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RESEARCH ARTICLE

Walking the Camino de Santiago: A case study of endurance and wearable technology

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ABSTRACT

This case study examines the use of wearable technology to monitor physiological and performance metrics during a 100+ km pilgrimage on the Camino de Santiago. The subject, a 34-year-old female amateur triathlete recovering from an ankle injury, used a Garmin Enduro device to track key data over five days. The study focuses on heart rate, speed, cadence, caloric expenditure, and environmental factors, shedding light on how wearable devices can provide valuable insights into endurance performance. Correlation analysis highlights significant relationships between physical performance and physiological markers, offering a deeper understanding of how such technology can enhance both athletic performance and the overall pilgrimage experience.

Keywords: Camino de Santiago; endurance walking; wearable technology; pilgrimage

1. Introduction

The Camino de Santiago, also known as "The Way of Saint James," is a renowned pilgrimage route located in the northwestern region of Spain, culminating at the Cathedral of Santiago de Compostela. According to Christian tradition, this is where the remains of Saint James, one of Jesus' followers, are believed to be interred. The official history of the pilgrimage states that the body of Saint James was discovered by a shepherd in Galicia during the 9th century[1]. The number of pilgrims walking the Camino de Santiago has fluctuated throughout history, but recent years have seen a significant rise in participation. In 2023, a record-breaking 440,368 pilgrims completed a Camino route, representing a slight increase from the previous year. Although 2024 has not yet concluded, the number of pilgrims completing the route is estimated to be around 400,000, according to official statistics[2].

Pilgrims are primarily motivated by spiritual growth, the desire for new experiences, the natural and physical challenges of the journey. Interestingly, religious motivations are cited as the least important. Study has shown that motivations vary based on factors such as gender, nationality, and the method by which pilgrims undertake the journey[1]. There are two predominant approaches to experiencing the Camino as a spiritual journey: as a pathway to religious experience (from spirituality to religion) or as the deepening of a pre-existing

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religious commitment (from religion to spirituality). These two approaches are fundamentally distinct from one another[3].

The Camino de Santiago has increasingly become a long-distance trek, drawing attention from travel medicine professionals, as the number of middle-aged and elderly hikers continues to grow. While younger pilgrims have been decreasing in number, middle-aged and elderly participants have been steadily rising. This demographic shift has raised health concerns, with acute coronary syndrome being the leading cause of fatalities. Elderly individuals, in particular, are at risk of experiencing cardiac problems during the trek[4].

Unprepared or overly motivated individuals may face exhaustion or circulatory problems, particularly when climbing the steep slopes of the Camino de Santiago. The strain of long-distance hiking can quickly overwhelm the circulatory system, potentially leading to coronary ischaemia. Therefore, pre-travel medical advice is crucial, especially for older and less physically prepared individuals[4]. Additional investigation is needed to fully understand the health problems that Camino pilgrims face. More in-depth studies with more accurate data are needed, and pilgrims should always be able to get medical advice before embarking on their journey[4]. Wearable devices, like GPS watches and smartwatches, have become an important way to keep an eye on people's health and body responses[5,6]. Given their capabilities, these wearable devices could also be a useful way to check on people's health and body responses while they are on pilgrimage.

This case study followed a 34-year-old female amateur triathlete, recovering from an ankle injury, who completed a 100 km pilgrimage from Sarria to Santiago de Compostela in April 2024. Throughout the journey, the athlete used a Garmin Enduro wearable device to track key physiological and performance data. The aim of this study is to examine how wearable technology, such as the Garmin Enduro, can be utilized to monitor endurance walking, providing insights into its potential to enhance physical performance tracking and improve the overall pilgrimage experience.

2. Methods

2.1. Description of the Pilgrimage

The pilgrimage was completed between 30 April and 4 May 2024, by a 34-year-old female amateur triathlon athlete. This journey was not only spiritual but also a means to recover from an ankle sprain sustained in December 2023, which had prevented her from training and competing in the months leading up to the pilgrimage. Seeking new challenges, both physical and mental, she embarked on the Camino de Santiago to push her body to new limits while embracing the spiritual magic of the route. The experience was intended to help her overcome the difficult period following her injury, rediscover her strength, and connect with the transformative essence of the Camino.

