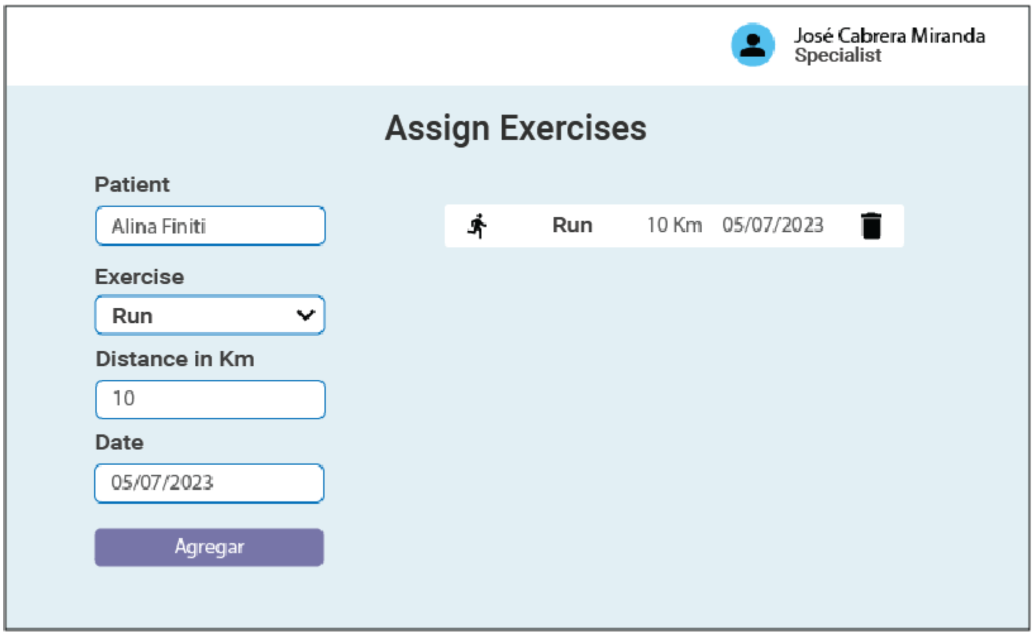

Figure 10.
Web System: Traceability of Physical Exercise Performed by a Patient. Information adapted from (Coello, 2022).

Figure 11.
Web System: Average Traceability for Patient's Physical Exercise Routines Over a Specific Date Range. Information adapted from (Coello, 2022).

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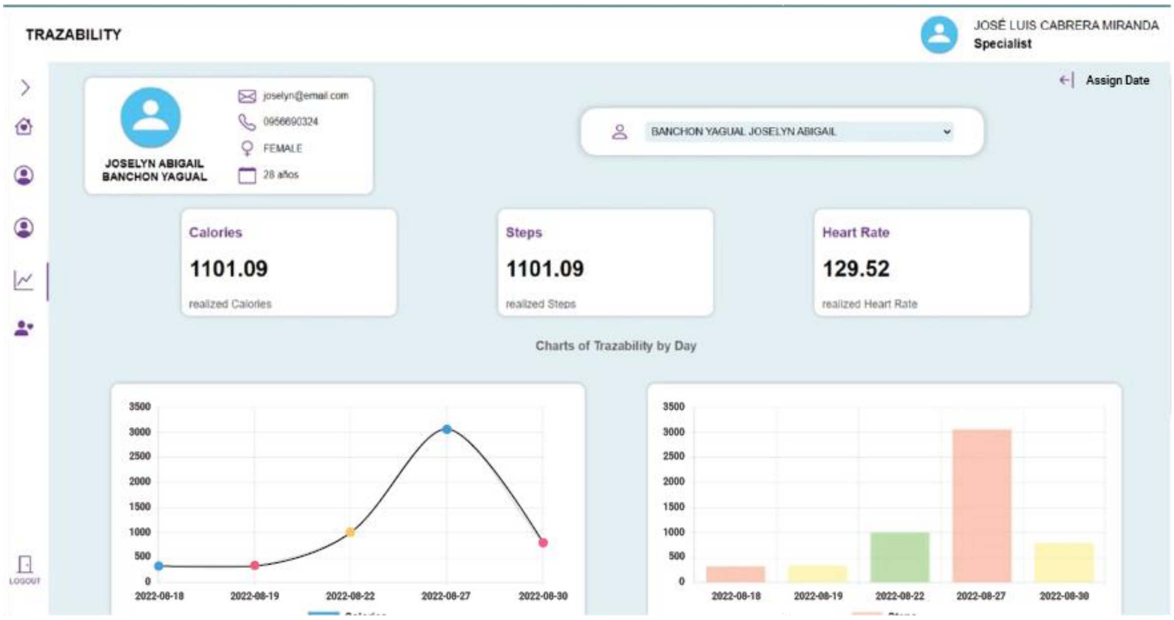

DISCUSSION

Over the past decade, Ecuador has made significant advances in leveraging information and communication technologies (ICT) for the monitoring and treatment of hypertension through physical exercise as a non-pharmacological intervention. Notable examples include the implementation of mobile applications and wearable devices at the Metropolitan Hospital of Quito for remote monitoring of hypertensive patients (Gómez, 2018), and the centralized electronic registry established by the “Healthy Ecuador” campaign to monitor the blood pressure of thousands of Ecuadorians (Martínez, 2020). However, these initiatives often focus on passive monitoring and lack the full integration necessary for personalized, real-time interventions.

