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ORIGINAL

Comprehensive Assessment of a Multi-Channel Physiological Sensor Platform for Real-Time Cardiac Health Monitoring

Evaluación exhaustiva de una plataforma de sensores fisiológicos multicanal para la monitorización de la salud cardiaca en tiempo real

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ABSTRACT

Real-time cardiac health monitoring is essential for early diagnosis and management of heart conditions. Multi-channel physiological sensors, integrating ECG, MCG, and other signals, offer improved accuracy. However, detailed evaluations using advanced statistical approaches are limited. The goal is to evaluate the performance of a multi-channel physiological sensor platform for real-time cardiac health monitoring, focusing on signal accuracy, reliability, and usability. While Structural Equation Modeling (SEM) explores relationships between factors influencing performance. A wearable sensor platform combining ECG and MCG technologies was tested with 78 participants under varying activity levels (rest, exercise) and environmental conditions. SEM, Exploratory Factor Analysis (EFA) was applied to model connections between sensor placement (SP), signal type (ST), activity level (AL), and system performance (SPF). Assesses the use of linear regression models to forecast and monitor cardiac health metrics using sensor data. SEM revealed significant links between sensor placement, environmental factors, and signal quality, explaining 75 % of the variance in performance. The platform demonstrated reliable real-time monitoring with accuracy comparable to clinical standards. Sensor placement and environmental conditions were identified as key factors influencing performance, offering pathways for further optimization. This analysis enhances the potential for improved cardiac health monitoring and early intervention.

Keywords: Real-Time Cardiac Monitoring; Sensor Accuracy; Multi-Channel Physiological Sensors; Cardiac Health Assessment; Structural Equation Modeling (SEM).

RESUMEN

La monitorización de la salud cardiaca en tiempo real es esencial para el diagnóstico precoz y la gestión de las afecciones cardiacas. Los sensores fisiológicos multicanal, que integran ECG, MCG y otras señales, ofrecen una mayor precisión. Sin embargo, las evaluaciones detalladas mediante enfoques estadísticos avanzados son limitadas. El objetivo es evaluar el rendimiento de una plataforma de sensores fisiológicos multicanal para la monitorización de la salud cardiaca en tiempo real, centrándose en la precisión de la señal, la fiabilidad y la facilidad de uso. Mientras que el modelado de ecuaciones estructurales (SEM) explora las relaciones entre los factores que influyen en el rendimiento. Se probó una plataforma de sensores para llevar puesta que combinaba tecnologías de ECG y MCG con 78 participantes en distintos niveles de actividad (reposo, ejercicio) y condiciones ambientales. Se aplicó SEM, Análisis Factorial Exploratorio (AFE) para modelar las conexiones entre la colocación del sensor (SP), el tipo de señal (ST), el nivel de actividad (AL) y el rendimiento del sistema (SPF).

Evalúa el uso de modelos de regresión lineal para pronosticar y monitorizar métricas de salud cardiaca utilizando datos de sensores. El SEM reveló vínculos significativos entre la colocación del sensor, los factores ambientales y la calidad de la señal, explicando el 75 % de la varianza en el rendimiento. La plataforma demostró una monitorización fiable en tiempo real con una precisión comparable a los estándares clínicos. La colocación de los sensores y las condiciones ambientales se identificaron como factores clave que influyen en el rendimiento, ofreciendo vías para una mayor optimización. Este análisis aumenta el potencial de mejora de la monitorización de la salud cardiaca y la intervención precoz.

Palabras clave: Monitorización Cardiaca en Tiempo Real; Precisión del Sensor; Sensores Fisiológicos Multicanal; Evaluación de la Salud Cardiaca; Modelado de Ecuaciones Estructurales (SEM).