2.2. Detailed account of the pilgrimage route taken

The pilgrimage route, **Figure 1**, began on day 1 with a journey from Sarria to Portomarín, covering 22.4 km with an ascent of 481.3 m. On day 2, the route continued from Portomarín to Palas de Rei, totaling 25.4 km and 574.2 m of elevation. Day 3 covered a distance of 28.5 km from Palas de Rei to Arzúa, with 565.3 m of ascent. Day 4 took the pilgrim from Arzúa to O Pedrouzo, covering 20.1 km with an elevation gain of 341.4 m. The final leg, on day 5, was a 20.2 km trek from O Pedrouzo to Santiago de Compostela, with 412 m of ascent. The maps were extracted from the Komoot website (https://www.komoot.com).

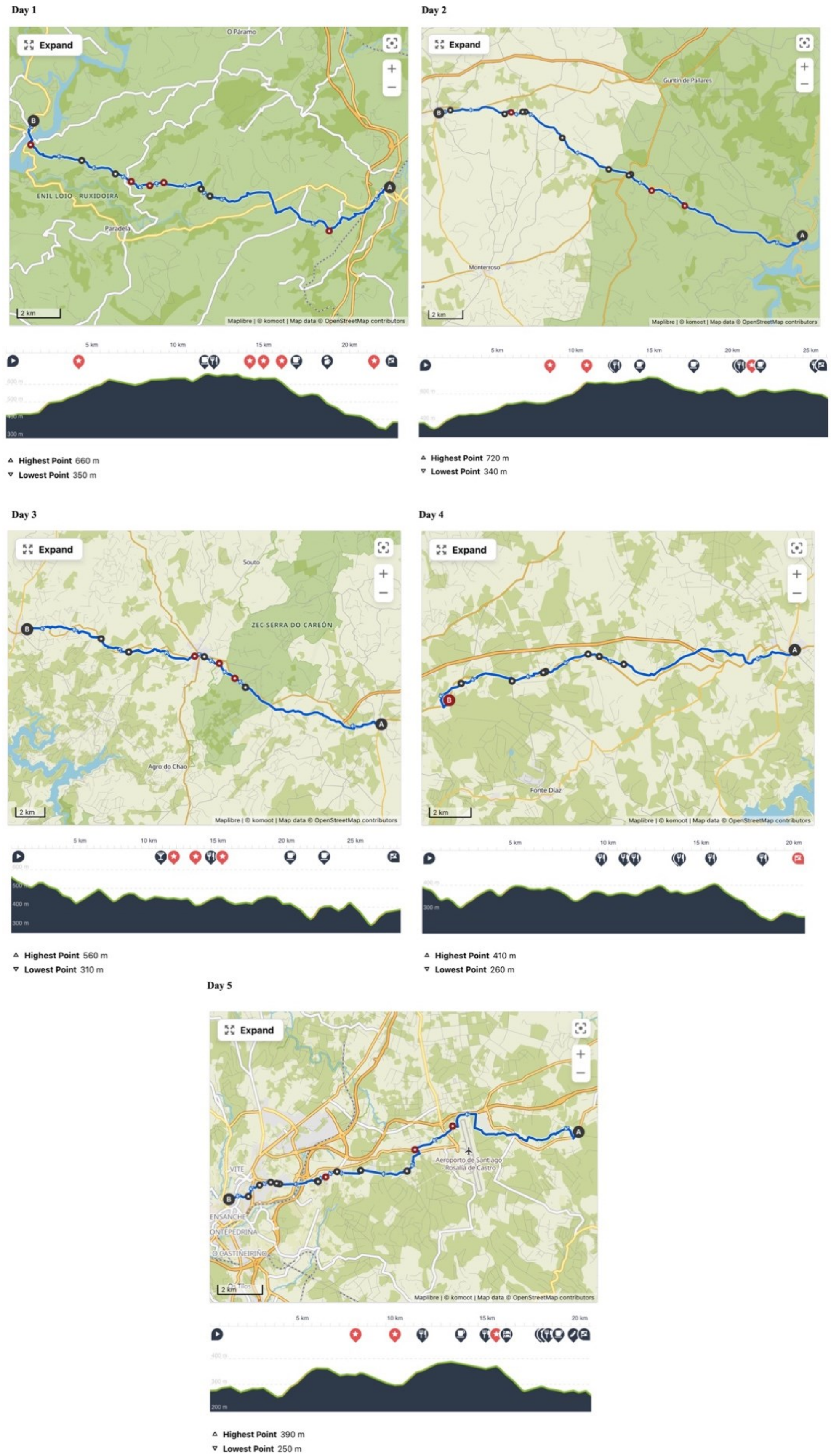

Figure 1. Pilgrimage route.

Notes: Day 1: Sarria (A) to Portomarín, (B); Day 2: Portomarín, (A) to Palas de Rei (B); Day 3: Palas de Rei (A) to Arzúa (B); Day 4: Arzúa (A) to O Pedrouzo (B); and Day 5: O Pedrouzo (A) to Santiago de Compostela (B).

2.3. Device overview

The Garmin Enduro is a high-performance GPS watch designed for endurance athletes and outdoor enthusiasts. It features advanced tracking capabilities, including real-time GPS navigation, heart rate monitoring, and altitude tracking. Additionally, it offers a long battery life, making it suitable for multi-day activities such as ultra-running and trekking. The device also tracks metrics such as pace, speed, distance, and calories burned, providing comprehensive data for performance analysis. For more information about the device, see (https://www.garmin.com/en-CA/p/702797).

The rationale for choosing the Garmin Enduro for this pilgrimage stems from the user's familiarity with the device, as it is regularly used in her daily training routines. Its robust tracking features, durability, and long battery life made it an ideal companion for the extended physical demands of the Camino de Santiago, offering reliable data and support throughout the journey.

2.4. Parameters tracked and data collection

The parameters tracked during the Camino de Santiago included a range of physical and physiological metrics. These involved distance-related measures such as average pace, best pace, and speed, with the maximum speed recorded during the activity. Elevation data, including total ascent, minimum elevation, and maximum elevation, was also monitored. Heart rate parameters, including average and maximum heart rate, were tracked alongside exercise intensity, measured through cadence with both average and maximum values. Energy expenditure was monitored