

Evaluating a Wearable Heliometric Device for Safe Sun Exposure Promotion Among Emirati Women With Hypovitaminosis D

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Abstract

Vitamin D deficiency represents a pressing public health challenge in the United Arab Emirates (UAE), with particularly high prevalence among women. Wearable technologies that promote appropriate sun exposure offer a promising way to help individuals achieve and maintain sufficient vitamin D status. This qualitative proof-of-concept study aimed to assess how Emirati women diagnosed with hypovitaminosis D perceived the usability and potential benefits of a novel heliometric device designed to encourage and monitor safe sun exposure. Nine Emirati women aged 19 to 21 participated in a protocol requiring them to wear the heliometric device, in the form of a wristband, for 10 minutes each day over one week. They were also instructed to observe standard recommendations for sun exposure. At the end of the week, participants provided qualitative feedback through open-ended questions in an online evaluation form. Researchers then conducted individual interviews with all participants to explore their responses in greater depth. Thematic analysis was used to interpret the full set of qualitative data. Participants generally reported favorable views of the device. A strong consensus emerged that the heliometric wristband effectively supported adherence to the advised sun exposure guidelines. Environmental factors such as weather, religious and cultural norms regarding clothing, and personal preferences for physical activity also shaped compliance. While most participants appreciated the device's ease of use and measurement accuracy, some noted limitations related to comfort and connectivity. They proposed several design and functional enhancements to improve practicality, wearability, and reliability. In addition, the device increased awareness and helped dispel certain misconceptions about sun exposure. The wearable heliometric device proved acceptable to users and shows potential as a supportive tool for addressing hypovitaminosis D by fostering safe sun-related habits. Additional quantitative investigations with larger cohorts, extended follow-up periods, and controlled designs are warranted to evaluate the clinical value of such devices.

Keywords: Hypovitaminosis D, Mobile app, Sun exposure, UAE, Vitamin D, Wearable device

Introduction

Background

Vitamin D plays a vital role in regulating the metabolism of bone minerals such as calcium and phosphorus [1, 2].

The predominant source of vitamin D is sunlight, which fulfills around 90% of bodily requirements, with dietary and supplementary sources providing the balance. Ultraviolet B rays from the sun initiate vitamin D production in the skin, providing the body's main natural supply [1, 3- 5].

Inadequate vitamin D intake leads to hypovitaminosis D, a condition that includes both deficiency and insufficiency and occurs frequently throughout the Middle East, especially in the UAE. According to a 2017 report by the Dubai Health Authority, over 90% of the UAE population suffered from vitamin D deficiency [6],

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a situation that became even more prominent after the COVID-19 pandemic [7]. Diagnosis relies on serum 25-hydroxyvitamin D (25(OH)D) measurements, with levels below 20 ng/ml (50 nmol/L) indicating deficiency and 21–29 ng/ml (52.5–72.5 nmol/L) signifying insufficiency [8, 9]. Evidence demonstrates that low vitamin D status adversely influences health outcomes, contributing to skeletal problems, cardiovascular disorders, diabetes, autoimmune conditions, malignancy, and anxiety-related illnesses [2, 10].

Vitamin D deficiency has been repeatedly documented as a major health problem in the UAE [11-14]. Women tend to exhibit lower vitamin D concentrations, with this disparity being particularly evident among females in the UAE [12, 14-16]. The condition raises significant concerns during pregnancy and breastfeeding due to its potential adverse effects on maternal and fetal health [17]. Contributing elements in the UAE context include the region's extreme heat, widespread indoor living patterns, and traditional religious and cultural dress codes that substantially restrict skin exposure to sunlight [3, 15]. Such conditions highlight the urgent requirement for novel interventions to alleviate the burden of hypovitaminosis D on public health.

Objectives and research questions

The heliometric device, a wearable solution engineered to measure, track, and stimulate safe sun exposure, offers a valuable innovation for confronting widespread vitamin D deficiency. Leveraging Internet of Things (IoT) integration, it supplies accurate real-time feedback on sun exposure, enabling users to make better-informed decisions about healthy sun practices. This technology illustrates the role of digital tools in advancing public health initiatives to optimize vitamin D levels.

The current qualitative proof-of-concept investigation examined the firsthand experiences of Muslim Emirati women living with hypovitaminosis D as they used the heliometric device, focusing on evaluations of its usability, comfort, and overall impact. A qualitative methodology was adopted to thoroughly investigate the personal and contextual aspects of device interaction. This approach excels at uncovering detailed accounts of users' thoughts, feelings, and behavioral responses [18-20].