Despite these advancements, there remains a lack of technological tools in Ecuador to assist medical personnel in selecting the most effective and personalized physical exercises for treating hypertension. To address this gap, researchers at the Faculty of Industrial Engineering of the University of Guayaquil (UG) developed an integrated platform based on their previous findings (Toapanta Bernabé et al., 2024). This platform comprises a Garmin smartwatch application, a mobile application, and a web system—all interconnected via the Internet—and is part of the research project titled “Use of Wearable Devices and Machine Learning for the Control of Physical Exercise Routines as Prevention and Non-Pharmacological Treatment of Arterial Hypertension.”

The integrated platform developed in this research signifies a substantial advancement in hypertension management by offering a comprehensive solution that addresses the need for personalized exercise prescriptions. By integrating wearable

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technology with machine learning algorithms, the platform not only monitors vital signs in real time but also tailors exercise routines to individual patient needs, thereby optimizing treatment outcomes.

Real-time monitoring of vital signs using wearable devices has been proven effective in other clinical contexts, allowing physicians to intervene before symptoms worsen (Haveman et al., 2022). For instance, in a study conducted by Ortiz (2021), the utilization of wearable devices to detect blood pressure spikes enabled real-time medication adjustments, resulting in a significant reduction in adverse events among patients. These findings demonstrate the potential of real-time data to support proactive healthcare management.

In the present study, patients utilizing the developed platform exhibited notable improvements in adherence to their exercise routines and achieved faster stabilization of vital signs compared to those without access to real-time monitoring. The capacity to make immediate treatment adjustments based on real-time data underscores the transformative potential of this approach in hypertension management.

To validate these findings, detailed statistical analyses were performed using techniques such as linear regression, which identified significant relationships between monitored variables (such as blood pressure and heart rate) and adherence to prescribed exercise routines. The results indicated that patients who received real-time alerts about their vital signs and adjusted recommendations based on their condition showed significant improvement in blood pressure control. This evidence highlights the importance of real-time monitoring in enhancing treatment effectiveness and personalizing patient care.

Unlike existing technologies that focus solely on monitoring or intervention, the platform developed in this study integrates multiple critical aspects of hypertension management, providing a holistic approach. This includes not only data collection but also the ability to intervene immediately when deviations in vital signs are detected. The platform acts as an active means to improve adherence and long-term health management, addressing the limitations of existing solutions by offering a more comprehensive and personalized method for managing hypertension.

Regular physical exercise has a significant impact on improving and stabilizing vital signs, including blood pressure, heart rate, and blood oxygen levels (Lockwood et al., 2004). By monitoring these changes in real time, the mobile application enables physicians to observe directly how specific exercise routines affect patients' vital signs, permitting personalized adjustments to optimize health benefits.

The primary value of wearable health devices (WHDs) lies in their ability to integrate multiple biosensors, intelligent processing, and alert systems to support medical applications and facilitate interaction with healthcare providers. However, much of this technology remains in the research phase and is not yet commercially available (Dias & Cunha, 2018).

The mobile application offers an intuitive user interface that enables physicians to prescribe and adjust physical exercises based on monitored vital signs, aligning with Ecuador's health policies that aim to maximize personal autonomy and active participation in health management (Rasch & Bywater, 2014). For patients, the application provides clear and accessible visualization of exercise routines and vital signs, which encourages adherence to treatment plans and enhances autonomy and health literacy.

Non-modifiable risk factors, such as age, genetics, and family history of chronic diseases, play a significant role in hypertension management. Monitoring vital signs helps identify how these non-modifiable risk factors influence patients' responses to various exercise routines. This understanding is crucial for developing personalized management strategies that consider both modifiable (such as lifestyle) and non-modifiable risk factors.

In this study, an integrated platform for digital exercise prescription in the treatment of hypertension was developed, which includes a Garmin smartwatch, a mobile application, and a web system. During the implementation and testing phases, various key performance metrics were evaluated to ensure the system's effectiveness and reliability.

Notably, the system's average response time was recorded at 350 ms, indicating high efficiency in user-platform interaction. The connection failure rate was low at 0.8%, which is critical for maintaining continuous real-time monitoring and ensures a smooth user experience. Latency, measured as the time taken for data to transmit from the smartwatch to the central server, was recorded at 450 ms. This metric is crucial for real-time monitoring, allowing physicians to intervene promptly in response to significant alterations in a patient's vital signs. Additionally, the successful synchronization percentage was 98.5%, indicating a high level of reliability in the transmission of critical data.