through resting and active calories, along with the total calories burned. Sweat loss was estimated, and environmental conditions, including average, minimum, and maximum temperatures, were recorded. Finally, the intensity of physical activity was quantified by tracking the duration of moderate and vigorous intensity activities. Data was extracted from the Garmin Connect website (https://connect.garmin.com) with the permission of the pilgrim. Nutritional status, such as food and fluid intake were not collected.

2.5. Ethical considerations

This case study did not require formal ethics committee approval as the data utilized was collected solely through a smartwatch website with the individual's informed consent. The participant voluntarily provided access to their personal activity data, which was monitored and recorded through wearable technology. All data were anonymized and handled following ethical standards related to data privacy and participant consent. The study adhered to the principles outlined in the Declaration of Helsinki concerning research involving human subjects.

2.6. Data analysis

Descriptive statistics were calculated to provide an overview of the key variables, including mean values and standard deviations. Additionally, partial correlations were computed to examine the associations between selected variables. All the correlations were controlled by the day. The partial correlation analysis was performed using Pearson's correlation coefficient. The hypothesis test for Pearson's correlation in partial correlation involves the null hypothesis (H_0), which assumes no linear relationship between the variables ($\rho = 0$), and the alternative hypothesis (H_1), which assumes a non-zero correlation ($\rho \neq 0$). Correlations with *p*-values < 0.05 were considered statistically significant. The significance of the correlations was interpreted based on[7] classification: correlations with values below 0.40 were considered weak, those between 0.40 and 0.75 were classified as reasonable to good, and values above 0.75 were deemed excellent. In line with this approach, correlations with significance values above 0.75 were reported as they were considered strong enough to provide new insights. Obvious and expected correlations were not reported in the results section, though they are available in the supplementary material. Statistical analyses were performed using the Jamovi project (2024). jamovi (Version 2.5) [Computer Software], Sydney, Australia. Retrieved from https://www.jamovi.org.