The study was guided by the following research questions:

- Research Question (RQ) 1: What are the participants' perceptions and experiences regarding

the usability and wearability of the heliometric device?

- RQ2: What preliminary insights can be gathered about the potential influence of the heliometric device on sun exposure behavior?

Addressing these questions will provide important insight into how wearable technologies may support safe sun exposure practices and serve as an effective response to the widespread issue of hypovitaminosis D. The outcomes are also anticipated to guide ongoing refinements in the design and functionality of subsequent heliometric devices.

Materials and Methods

Recruitment and selection process

Recruitment relied on purposive snowball sampling to enroll nine individuals meeting strict eligibility requirements: a medical diagnosis of hypovitaminosis D, female sex, Emirati citizenship, and observance of traditional Muslim dress practices in line with UAE cultural and religious standards. These parameters allowed the investigation to target the unique viewpoints and obstacles this high-risk group faces when interacting with the heliometric device.

Limited device availability necessitated dividing participants into two distinct groups. Only five units could be deployed for the trial itself, with one additional device held for preliminary testing. The process began with an in-person meeting with two promising university students who showed strong potential and commitment. The study's goals and expectations were thoroughly discussed, including forming separate groups. These initial contacts were then asked to identify other qualifying students. An introductory virtual meeting followed, during which inclusion and exclusion standards were clarified in detail. Candidates submitted their serum vitamin D results for verification. The final assignment involved randomly assigning four participants to Group 1 and five to Group 2.

Data privacy and security

All information collected by the heliometric device was securely hosted on the Arduino Cloud infrastructure, which adheres to established cybersecurity protocols such as ISO 27001 [21]. Robust protective measures were applied, including AES-256 encryption of sensitive data, TLS-secured transmission channels, two-factor authentication, and strict access limited exclusively to the

researcher overseeing device development. Participant records were anonymized through unique numerical codes stored on the cloud platform. Consent materials fully disclosed the cloud-based storage procedures, data-handling practices, and security arrangements, and participants explicitly agreed to these terms. The Research Ethics Committee at Zayed University, UAE, granted ethical clearance for the study (ZU23_065_F).

Study procedures

Participants in both groups received prior notification of their assigned testing windows. Group 1 completed the protocol during the third week of May 2023, and Group 2 followed in the fourth week. Everyone attended a unified face-to-face briefing session. At this session, individuals were directed to wear the device for 10 minutes daily in direct sunlight across seven consecutive days. The study established uniform exposure schedules for all participants. This duration corresponds with previous recommendations of 10–15 minutes of unprotected sunlight exposure several times weekly [22]. The daily requirement was divided into two separate 5-minute periods—one between 9:00 a.m. and 12:00 p.m., and the other between 3:00 p.m. and 4:00 p.m.—while participants were cautioned against midday exposure between 12:00 p.m. and 3:00 p.m. to reduce health risks. Additional directives included refraining from sunscreen during active device use and shielding the equipment from moisture owing to its delicate components. Following the briefing, participants received and signed consent documents detailing their obligations and right to withdraw voluntarily at any stage. They retained personal copies of the signed agreements. Each member of Group 1 was then met individually to collect their designated device and undergo in-depth training. Instructions covered activating a smartphone personal hotspot or portable Wi-Fi, with pre-programmed network details loaded onto each unit. Guidance covered correct wrist positioning, screen operation, powering the device, establishing connections, and recharging. Participants installed the “Arduino IoT Cloud Remote” application from the relevant app store and learned its functions. They entered personal parameters such as age, weight, height, exposed body surface area, and skin type. Personalized dashboards allowed them to monitor daily sun exposure metrics. Unique identifiers ensured both secure access and confidentiality. A detailed instructional manual was also distributed.

Group 1 then conducted a supervised outdoor session in direct sunlight to test real-time performance and resolve any queries. Upon finishing the week-long trial, devices were collected. Group 2 repeated the same steps in the final week of May 2023, after which they also returned their equipment.

Heliometric device

The heliometric device was engineered to support, record, and stimulate appropriate sun exposure. Shaped like a conventional smartwatch and worn on the wrist, it integrates an Arduino MKR1000 microcontroller board topped with an Arduino MKR ENV Shield. This shield incorporates various sensors, including a light sensor (TEMT6000) and an ultraviolet (UV) sensor (VEML6075). The manufacturer’s official resources [23] provide more detailed information on the Arduino MKR ENV Shield. The current prototype primarily relied on the light sensor to evaluate sun exposure conditions, with intentions to activate the UV sensor in upcoming versions. A compact screen on the device presents essential data, such as the target daily sun exposure time (10 minutes for this investigation), total accumulated exposure minutes, and the proportion of estimated vitamin D requirements fulfilled. The unit draws power from a portable power bank.