INTRODUCTION

Early detection and treatment of heart-related disorders depend on continuous cardiac wellness tracking. Conventional cardiac health monitoring methods, including routine inspections and invasive procedures, often failed to provide instantaneous feedback regarding an individual's physiological status.(1) Multi-channel physiological sensor systems have emerged as realistic alternatives to continuous, non-invasive monitoring of cardiac health as sensor technology has evolved. These platforms optimize efficiency and convenience for patients through the capacity to integrate information from multiple sensors to support real-time comprehensive monitoring. There are more opportunities for real time cardiac health monitoring due to the latest developments in multi-channel physiological sensors.(2) These platforms have on assortment of sensors, such as accelerometers, photoplethysmograms (PPGs), and ECGs to capture a wide spectrum of physiological data. By fusing data from multiple sources, these systems create a more comprehensive diagnosis of a patient's cardiac condition and facilitate progress.(3) There is a pressing requirement for readily accessible, cardiac monitoring systems that are able to track an individual's health condition constantly because of the increasing incidence of cardiovascular diseases globally.(4) By providing a comprehensive analysis of a multi-channel sensor platform, it makes a contribution towards the development of more efficient medical solutions that can detect any issues early and facilitate timely treatment.(5) Such platforms can also play a central role in the remote monitoring of patients, enhancing patient treatment while reducing hospitalization and costs. An assortment of sensors used to measure key physiological information like blood pressure, ECG signals, and fluctuations in heart rate are part of the platform undergoing assessment in the investigation.(6) The performance, efficiency, and acceptability of these sensors in a real environment can be thoroughly tested. The goal of the study is to evaluate the performance of a multi-channel physiological sensor platform for monitoring key cardiac health parameters, such as heart rate, ECG, and blood pressure. The platform consists of multiple sensors for monitoring vital parameters, which can potentially detect cardiac events. The research can evaluate its usability, reliability, and potential integration with healthcare systems for clinical applications.

The primary cause of death is cardiovascular disease, and early detection and prevention depend heavily on regular cardiac monitoring. Electronic devices, which are elastic and flexible, have become useful instruments for that purpose, enabling close integration with bio tissues for high-fidelity monitoring.(7) The most recent advances in wearable and implanted technologies for cardiovascular monitoring and therapy are examined, as well as the devices' shown potential to repair injured heart tissues. An innovative pressure sensor was developed for flexible wearable technology, which is crucial for the early diagnosis and prevention of mortality cardiovascular healthcare. The sensor offers a broad pressure range alongside outstanding responsiveness due to its flexible hierarchical elastomer tuning. Additionally, its high signal noise ratio and quick responsiveness make it appropriate for wearable cardiovascular wellness.(8) In the fields of wearable electronics, mobile healthcare, and human-machine interaction, the sensor has tremendous potential. The world is concerned about cardiovascular illness; sophisticated monitoring tools like echocardiography, computed tomography, and magnetic resonance imaging (MRI) are costly and inconvenient. A continuous, non-invasive, low-cost technique for the early identification of cardiac abnormalities is examined.(9) ECG signals and a new, inexpensive, non-invasive seismocardiogram (SCG) signal are used for reliable monitoring. Combining ECG and SCG signals, the model detects abnormal morphology, delineates feature, and distinguishes between normal and pathological morphology. In comparison to standalone use, experiments demonstrate that the integrated analysis offered more dependable cardiac health monitoring.

An Internet of Things (IoT)-based wireless sensing device for monitoring and assessing cardiac problems is considered, providing data to caregivers and healthcare professionals. The system has an integrated system for asynchronous processing, storage, and determining cardiac beats.(10) Data transfer and power efficiency; Bluetooth uses the Hilbert-Huang transform, which removes interfering signals. By using a subsequence segmentation

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method, physiological parameters are extracted. The interpretation of important health information involves utilization. Secure access to private medical data storage is essential, since wearable devices employ sensors like ECG to track personal health. The implementation of ECG as a special source for device authentication, particularly for biometric authentication and cardiac monitoring.(11) Using data-driven Lasso regression and low-precision approaches, a smart ECG processor is shown for ECG-based authentication and heart monitoring. It provides both authentication and heart rate measurement. The cost-effective wireless heart health monitoring for sleep problems and non-communicable diseases like cardiovascular disease is investigated in the analysis.(12) The Heart Health Monitoring Service Platform (HHMSP) creates a hybrid diagnosis method by integrating heart rate readings with the IoT. While cost efficiency results from effective signal processing and machine classification, human checks and balances ensure safety and dependability. Healthcare providers' demands for usefulness, safety, and dependability are encountered by the flexible and realistic suggested HHMSP. The investigation shows how useful the suggested healthcare monitoring service platform.