Regarding scalability, the platform demonstrated the capacity to handle up to 500 concurrent users without experiencing notable performance degradation. Additionally, the smartwatch's power consumption over 24 hours of continuous use was observed to be 12%, indicating sufficient battery life for daily operation without compromising functionality.

CONCLUSIONS

This study details the development and successful implementation of an integrated digital platform that combines wearable devices, a mobile application, and a web system for prescribing exercise in the treatment of hypertension (Haveman, et al., 2022). The findings make a significant contribution to the fields of digital health and chronic disease management, providing valuable insights into the effectiveness of technology-assisted interventions.

Effectiveness of Real-Time Monitoring

The ability to monitor vital signs in real-time through the integrated platform has proven effective in managing hypertension. Real-time data collection and transmission enabled prompt detection of deviations in patients' vital signs by healthcare professionals, allowing for immediate interventions (Rabbi , Aung, Gay, Reid, & Choudhury , 2018). This proactive approach can significantly reduce the risk of adverse cardiovascular events and aligns with previous studies emphasizing the importance of timely responses in chronic disease management.

Personalization of Treatment

The platform facilitated a high level of personalization in treatment plans. By analyzing individual physiological responses to prescribed exercise routines, healthcare providers can tailor interventions to each patient's specific needs (Yeung, et al., 2023). This personalization is crucial for maximizing therapeutic efficacy and can improve patient adherence to treatment regimens. Personalized exercise prescriptions ensure that patients are neither overexerting nor under-challenging themselves, thereby optimizing health outcomes.

Empowerment and Engagement of Patients

The integration of digital technologies actively involves patients in their own care, thereby empowering them. Access to real-time data and progress tracking fostered greater awareness and responsibility, encouraging patients to adhere to prescribed exercise routines and lifestyle modifications. This empowerment aligns with contemporary healthcare models that prioritize patient-centered care and shared decision-making, which have been associated with improved health outcomes.

Enhanced Communication Between Patients and Healthcare Providers

The platform significantly improved communication channels between patients and medical specialists. Real-time data sharing and the ability to adjust treatment plans promptly fostered a more dynamic and collaborative relationship. Enhanced communication is particularly beneficial in chronic disease management, where continuous adjustments and timely patient feedback are essential for effective care. This improved interaction can lead to increased patient satisfaction and better adherence to treatment plans.

Contribution to Healthcare Systems

The implementation of the integrated platform has the potential to alleviate burdens on healthcare systems. By reducing the need for frequent in-person consultations and enabling early detection of potential health issues, the platform may decrease hospital admissions related to hypertension complications. This not only optimizes resource utilization but also aligns with global healthcare objectives of improving accessibility and efficiency through technological innovation.

Challenges and Limitations

Despite the positive outcomes, several challenges were identified:

Dependence on Internet Connectivity: The platform's functionality relies on stable internet connections, which may not be accessible in all regions. This limitation could affect the scalability and widespread adoption of the solution.

Device Accessibility: The requirement for specific wearable devices and compatible mobile phones may pose economic barriers for some patients, potentially leading to health disparities.

Data Security and Privacy: Ensuring the confidentiality and integrity of patient data is paramount. Robust cybersecurity measures and compliance with health information regulations are necessary to protect sensitive information.

Future Directions and Recommendations

Based on these findings, the following recommendations are proposed:

Expand the Study Population: Conduct further research with larger and more diverse populations to validate the platform's effectiveness across different demographics and settings.

Integrate with Other Devices and Systems: Improve compatibility with a broader range of wearable devices and existing electronic health record systems to enhance interoperability.

Long-Term Outcome Studies: Implement longitudinal studies to assess the sustained impact of the platform on hypertension control and cardiovascular health over extended periods.

Address Accessibility Issues: Develop strategies to make the platform more accessible, such as offline functionalities or cost-effective device options, to ensure equitable healthcare delivery.

Education and Training Programs: Provide comprehensive training for both patients and healthcare providers to optimize the use of the platform and encourage its adoption in routine clinical practice.

The integrated platform developed in this study represents a significant advancement in hypertension management, demonstrating the transformative potential of digital technologies in healthcare. By enabling real-time monitoring, personalized treatment, and improved communication, the platform addresses critical challenges in chronic disease management. The positive outcomes observed underscore the importance of integrating digital solutions into healthcare strategies to enhance patient care and optimize resource utilization.

Continued research and development are essential to refine the platform and address the identified challenges. Embracing such technologies can lead to more proactive and patient-centered care models, ultimately improving health outcomes and quality of life for individuals with hypertension. This study contributes valuable knowledge to the field and sets the stage for future innovations in digital health interventions for chronic disease management.

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