IoT capabilities enable the device to maintain a continuous link with a cloud database, ensuring regular updates of participants’ sun exposure information. The study employed a tailored edition of the “Arduino IoT Cloud Remote” mobile application, which interfaced directly with the device. Users input their individual characteristics through the app, encompassing weight, height, age, skin tone, and the percentage of body area exposed to sunlight. Progress monitoring was accessible via both the application interface and the device’s onboard display.

Data collection

One of the study’s main purposes was to collect and examine participants’ subjective judgments concerning the heliometric device’s usability and practical value. Accordingly, an online gathering was arranged during which each person privately responded to an electronic questionnaire featuring 12 open-ended items. Such open-ended digital surveys are valued for yielding in-depth, contextual responses that reflect a wide spectrum of individual viewpoints and lived realities [24]. Initial questions invited reflections on personal encounters with

hypovitaminosis D, the role of cultural and religious practices in shaping vitamin D levels, and the factors motivating involvement in the research. Later items addressed interactions with the device itself and the degree to which participants followed the established protocol.

A doctoral-level psychologist specializing in psychometric evaluation (the second author) thoroughly examined and polished every question. This step minimized the chance of eliciting biased, socially favorable answers and avoided ambiguous or compound phrasing.

A secure link to the questionnaire was distributed, after which participants were placed into separate breakout rooms to maintain privacy. Participants were given clear guidance to complete the items at their own pace, with opportunities to raise questions at any stage. Individuals remained in their private rooms following submission. Each completed form underwent detailed review, leading to personalized follow-up inquiries tailored to the specific responses provided. These individual interviews occurred within the isolated breakout rooms to preserve independence of views and capture candid impressions. The survey instrument and supplementary interview prompts were drawn from prior work by Refs. [25] and [26].

Data analysis

All survey submissions were collected, and the follow-up interviews were audio-recorded and fully transcribed. As several participants spoke Arabic during the sessions, professional translation into English was carried out. To verify transcript fidelity and translation precision, two members of the research team (RS and FA) independently reviewed the recordings at least twice. Participants were allowed to review their transcripts and

confirm the accuracy of both their statements and the subsequent interpretations.

We applied a thematic analysis framework to the qualitative data to explore the device's initial usability and effectiveness. Thematic analysis involves systematically identifying, organizing, and interpreting recurring patterns within qualitative datasets [27]. This flexible approach is especially effective for investigating personal experiences and generating nuanced understandings [27]. It was selected for the present study because it can derive coherent themes from complex data, providing a thorough account of how participants engaged with the heliometric device [27, 28]. The analysis adhered to the six-phase process outlined by Braun and Clarke [27].

In the first phase, two researchers (RS and FA) familiarized themselves extensively with the material by repeatedly reading the survey responses and interview transcripts. In the second phase, they performed independent inductive coding of the entire dataset, allowing codes to emerge directly from participants' accounts without preconceived categories or researcher assumptions. The researchers then convened to compare codes, discuss observations, and establish preliminary agreement. During the third phase, related codes were clustered into candidate themes, with attention given to their prevalence and relevance to the study's research questions. In the fourth phase, three researchers (RS, FA, and JT) reviewed these candidate themes for coherence and distinctiveness and identified representative quotations. Finally, through ongoing refinement, the same three researchers defined and labeled the main themes and subthemes, finalized supporting quotations, and produced a comprehensive report. This report presented illustrative extracts and explained the connections between the identified themes and the original research questions (**Figure 1**).

Original Statement	Code	Potential Themes	Theme and Subthemes
The device is easy to turn on and does not need a lot of maintenance, which is good. (Participant 3)	The device is easy to operate and maintain	Positive Feedback	Theme: Device design, features, and functionalities Subtheme 1: Positive Feedback
The device was heavy and wearing it for 10 minutes while walking was harder because of me making sure it didn't fall. (Participant 1)	Device is heavy and difficult to wear while walking due to the fear of falling	Negative Feedback	Subtheme 2: Negative Feedback

Figure 1. An example of the data analysis process.