3. Results

Table 1 summarizes key physical activity and physiological variables for a female individual over five days of the Camino de Santiago. The individual, a 34-year-old female with more than 10 years of experience in triathlon, had a history of an ankle sprain in December 2023, which was the only significant injury that temporarily impeded her ability to continue training for triathlon competitions. Anthropometric data included a body weight of 64.2 kg ± 0.2 kg, a height of 1.67 m, and a BMI of 23.0 kg/m^2 ± 0.1 kg/m^2. The average pace was 11.6 min/km ± 0.5 min/km, with a best pace of 5.1 min/km ± 3.3 min/km. The average speed was 5.4 km/h ± 0.2 km/h, with a maximum of 17.2 km/h ± 12.7 km/h. The individual spent an average of 4.4 h ± 0.5 h per day walking, with a heart rate averaging 97.0 bpm ± 3.5 bpm and peaking at 131.0 bpm ± 12.0 bpm. The exercise load was 20.4 ± 12.5, and cadence averaged 110.4 ± 2.7 steps per minute (SPM). Total ascent was 474.6 m ± 99.8 m, and total daily caloric expenditure was 1025.6 kcal ± 153.5 kcal, with sweat loss averaging 2186.0 mL ± 428.9 mL. The average temperature was 21.8 °C ± 3.0 °C, and moderate-intensity exercise averaged 163.4 ± 49.8 min/day. Humidity data was not collected in this study.

Table 1. Summary of physical activity variables over 5 days.

Variables	Days	Mean	SD
Anthropometric			
Body weight (kg)	5	64.2	0.2
Height (m)	5	1.67	-
BMI (kg/m^2)	5	23.0	0.1
Physical activity metrics			
Average pace (min/km)	5	11.6	0.5
Best pace (min/km)	5	5.1	3.3
Average moving speed (km/h)	5	5.4	0.2
Average moving pace (km/h)	5	10.9	0.4
Average speed (km/h)	5	5.2	0.2
Maximum speed (km/h)	5	17.2	12.7
Total time (h)	5	4.4	0.5
Moving time (h)	5	4.1	0.7
Elapsed time (h)	5	5.5	0.9
Total time (min)	5	263.1	29.3
Moving time (min)	5	245.6	39.6
Elapsed time (min)	5	329.1	57.0
Moderate intensity (min/day)	5	163.4	49.8
Vigorous intensity (min/day)	5	8.2	9.4
Total intensity (min/day)	5	179.8	49.7
Cardiovascular parameters			
Average Heart rate (bpm)	5	97.0	3.5
Maximum Heart rate (bpm)	5	131.0	12.0

Table 1. (*Continued*).

Variables	**Days**	**Mean**	**SD**
Aerobic	5	1.6	0.8
Exercise load	5	20.4	12.5
Average cadence (SPM)	5	110.4	2.7
Maximum cadence (SPM)	5	210.8	42.1
Altitude			
Total ascent (m)	5	474.6	99.8
Minimum elevation (m)	5	305.0	46.6
Maximum elevation (m)	5	558.2	151.1
Energy expenditure and sweat loss			
Resting calories (kcal)	5	301.0	36.9
Active calories (kcal)	5	724.6	119.7
Total calories burned (kcal)	5	1025.6	153.5
Estimated sweat loss (mL)	5	2186.0	428.9
Temperature			
Average temperature (°C)	5	21.8	3.0
Minimum temperature (°C)	5	17.4	4.2
Maximum temperature (°C)	5	27.2	1.3

Notes: Data is presented as mean and standard deviation (SD). **Abbreviations**: Minutes per kilometer (min/km); kilometer per hour (km/h); hour (h); minutes (min); beats per minute (bpm); steps per minute (SPM); meters (m) kilocalories (kcal); milliliter (mL); graus Celsius (°C); and minutes per day (min/day).