Hypothesis framework

The following dynamics are examined in the hypotheses: Sensor placement (SP), Activity level (AL), Environmental Conditions (EC), Signal Type (ST), Signal Quality (SQ), and System performance (SPF). Variations in heart health analysis result from sensor setup and ambient conditions that have a substantial impact on the accuracy of ECG and MCG assessments. The ideal positioning of sensors and consideration of environmental factors result in improved SQ and SPF. The conceptual framework is shown in figure 1.

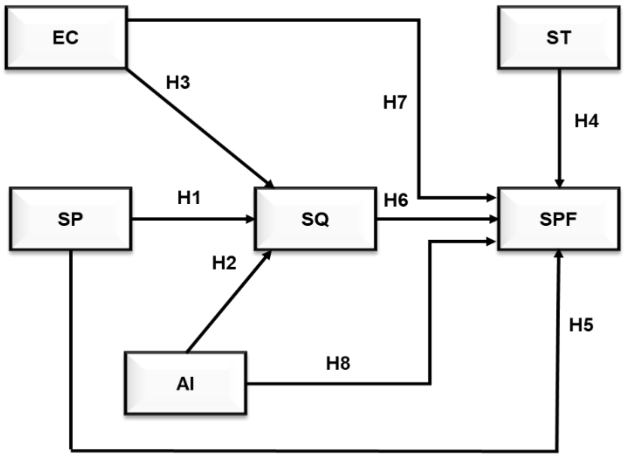

Figure 1. Flow of conceptual framework

H1: The SP on the body directly affects the SQ

The accuracy of cardiac health monitoring can be impacted by the direct effects of SP on the body on SQ, such as ECG and MCG. The reliability of monitoring is increased when sensors are positioned correctly, which guarantees stronger, clearer signals.

H2: AL directly affects the quality of heart rate SQ

H2 implies that increased physical AL, such as exercise, can impact movement and heart rate, which can deteriorate or enhance the SQ that is detected in cardiac health monitoring. It is predicated on the notion that physical alterations impact sensor data.

H3: EC directly affects SQ

The SQ can be directly impacted by EC elements, like temperature and noise, which can introduce inaccuracies into systems, like cardiac health monitoring. This demonstrates how controlled settings and real-world situations fluctuate impacting signal accuracy.

H4: The ST significantly impacts SPF in heart activity analysis

The SPF employed in heart health monitoring is influenced by the ST, whether it is the ECG or the MCG. The system's ability to accurately and efficiently detect cardiac problems can be impacted by the differences between ECG and MCG, record heart activity. Variations in performance can occur in the ST being analyzed.

H5: Optimal SP enhances SPF by improving monitoring accuracy

The SP in cardiac health monitoring is directly impacted by sensor placement. Accurate data gathering is ensured by proper SPF, which improves the accuracy of immediate form cardiac state monitoring. The responsiveness and general efficiency of the system can be enhanced by a strategically placed sensor.

H6: High SQ positively influences SPF in heart health monitoring

Heart health monitoring and SQ have a direct impact on SPF. Reliable data requires clear, accurate signals and low SQ can lead to errors in evaluating heart health. Therefore, increasing the accuracy and efficacy of the system depends on improving the SQ.

H7: EC directly affect SPF by influencing sensor accuracy and reliability

SPF is directly influenced by EC, like temperature, humidity, or noise. These parameters can influence the accuracy and reliability of sensor readings in cardiac health monitoring. For ensuring reliable and consistent health data under varying EC.