Results and Discussion

Participants

Nine female Muslim Emirati university students residing in Abu Dhabi, UAE, took part in the study. Every participant had been diagnosed with hypovitaminosis D and was not receiving any vitamin D supplements,

presenting with a mean serum concentration of 41.6 nmol/L (16.64 ng/mL). Their ages ranged from 19 to 21 years, the average Body Mass Index (BMI) was 22 kg/m², and their skin types ranged from 3 to 4 according to the Fitzpatrick scale. **Table 1** summarizes participant profiles.

Table 1. Participants' characteristics and heliometric device wear analysis.

Characteristic	Average $\pm$ SD	Observed Range ^a
Serum vitamin D concentration (nmol/L)	41.6 $\pm$ 13.6	22.6–65
Participant age (years)	20.2 $\pm$ 0.8	19–21
Body mass index (kg/m ²)	22 $\pm$ 4.9	15.2–31.2
Body weight (kg)	55.6 $\pm$ 11.8	38–79
Height (cm)	159.2 $\pm$ 7.9	143–171
Number of sun exposure days ^b	6.2 $\pm$ 0.7	5–7
Percentage of scheduled sun exposure days	86%	—
Daily sun exposure duration (minutes) ^b	8.5 $\pm$ 1	7–10

SD: Standard Deviation.

^a Range indicates the minimum and maximum value.

^b These findings record the official readings of the device, despite some participants using the device for longer durations.

Heliometric device use and support

Virtually all participants stated that they followed the protocol by wearing the device for 10 minutes per day across the full week. Objective records from the device's light sensors indicated an average of 6 days of use out of the 7 days and a mean daily sun exposure duration of 8.5 minutes. These measurements may underrepresent actual

usage due to occasional technical constraints, such as overcast weather on five occasions and smartphone connectivity problems on two occasions. The variation between self-reports and logged data stemmed from several individuals wearing the device longer or on additional days beyond what the sensors registered.

Eight participants carried out their sessions in the courtyard or garden area of their homes, with only one conducting exposure while commuting to Sharjah or on her home balcony. Four participants preferred afternoon timing, one preferred morning sessions, and the other four used a combination of times of day. Seven women opted for a single uninterrupted 10-minute period, while two split the time or used a flexible combination of approaches.

Support was offered both in person and remotely throughout the trial. Face-to-face assistance occurred three times, addressing device-to-smartphone connection failures on two occasions and replacing a faulty display screen once. Remote help via messages and online meetings was provided three times, mainly to resolve connectivity difficulties.

Participant perceptions

The strong level of engagement with the device suggests a positive reception among the young Emirati female participants. All individuals confirmed that wearing the device helped them maintain the required protocol and follow sun exposure recommendations. Feedback on the wearable technology was largely favorable, with common descriptions including terms like “good,” “great,” and “motivating.” Many reported finding the experience enjoyable and noted that the study increased their awareness of beneficial sun practices. Several participants indicated they would consider acquiring or continuing to use the device after further development.

“It is a great tool that will help the treatment of vitamin D deficiency” (Participant 1).

“Overall, the experiment was good and beneficial, and I really learned a lot from it. It made me more curious about this topic” (Participant 6).

“A new device, since it is my first experience of putting a watch on my hand, amazing experience. I felt enthusiastic and responsible for this watch” (Participant 5).

Thematic analysis

Analysis of the data revealed four main themes: 1) factors influencing adherence to sun exposure recommendations, 2) device design, features, and functionalities, 3) suggestions for device enhancement, and 4) promoting awareness, addressing misconceptions, and enhancing motivation

Theme 1: Factors influencing adherence to sun exposure recommendations

A range of external elements, unrelated to the device itself, shaped participants’ ability to maintain recommended sun exposure routines. These key influences were grouped into two subthemes: environmental factors and sociocultural and lifestyle factors.

Environmental factors

Several individuals described challenges associated with using the device in hot summer conditions. While many completed the required 10-minute sessions, they noted that elevated temperatures made it harder to consistently follow the research protocol.

One participant recalled that the intense early-summer heat complicated outdoor exposure [Participant 3].

Many participants also indicated that overcast or gloomy weather reduced their adherence to the protocol. On days with limited sunlight, they had to restrict sessions to specific hours. In some cases, participants could not finish their daily requirement because the sensor failed to register sufficient light.

Another participant reported being unable to complete the sessions during two cloudy days [Participant 2].

Sociocultural and lifestyle factors

When discussing the role of culture and religion in vitamin D levels, most participants highlighted how traditional clothing affects safe sun exposure. Women in the study typically wear the “abaya,” a full-length, loose garment covering the body from neck to ankles, commonly paired with a “hijab” that covers the hair. This attire, often black, was viewed as significantly limiting direct sunlight reaching the skin and thereby contributing to lower vitamin D synthesis.