Table 2 shows the partial correlation analysis, controlling for the variable 'Day,' which revealed several key relationships. Maximum heart rate showed a strong positive correlation with moving time ($r = 0.997$, $p = 0.051$). Aerobic activity was positively correlated with average speed ($r = 0.956$, $p = 0.044$). Resting calories demonstrated significant positive correlations with best pace ($R = 0.952$, $p = 0.048$), average speed ($r = 0.984$, $p = 0.016$), and moving time ($r = 0.992$, $p = 0.008$). Active calories were negatively correlated with average pace ($r = -0.983$, $p = 0.017$) and positively correlated with moving time ($r = 0.96$, $p = 0.04$). Total calories burned followed a similar pattern, being negatively correlated with average pace ($r = -0.981$, $p = 0.019$) and positively correlated with moving time ($r = 0.979$, $p = 0.021$).

Estimated sweat loss was positively correlated with best pace ($r = 0.956$, $p = 0.044$), while minimum temperature also showed a positive correlation with best pace ($r = 0.975$, $p = 0.025$). In contrast, the maximum temperature was negatively correlated with the best pace ($r = -0.947$, $p = 0.053$). For intensity-related metrics, vigorous intensity minutes showed strong correlations with average pace ($r = -0.984$, $p = 0.016$), best pace ($r = 0.999$, $p < 0.001$), average speed ($r = 0.957$, $p = 0.043$), and moving time ($r = 0.975$, $p = 0.025$). Moderate-intensity minutes correlated positively with minimum temperature ($r = 0.977$, $p = 0.023$).

Table 2. Correlations of physiological and environmental variables with performance metrics.

Variable	**Correlated variable**	**Pearson's r**	***p*-value**
Max heart rate (bpm)	Moving time (h)	0.997	0.051
Aerobic activity	Average speed (km/h)	0.956	0.044
	Best pace (min/km)	0.952	0.048
Resting calories (kcal)	Average speed (km/h)	0.984	0.016
	Moving time (h)	0.992	0.008

Table 2. (*Continued*).

Variable	Correlated variable	Pearson's r	*p*-value
Active calories (kcal)	Average pace (min/km)	−0.983	0.017
	Moving time (h)	0.960	0.040
Total calories burned (kcal)	Average pace (min/km)	−0.981	0.019
	Moving time (h)	0.979	0.021
Estimated sweat loss (mL)	Best pace (min/km)	0.956	0.044
Minimum temperature (°C)	Best pace (min/km)	0.975	0.025
Maximum temperature (°C)	Best pace (min/km)	−0.947	0.053
Vigorous intensity minutes (min/day)	Average pace (min/km)	−0.984	0.016
	Best pace (min/km)	0.999	< 0.001
	Average speed (km/h)	0.957	0.043
	Moving time (h)	0.975	0.025
Moderate intensity minutes (min/day)	Minimum temperature (°C)	0.977	0.023

Abbreviations: Kilometer per hour (km/h); hour (h); beats per minute (bpm); kilocalories (kcal); milliliter (mL); degrees Celsius (°C); and minutes per day (min/day)

4. Discussion

The objective of this case study was to examine how wearable technology, such as the Garmin Enduro, can be utilized to monitor endurance walking, providing insights into its potential to enhance physical performance tracking and improve the overall pilgrimage experience. The results provided insightful information on a range of physiological and physical activity indicators recorded over five days during the Camino de Santiago, showcasing the potential of wearables to record performance data under actual settings.

According to the descriptive statistics, the pilgrim traveled at an average rate of 11.6 min per kilometer, with sporadic accelerations, as seen by the best pace of 5.1 min per km. These results are consistent with previous research on long-distance walking, which found that endurance exercises require a steady pace[8]. The pilgrimage's endurance component is further evidenced by the average daily walking time of 4.1 h, which is in line with research on ultra-endurance activities that show comparable time-on-foot durations[9]. The steady workout load and cadence (110.4 spm) highlight how crucial it is to maintain effort throughout such extended physical activity.