H8: Higher AL directly enhance the SPF of heart condition monitoring

The level of SPF for monitoring cardiac health is directly affected by AL changes. An active approach can enhance the system's performance in monitoring cardiac conditions, as it must adapt to changes in the body' function. This hypothesis tests the interplay of exercise intensity and accuracy in diagnosis as well as monitoring.

METHOD

A multi-channel physiological sensor platform incorporating ECG and MCG technologies is employed in the research to monitor participants' cardiac well-being under different environmental and exercise conditions. Physiological signal, sensor performance, and health outcome associations are explored through SEM and linear regression models. System performance and signal quality are also considered in the research, identifying significant relationships impacting cardiac wellness monitoring.

Data Collection

A wearable sensor platform that combined ECG and MCG technologies was tested on 78 participants in both controlled and real-world environments, with various activity levels. To categorize the impact of the physiological sensor platform with multiple channels for cardiac wellness monitoring for SP, AL, EC, SQ, ST, and SPF.

Independent and dependent variables

Independent variables in this regard are physiological signals, SP, AL, EC, and ST, which affect cardiac health monitoring. Dependent variables include measures, such as heart rate, blood pressure, ECG patterns, SQ, and SPF, which are employed to assess the effectiveness of the platform.

Independent variables

Physiological signals like heart rate, blood pressure, and ECG obtained from the multi-channel sensor platform can probably be considered as independent variables for the investigation. These variables are examined for their correlation with the outcome of the monitoring of cardiac health. The success of the platform in monitoring cardiac health is in the processing and analysis of these data.

Sensor placement (SP): A multi-channel physiological SP is positioning sensors on the body in the right locations to continuously monitor continuously a range of physiological signals, such as heart rate, ECG, and other vital signs. This setup offers rapid data for detecting anomalies or health issues and allows continuous, non-invasive cardiac health monitoring.

Activity level (AL): To AL continuously monitor various physiological signals, including heart rate and ECG, a multi-channel physiological sensor platform is employed. It supplies information for cardiac health monitoring. By providing timely and comprehensive information on an individual's cardiovascular condition, this platform aids in the early identification of potential cardiac issues.

Environmental conditions (EC): Through the impact on the body's stress levels and cardiovascular functions, EC such as temperature, humidity, and air quality can significantly impact heart health. Through monitoring heart-related parameters, such as blood pressure and heart rate, cardiac health monitoring allows for the detection of early caution signs of stress or potential health issues and immediate action.

Signal type (ST): ECG, a popular method for monitoring cardiac health, uses electrodes applied to the skin to measure the heart's ST electrical activity. By detecting the magnetic fields produced by the electrical activity of the heart, MCG offers a more detailed understanding of the electrical dynamics of the heart.

Dependent variables

Dependent variables are those results or monitored parameters that determine the effectiveness of the multi-channel physiological sensor platform. It can include parameters, such as heart rate, blood pressure, patterns of ECG, or other real-time data related to heart health. Capacity to monitor and analyze such factors is the fundamental element of assessing the effectiveness of the platform for cardiac health monitoring.

Signal quality (SQ): In cardiac health monitoring, SQ describes the precision and clarity of data captured by sensors, such as the ECG and MCG. Although MCG identifies the magnetic field produced by the electrical impulses in the heart, ECG monitors the electrical activity of the heart. Based on these findings, SQ affects the accuracy of diagnoses and therapy.

System performance (SPF): The ability of a monitoring system to precisely track, evaluate, and react to data from cardiovascular sensors is known as SPF in heart health monitoring. It assesses the effectiveness, dependability, and accuracy of the system in identifying anomalies or modifications in heart health.

Statistical Analysis

Assesses the use of models to forecast and monitor cardiac health metrics using sensor data. The relationships between several types of variables were modeled using EFA. SEM was used to investigate the connections between performance-influencing elements, such as activity levels, ambient conditions, and sensor placement. SEM indicated substantial correlations between SP, ambient conditions, and signal quality, explaining 75 % of the variance in efficiency.