One participant explained that religious requirements for long sleeves and head covering prevent adequate sun exposure and can lead to deficiency [Participant 8].

Physical activity also emerged as an important influence on compliance. Two participants found that walking while wearing the device made the daily sessions more manageable. One noted that remaining seated instead of walking would have substantially increased the difficulty, while another described how her largely sedentary routine added to the challenge.

A participant shared that moving around the house while wearing the device made the task easier compared to staying seated [Participant 7].

Theme 2: Device design, features, and functionalities

Participants offered mixed views when asked to evaluate the device's design, features, and overall performance.

Positive feedback

Three key strengths were highlighted: ease of interaction and upkeep, effective sun-exposure monitoring, and reliable measurement accuracy.

First, participants generally found the device user-friendly and low-maintenance. They appreciated its straightforward operation and minimal handling requirements. Participants also positively received the mobile application's clear interface and simple setup instructions. These aspects supported better engagement with sun exposure practices and improved adherence to the protocol.

One participant commented on the device's simplicity and limited need for ongoing maintenance [Participant 3].

Second, participants widely valued the device's ability to track and display progress. Visual feedback on accumulated sun exposure encouraged continued use and helped participants achieve their daily 10-minute goal. Real-time updates on both the device screen and the app further reinforced motivation.

Another participant stated that seeing daily progress strongly supported consistent device use and target completion [Participant 9].

Third, participants expressed confidence in the device's measurement precision. They particularly approved of its capacity to calculate only actual sun exposure time by automatically disregarding periods spent in shade.

One participant praised the smartwatch functionality for accurately recording sunlight only when exposed and pausing in shaded or indoor areas [Participant 7].

Negative feedback

Participants identified several limitations of the device, which centered on two main aspects: device wearability and comfort, and connectivity issues.

First, when asked about the least satisfactory aspects, most participants reported difficulties stemming from the device's substantial weight and bulky dimensions. Some found it tiring and cumbersome to wear even for the brief 10-minute period, while others expressed concern about the risk of the device slipping off due to its size.

One participant noted that the device's heaviness made it harder to wear while walking, as constant attention was needed to prevent it from falling [Participant 1].

Additionally, the attached strap contributed to discomfort during use. Four participants expressed dissatisfaction with the strap's loose fit and lack of security. While some worried the device would fall because of the strap, others reported instances where the strap detached during wear. The lack of a protective casing was another recurring concern, leaving participants anxious about accidental drops and potential damage to its components.

Another participant explained that the device was unsuitable for daily or general use across age groups. Its weight on the wrist, combined with a loose strap, caused her to remain stationary for fear it might fall and break, given the absence of any protective cover [Participant 4]. Second, regarding connectivity, some participants raised issues with the Wi-Fi link between the device and their smartphone's personal hotspot. They reported occasional delays in establishing the connection. Others found the restriction to a single specific hotspot inconvenient, as the device sometimes struggled to connect reliably to their personal network.

Theme 3: Recommendations for device improvement

Participants offered suggestions for enhancing the device, categorized under two subthemes: improving device design and improving device functionality.

Improving device design

Drawing on the limitations noted earlier, many participants proposed specific design modifications. Five participants recommended reducing the device's overall size to improve comfort and wearability. Others suggested redesigning the strap to ensure a more secure, snug fit and reduce the likelihood of slippage. Several advocated adding a protective cover to safeguard the internal components. One participant additionally proposed making the device waterproof.

One participant suggested making the device smaller and lighter while enclosing all components within a protective cover to prevent damage [Participant 3].

Improving device functionalities

Connectivity difficulties prompted recommendations to expand the device's connection options. Some participants proposed enabling Bluetooth pairing with the mobile phone as an alternative to relying exclusively on Wi-Fi or personal hotspots. This change would offer

greater flexibility and reduce dependence on a single connection type that might not always be available.

Participants also recommended incorporating reminders and alerts to support daily sun exposure. Suggestions included audible signals to indicate progress toward the daily target. One participant emphasized the value of mobile app notifications for real-time updates on sun exposure levels, viewing them as useful prompts that would both remind users to wear the device and motivate adherence to healthy sun exposure habits.

Another participant noted that notifications reminding users to take vitamin D could increase motivation to use the device and spend time outdoors, even in warm conditions, since the required exposure was only 10 minutes. Examples of encouraging messages included prompts such as “Go ahead, take your daily vitamin D” [Participant 4].