Important correlations between physiological parameters and walking performance are shown by the partial correlation analysis. Interestingly, there is a substantial positive association (r = 0.997) between maximum heart rate and movement time, which is in line with other research showing that lengthy endurance sports increase cardiovascular stress[10]. The fact that aerobic exercise is linked to average speed (r = 0.956) backs up research that shows how aerobic capacity can improve endurance performance[11]. These kinds of studies show that having more aerobic fitness makes you more efficient at moderate speeds. This means that having more aerobic output lets people move faster for longer.

The relationship between resting calories and best pace (r = 0.952) and moving time (r = 0.992) supports the idea that people with higher basal metabolic rates do better at endurance tasks[12]. This connection shows how important metabolic efficiency is for tasks that need a steady flow of energy. This is supported by research that connects resting metabolic rate to long-term exercise performance[13]. In contrast, the fact that there is a negative association between active calories and average pace (r = −0.983) suggests that walking at a lower intensity (i.e., a slower average pace) requires more calories to be burned for a longer period. Supported by studies showing that longer, lower-intensity workouts use more energy because they last longer[14].

It has been known for a long time that temperature and other environmental factors have a big impact on how well people do in endurance exercises[15]. The strong links found in this study between the lowest and highest temperatures and best walking speed show that weather conditions do affect walking speed. The positive relationship between minimum temperature and best pace (r = 0.975) shows that faster speeds are more likely to happen when it is cooler. This is in line with previous research that found lower temperatures to be linked to better endurance performance[16]. On the other hand, the negative correlation with maximum temperature (r = −0.947) suggests that higher temperatures may hurt performance. This is in line with what[17] found, which is that too much heat can hurt performance because it causes more thermal stress and dehydration.

The strong link (r = 0.956) between expected sweat loss and the best pace shows how important it is to stay hydrated when endurance walking. Previous study has shown that staying properly hydrated can help keep up physical performance, especially when it's hot outside[18]. Although humidity data was not collected in this study, it is well established that high humidity can exacerbate thermal strain and negatively affect performance by impairing the body's ability to cool itself efficiently[19].

This shows how important it is for pilgrims and long-distance walkers to keep track of how much water they drink and sweat to keep up their exercise levels. Lastly, the strong link between minutes of vigorous-intensity and important performance measures like average pace (r = −0.984) and moving time (r = 0.975) is in line with what other studies have found about interval training in endurance sports. The study conducted by Seiler[20] shows that alternating long-duration efforts with short bursts of high intensity can improve total performance by making both aerobic and anaerobic energy systems work better. This knowledge can be very helpful for pilgrims who want to get better at walking long distances.

5. Limitation

One limitation of this study is its focus on a single subject, which inherently limits the generalizability of the findings. Additionally, the study did not include a control group, meaning that we cannot isolate the specific effects of the wearable technology from other factors. As an exploratory case study, the primary aim was to examine the application of wearable technology in endurance walking for one individual, providing preliminary insights into its potential use. Furthermore, due to the small sample size, several p-values were close to the 0.05 threshold (e.g., p = 0.051), which we have noted as “marginally significant.” Due to the small sample size, statistical power was likely reduced; therefore, these findings should be interpreted with caution.

6. Conclusion

Overall, the data from this case study demonstrate the utility of wearable technology in tracking key variables such as speed, cadence, heart rate, and caloric expenditure. While the findings are based on a single subject, they align with existing literature on endurance activities and provide valuable insights into how wearables can help optimize physical performance and enhance the pilgrim experience. Although caution is needed in generalizing the results, the potential of wearable devices to improve performance and safety through real-time physiological monitoring and feedback is evident. Future studies involving larger, more diverse samples will help to further validate and expand on these findings.

Ethical approval

This case study did not require formal ethics committee approval, as the data collected were obtained solely through the use of a wearable device with the participant’s informed consent. All procedures performed in this study adhered to the ethical standards of the Declaration of Helsinki.

Consent to participate

The participant provided informed consent to share their personal activity data collected during the pilgrimage. This data was monitored and recorded using wearable technology.

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Conflict of interest

The author declares no conflict of interest.

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