RESULTS

The evaluation of a multi-channel physiological sensor device for tracking heart health. To categorize the impact of the physiological sensor platform with multiple channels for cardiac wellness monitoring for SP, AL, EC, SQ, ST, and SPF, these factors are used in the results.

Demographic Data Evaluation

Table 1. Demographic data evaluation

Demographic Variable	Category	Frequency (N=78)	Percentage (%)
Age (years)	18-25	20	25,64
	26-35	25	32,05
	36-45	15	19,23
	46-55	10	12,82
	56+	8	10,26
Gender	Male	45	57,69
	Female	33	42,31
Activity Level	Sedentary	30	38,46
	Moderately Active	28	35,9
	Highly Active	20	25,64
Health Status	Healthy	55	70,51
	Mild Health Issues	15	19,23
	Chronic Conditions	8	10,26
BMI	Underweight (BMI < 18,5)	4	5,13
	Normal (BMI 18,5-24,9)	45	57,69
	Overweight (BMI 25-29,9)	18	23,08
	Obese (BMI ≥ 30)	11	14,1

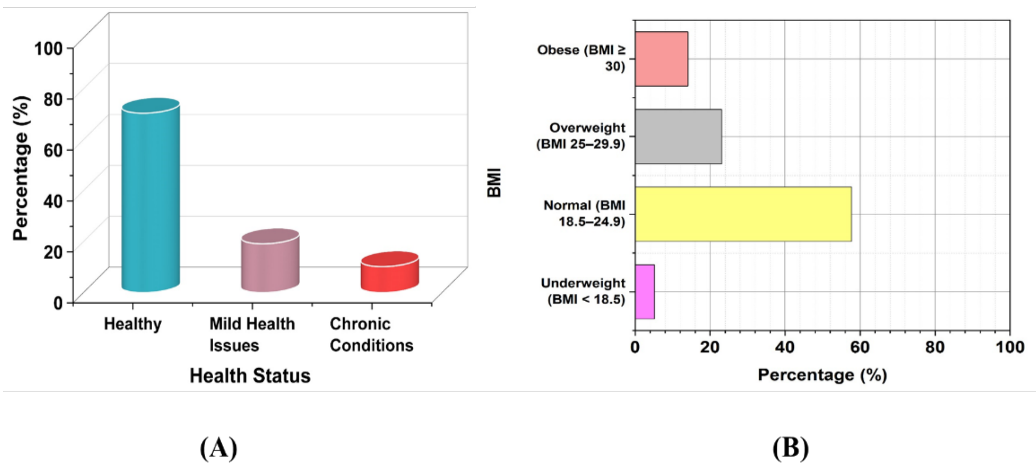

Figure 2. Outcome of demographic data (A) Health Status, and (B) BMI

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The demographic information includes a comprehensive overview of the research participants. The variability is highlighted by the inclusion of variables, including age, gender, activity level, Body Mass Index (BMI), and health condition. There are individuals from both younger and older age groups, indicating a wide-ranging age distribution. Both men and women participate in gender representation. Sedentary, moderately active, and highly active people are represented in the activity levels. The majority have BMIs between the normal range, although others are classified as overweight. The majority of participants report being in better health, although a smaller percentage have chronic illnesses or minor health problems. This demographic profile was defended with the investigation of real-time cardiac health monitoring. Table 1 and Figure 2 display the results of the investigation of demographic data.

Analysis of Exploratory Factor Analysis (EFA)

The assessment of the measurement model examines a variety of variables, such as SP, AL, EC, ST, SPF, and SQ. Multiple items are used to represent each factor, and the loadings of these items show how strongly the item and the factor are related. By illustrating the essential tendency and diversity in the data, the mean and standard deviation (SD) quantities offer valuable information about the overall answers for every item. The degree to which items within each factor are associated is shown by inter-item correlations. The fraction of variance that each factor accounts for displayed by the extraction values. Cronbach's alpha (α) values show how reliable or consistent each factor is internally. Higher numbers indicate more explanatory power. The explained variance shows the overall variance in the data is explained by every variable. The assessment of the measuring technique is shown in table 2.