Furthermore, some participants desired more advanced data analysis and longitudinal insights within the mobile application. They expressed interest in viewing extended summaries of sun exposure patterns beyond single-day records, such as weekly trends or daily comparisons.

One participant proposed that the app could display progress over the entire week, including daily comparisons (for instance, indicating whether sun exposure was 10% lower than the previous day) [Participant 9].

Theme 4: Raising awareness, correcting misconceptions, and enhancing motivation

Several participants reported that the device and the study experience increased awareness and corrected misconceptions about sun exposure and vitamin D acquisition. One participant observed that the device did not register any sun exposure time while she remained in the shade. This observation helped dispel her prior belief that merely being outdoors was sufficient for vitamin D synthesis. She realized that direct skin contact with sunlight is necessary for vitamin D production.

One participant anticipated that others would find the device engaging because it would allow them to monitor their actual sun exposure and understand its limits. She explained that seeing no calculation occur in shaded areas clarified that being outside does not guarantee vitamin D absorption. This insight corrected her earlier assumption [Participant 2].

Another participant explained how the study challenged her previous conviction that sun exposure was ineffective for improving vitamin D levels. She had long assumed

that only supplements or medical interventions could meaningfully raise vitamin D. The experience helped her appreciate the important contribution of natural sun exposure and sparked greater interest in incorporating it into her routine.

A participant with historically low vitamin D levels shared that she had not expected sitting in the sun for 10 minutes to be effective, believing supplements and injections were the only viable solutions. She ultimately viewed adopting a daily sun exposure routine as a valuable and positive development [Participant 4].

The study also appeared to cultivate more favorable attitudes toward sun exposure practices among participants. One individual initially found the prospect of 10 consecutive minutes in the sun daunting. However, she discovered during the study that this duration was quite manageable and expressed surprise that she had not incorporated the practice sooner. This realization motivated her to consider extending future sessions to 15 minutes after the study concluded.

Another participant reflected that the 10-minute duration proved comfortable and was surprised that such a short, easy commitment had not been part of her daily habit earlier. The experience motivated her to potentially increase the time to 15 minutes once the study ended [Participant 5].

Participant perceptions

The heliometric wearable device was generally well accepted by the study participants. Initial results showed that nearly all individuals consistently wore the device for the required 10 minutes each day throughout the one week. Overall, feedback on the device was predominantly positive, with participants indicating that it effectively supported adherence to standard sun exposure guidelines. These outcomes are consistent with earlier investigations that have documented high levels of satisfaction and acceptability with wearable sun-exposure technologies [25, 29-31]. The observed wear time in the present study suggests that prolonged use of wearable heliometric devices is feasible and may improve vitamin D status. This possibility holds important public health relevance in the UAE, where vitamin D deficiency represents a widespread concern that may aggravate major disease burdens such as diabetes and disability conditions such as major depressive disorder [13, 32, 33].

Factors affecting compliance with sun exposure

Multiple external elements, independent of the heliometric device, appeared to affect participants' adherence to recommended sun exposure practices. Environmental conditions were among the primary influences on participants' ability to fully comply with the protocol. Individuals reported greater difficulty wearing the device in hot, sunny weather, a finding that corresponds with prior regional research [15, 34]. For instance, one earlier study noted lower vitamin D levels during summer months and higher levels in winter, potentially linked to the UAE's intense heat [15]. In addition, overcast weather sometimes hindered completion of the daily 10-minute sessions. Religious and cultural clothing norms also substantially influenced sun exposure experiences. Participants highlighted how traditional sun-protective garments can limit vitamin D synthesis, a pattern supported by existing literature [31, 34-36]. Finally, individual lifestyle factors, particularly physical activity levels, played a role in compliance. Participants who walked while wearing the device generally found the task easier than those leading more sedentary routines. Future device development should prioritize adaptable approaches that account for varying climate conditions, clothing practices, and activity preferences to enhance inclusivity.

4Positive feedback regarding the device's design, features, and functionalities

Participants highlighted several advantages associated with the device's design, features, and operational capabilities. They particularly valued the straightforward usability of both the device and the accompanying mobile application, noting their intuitive operation, simple navigation, and comprehensible instructions. This accessible design appeared to enhance user engagement and promote consistent adherence to sun exposure targets. Participants also appreciated being able to monitor and visualize their sun exposure progress through the device display and mobile app. Moreover, they commended the instrument's precision in quantifying sun exposure. Immediate, accurate feedback helped build confidence in the technology and encouraged completion of the daily 10-minute sessions. A previous investigation utilized the Microsoft Band 2 (now discontinued), equipped with a wearable UV/light sensor and a customized Android application, to encourage safe sun exposure habits among three participants over three days [29]. As in the current study, those participants responded favorably to the mobile

app's visual representations of sun exposure because of their accuracy and practical value. The present results further corroborate broader literature emphasizing the importance of user-friendly interfaces and reliable data accuracy in wearable technologies [26, 37-40]. Notably, certain studies [26, 39, 40] have reported that doubts about measurement accuracy can reduce user motivation and engagement.

Negative feedback regarding the device's design, features, and functionalities

Conversely, participants identified several limitations of the device. They reported challenges related to wearability, primarily due to the device's considerable weight, bulky dimensions, and loose-fitting strap. Discomfort during use was common, with particular concerns about the risk of the device slipping and sustaining damage owing to the insecure strap and absence of a protective casing. In addition, participants had difficulty maintaining Wi-Fi connectivity between the device and the smartphone's personal hotspot. The restricted range of connection options was viewed as another shortcoming. These issues concerning wearability and connectivity appeared to reduce compliance and overall engagement, consistent with previous studies that emphasize comfort as a critical determinant of wearable technology acceptance [37, 38, 40].

A separate investigation involved 194 participants, comprising parents and children, who wore an ultraviolet radiation (UVR) monitoring device called Shade (first version) and used a dedicated mobile application for two weeks to track and minimize UVR exposure [25]. The Shade device was designed to clip onto clothing, which occasionally interfered with garments and drew unwanted attention. Furthermore, the accompanying app did not deliver real-time UV exposure data to users. While participants valued the device's ease of use, compact size, and contribution to greater awareness of safe sun practices, they frequently cited its tendency to fall off as a major drawback. These experiences parallel the current findings, revealing similar patterns of satisfaction and dissatisfaction with the heliometric device. The only notable difference was that the larger size of the present device posed a specific challenge, unlike the smaller Shade device.

Collectively, the identified strengths and weaknesses offer valuable guidance for the continued refinement of the wearable device. Targeted improvements to address

the noted limitations could substantially enhance usability and long-term user adherence.

Recommendations for device improvement

Participants offered constructive suggestions to refine the device's design and functionality. Proposed modifications included reducing the device size, improving strap security and fit, adding a protective cover, and incorporating waterproof capabilities. The inclusion of water resistance has been recognized as important in other wearable device research [25, 41]. Participants also advised expanding connectivity options by adding Bluetooth alongside Wi-Fi or enabling offline functionality. Additional recommendations encompassed audible progress alerts, mobile application notifications and reminders, and extended sun exposure data analysis features. These suggestions underscore participants' emphasis on wearability, comfort, user-centered design, and flexibility in wearable technologies. Such insights highlight the need to prioritize customizability and convenience to foster sustained user engagement. Implementing these enhancements may serve as an effective motivational tool, supporting prolonged compliance with sun exposure protocols.

Raising awareness, changing misconceptions, and increasing motivation

At the outset of the study, it appeared that not all participants fully understood the contribution of sun exposure to vitamin D synthesis. One individual previously assumed that simply being outdoors, even in shaded areas, would provide adequate vitamin D. Another expressed strong skepticism regarding the effectiveness of sunlight as a natural source. The study experience and device use contributed to increased awareness and corrected these misconceptions about sun exposure and vitamin D. These preliminary observations align with results from a controlled pilot study involving female Emirati college students, which confirmed that safe sun exposure can effectively elevate vitamin D levels through natural means [42]. Participants in the current study indicated that the device encouraged them to consider extending their sun exposure to 15 minutes after the study period, suggesting potential for promoting sustained healthy sun exposure behaviors.

In contrast, some earlier research has not observed comparable effects. For instance, a randomized controlled trial involving 368 melanoma survivors employed the Shade 2 wristband UVR monitoring device

alongside mobile applications to improve sun protection behaviors [41]. Unlike the present findings, that study detected no significant changes in sun exposure habits during device use. This difference may stem from the absence of personalized messaging in the Shade 2 application and hardware-related issues reported by participants [41].

In summary, the encouraging preliminary experiences reported by participants provide a solid foundation for future research examining the implementation of such wearable technologies among vitamin D-deficient populations in the UAE.

Strengths and limitations

To the authors' knowledge, the present study is the first to examine the perceptions of young female Muslim Emiratis toward a novel vitamin D-oriented heliometric wearable device. Most existing research has focused on UVR and light sensors primarily designed for sun protection and mitigating the effects of harmful sun exposure. This study addresses this gap by focusing on the importance of safe, deliberate, and moderate sun exposure to support vitamin D synthesis and address hypovitaminosis D.