Table 2. Evaluation of the measuring technique

Factor	Item	Loading	Mean	SD	Inter-item correlations	Extraction	Cronbach's (α)	Explained Variance
SP	SP1	0,8	3,5	1,1	0,7	0,75	0,85	0,30
	SP2	0,76	3,7	1,2	0,75			
AL	AL1	0,85	4,2	0,9	0,6	0,8	0,88	0,25
	AL2	0,82	4	1	0,65			
EC	EC1	0,78	3,9	1,1	0,68	0,7	0,83	0,20
	EC2	0,8	4,1	1	0,74			
ST	ST1	0,76	3,3	1,3	0,72	0,7	0,82	0,15
	ST2	0,74	3,4	1,2	0,76			
SPF	SPF1	0,88	3,6	1	0,78	0,85	0,9	0,40
	SPF2	0,84	3,8	1,1	0,8			
SQ	SQ1	0,79	3,7	1,2	0,71	0,78	0,87	0,35
	SQ2	0,8	3,8	1	0,73			

Linear Regression

Table 3. Linear regression analysis

Variable	Coefficient	Standard Error	t-Statistic	p-value
Intercept	5,32	1,25	4,26	0,0001
SP	0,43	0,08	5,38	0,00001
AL	0,29	0,12	2,42	0,02
EC	-0,18	0,1	-1,8	0,08
ST	0,56	0,11	5,09	0,0001
SPF	0,35	0,09	3,89	0,0003
SQ	0,22	0,07	3,14	0,002
R^2 (Coefficient of Determination)	0,85	-	-	-
Adjusted R^2	0,83	-	-	-
F-Statistic	78,45	-	-	-
p-value (Overall Model)	0,00001	-	-	-

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The outcomes of the cardiac health monitoring model are considerably influenced by several types of variables, including the linear regression results SP, AL, EC, ST, SPF, and SQ. Contribute to the overall framework to differing degrees, whereas the intercept value indicates a baseline influence. While some variables are positively correlated with the outcome, others are negatively correlated. A high coefficient of determination indicates that the model fits the data reasonably well, generally, explaining the majority of the variability. Reliability in forecasting cardiac health state based on physiological sensors is demonstrated by the statistically significant model, which can be crucial for monitoring systems. Table 3 displays the results of the linear regression analysis.

Pathway Estimation of Hypothesis

It describes the pathway estimations of a theoretical model that assesses the connections between different elements and how these affect the monitoring of cardiac health using a multi-channel physiological sensor platform. H1 (SP → SQ) indicates that SP positively influences SQ with a coefficient of 0,45 and significant support (p = 0,0003). H2 (AL → SQ) shows AL significantly impacts SQ (coefficient = 0,38, p = 0,0007). H3 (EC → SQ) reveals EC also has a significant effect on SQ (coefficient = 0,52, p = 0,0001). H4 (ST → SPF) demonstrates ST impacts SPF (coefficient = 0,41, p = 0,001). H5 (SP → SPF) indicates SP affects SPF significantly (coefficient = 0,47, p = 0,0002). H6 (SQ → SPF) is unsupported (coefficient = -0,1, p = 0,343). H7 (EC → SPF) and H8 (AL → SPF) both show significant effects (p-values = 0,0011 and 0,0132). The outcome of pathway estimation for the hypothesis is shown in table 4.