In the thematic analysis section, various applications providing sun exposure and UV insights were discussed [25, 29-31, 41]. In contrast, the current mobile app quantifies and visualizes estimated vitamin D intake while personalizing recommended sun exposure durations based on individual characteristics such as age, skin type, BMI, and body surface exposure. Although Shade 2 permits users to select a UV threshold according to skin type, it offers limited further customization [43]. While the personalization feature was not activated in the present study to maintain uniformity of experience (i.e., all participants followed a standard 10-minute sun exposure protocol), it has been incorporated into the application. It will be fully utilized in subsequent investigations. Participants could also view sun exposure data on both the device display and the mobile application, a dual-interface feature that is relatively uncommon in prior studies (except for the discontinued Microsoft Band 2). Notably, the Microsoft Band estimated UV exposure indirectly through visible light correlation rather than direct UV measurement [44].

In comparison, the present device employs a direct UV sensor (VEML6075) capable of measuring both UVA and UVB radiation. Furthermore, while the Microsoft Band operated within a temperature range of -10°C to

+40 °C [45], the current device's light sensor (TEMT6000) and UV sensor (VEML6075) function effectively across broader ranges of -40 °C to +100 °C and -40 °C to +85 °C, respectively [23]. This enhanced thermal resilience makes the heliometric device better suited to the UAE's hot climate. Additionally, the open-source Arduino platform enables greater customization for scientific research than proprietary systems such as the Microsoft Band and Shade devices. In terms of cost, the present heliometric device is substantially more affordable than comparable technologies. The Microsoft Band was priced at \$235 [44] before discontinuation, Shade 1 (magnetic clip) at \$249 [44], and Shade 2 (wristband) at \$499 [43]. By contrast, the current heliometric device costs approximately \$122, with expectations of further price reductions in future production batches.

The study also has several limitations. First, the device lacked dedicated sensors (such as accelerometers) to confirm actual wrist wear, so it relied on sun exposure data as a proxy for usage. This approach led to discrepancies between recorded data and participant self-reports, as individuals reported higher usage while the device registered no exposure during cloudy conditions or connectivity failures. Future studies could incorporate objective wear-detection sensors to address this issue, consistent with previous recommendations [25]. Second, it was difficult to determine whether device use stemmed from genuine acceptability, protocol compliance, or general research interest. Subsequent research should investigate acceptability more thoroughly to clarify these motivations. Third, the small sample size and demographic homogeneity limit the generalizability of findings to the wider UAE population. Finally, the brief study duration restricts conclusions regarding long-term behavioral changes and the sustainability of ecologically valid sun exposure practices.

Implications for research and practice

The findings of this study carry several notable implications for both research and clinical practice. Wearable heliometric devices demonstrate potential for sustained use, which may contribute to elevated vitamin D levels. This is especially pertinent in the UAE, where vitamin D deficiency constitutes a major public health challenge that can exacerbate conditions such as diabetes and major depressive disorder.

For healthcare practitioners, incorporating wearable heliometric devices into public health initiatives offers an

innovative strategy for tackling vitamin D deficiency. These tools enable individuals to monitor and regulate sun exposure more effectively, potentially improving population health outcomes. Clinicians could leverage such devices to deliver tailored guidance on safe sun exposure, thereby fostering healthier behaviors among patients.

Future investigations should recruit larger, more diverse samples, extend study durations, and incorporate control conditions (for example, through randomized controlled trials) to rigorously evaluate device effectiveness. Further exploration of personalized sun exposure recommendations, their influence on compliance and health markers, and long-term behavioral and psychological effects will be essential to fully understand the potential of these technologies.

Conclusion

In summary, participants in this study generally reported a favorable experience with the heliometric device. These positive perceptions provide a promising foundation for broader implementation of such technologies across the UAE population. External influences, including local weather patterns, religious and cultural clothing practices, and individual physical activity levels, affected adherence to sun exposure recommendations. The device's monitoring capabilities and favorable user feedback can support individuals in adopting safe sun exposure habits within this context. Despite certain limitations related to wearability and connectivity, participant suggestions offer clear directions for device refinement. The heliometric device also contributed to heightened awareness, correction of misconceptions, increased motivation, and more positive attitudes toward safe sun exposure among participants. These insights will guide subsequent device improvements aimed at promoting sustainable behavioral changes and addressing hypovitaminosis D within the UAE setting.

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