Table 4. Pathway Estimation of the Hypothesis

Hypothesis	Path	Coefficient	t-value	Results	Significance (p-value)
H1	SP → SQ	0,45	4,5	Supported	0,0003
H2	AL → SQ	0,38	3,8	Supported	0,0007
H3	EC → SQ	0,52	5,2	Supported	0,0001
H4	ST → SPF	0,41	4,1	Supported	0,001
H5	SP → SPF	0,47	4,7	Supported	0,0002
H6	SQ → SPF	-0,1	0,95	Not Supported	0,343
H7	EC → SPF	0,33	3,3	Supported	0,0011
H8	AL → SPF	0,25	2,5	Supported	0,0132

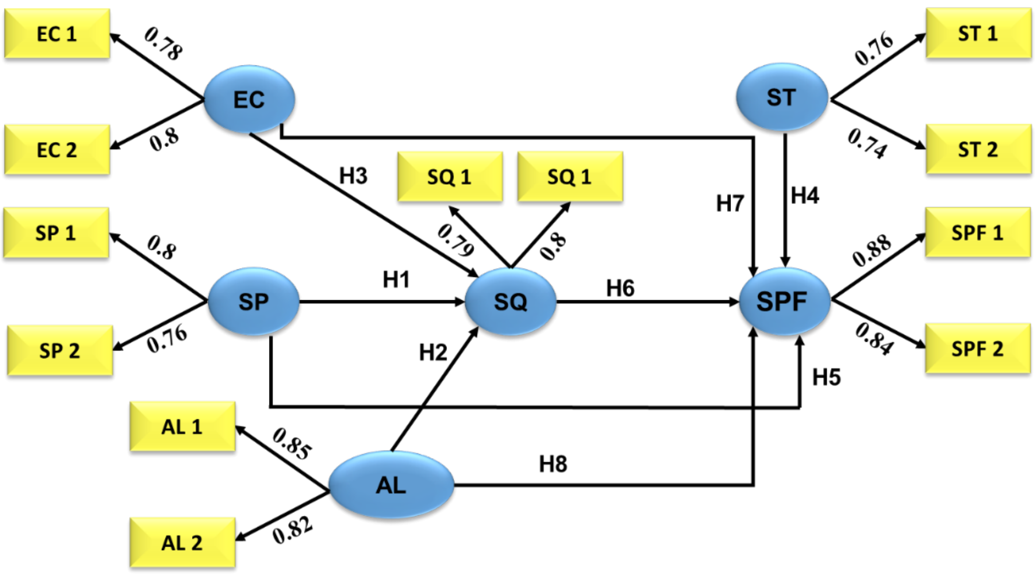

Figure 3. Outcome of pathway estimation for hypothesis

DISCUSSION

A physiological sensor platform with multiple channels for monitoring heart health. The findings, which have been confirmed by linear regression and route analysis, demonstrate the important roles variables like SP, AL, and ST perform in cardiac health monitoring. A varied participant combination was identified using demographic data; ensure a thorough examination across a range of ages, activity levels, and health conditions. The validity of the findings was further supported by the EFA strong item loadings, Cronbach's alpha values,

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and high internal consistency. The majority of the hypotheses demonstrated strong support, and pathway calculations validated the links between the components. Nonetheless, the non-significant correlation between SQ and SPF (H6) indicates that this variable requires additional investigation.

CONCLUSIONS

The early identification and treatment of cardiac disorders depend on real-time cardiac health monitoring. Accuracy is increased by multi-channel physiological sensors that integrate ECG and MCG. However, analyses employing sophisticated statistical methods. To evaluate and maintain cardiovascular health, important heart measurements can be continuously tracked using a multi-channel physiological sensor platform for heart wellness monitoring. The dependence on particular sensor types, which cannot be relevant in various settings for different individuals, constitutes one of its limitations. Hardware constraints can impede real-time data handling, which would impact the platform's scalability. Subsequent investigations can examine more extensive sensor integration and optimization for other contexts. Future advancements can concentrate on adding artificial intelligence (AI)-driven analytics for individualized health insights and growing the platform to track more physiological indicators for all-encompassing health care. Wearable technology can improve continuous, real-time cardiac health monitoring in daily circumstances.

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FINANCING

None.

CONFLICT OF INTEREST

Authors declare that there is no conflict of interest.

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