Original Paper
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Acceptability of Continuous Glucose Monitoring in Free-living Healthy Individuals: Implications for the Use of Wearable Biosensors in Diet and Physical Activity Research
Abstract

Background: Wearable sensors have been increasingly used in behavioral research for real-time assessment and intervention purposes. The rapid advancement of biomedical technology typically used in the clinical settings has made wearable sensors more accessible to a wider population. Yet the acceptability of this technology for non-clinical purposes has not been examined.

Objective: To assess the acceptability of wearing a continuous glucose monitoring (CGM) device among a sample of non-diabetic individuals; and to compare the acceptability of CGM between a mobile diet tracking app (MyFitnessPal) and an accelerometer.

Methods: A total of 30 non-diabetic adults went through a 7-day observational study. They wore a CGM sensor, tracked their diet and physical activity using the CGM receiver and the MyFitnessPal, and wore an accelerometer on their waist. After the monitoring period, they completed a 10-item survey regarding acceptability of each of the study tool. Two-tailed paired-samples t-tests were conducted to examine whether the summary acceptability score was comparable between CGM sensor/receiver and MyFitnessPal/accelerometer.

Results: More than 90% of the study participants agreed that the CGM sensor and receiver were easy to use, useful, and provided relevant information that was of interests to them. There was no significant difference in the summary acceptability scores between CGM sensor and MyFitnessPal, and between CGM receiver and MyFitnessPal. Both the CGM sensor and receiver had a higher acceptability score than the accelerometer ($p < .01$).

Conclusions: The high acceptability of using a CGM from the current study suggests a great potential for using CGM in non-diabetic adults in research settings. The continued
advancement in wearable sensor technology makes the barrier to track and collect personal physiological data become more and more minimal.

**Keywords:** wearable sensors; remote monitoring; physiological monitoring; accelerometry; user experience
Introduction

Diet and physical activity are the two leading modifiable lifestyle behaviors that could significantly impact future health outcomes such as obesity, hypertension, diabetes, and heart disease [1]. Nevertheless, in the U.S., adherence to meeting the dietary and physical activity guidelines has remained low for the past few decades [2-4]. Numerous efforts have been devoted to understanding the determinants and correlates of diet and physical activity behavior with the goal of developing novel and more effective interventions to promote and sustain positive health behavior changes. In recent years, behavioral research has seen a sharp increase in the use of mobile and wearable technology in diet and physical activity assessment and interventions [5]. Some of the widely used technologies include mobile apps and wearable activity trackers [5-7], reflecting researchers' interests in utilizing wearable devices to understand and improve behavioral health.

New technologies are being developed to capture an extraordinary array of health-related information. Biosensors, wearable devices that either continuously or frequently measure physiological parameters [8,9], are becoming more affordable and accessible; providing opportunities for their application beyond clinical settings. One example of a wearable biosensor with the potential to be used in behavioral research is the continuous glucose monitor (CGM). CGM measures the concentration of glucose subcutaneously (interstitial fluid) in real-time through a tiny sensor inserted under the skin [10]. CGM has been primarily utilized by patients with type 1 diabetes treated by intensive insulin therapy to make treatment decisions that promote glycemic control [11]. In recent years, the use of CGM has increased in primary care of patients with uncontrolled type 2 diabetes to improve patient’s self-management skills (i.e., treatment
adherence, lifestyle changes) [12]; demonstrating a broader application potential for CGM.

Related to the use of CGM for disease management, an increasing number of studies have begun to use CGM in research to examine the acute effect of dietary intake and physical activity on insulin concentrations and glucose metabolism in both diabetic [13-16] and non-diabetic populations [17-21]. For example, using CGM in free-living settings, Brynes and colleagues [13] demonstrated the beneficial effect of a low glycemic diet on 24-hr glucose profile in type 2 diabetic individuals, as well as in healthy young people [17]. In a controlled lab setting (whole-room calorimeter) with 2-day CGM assessment, DiPietro and colleagues found that both sustained (45-min) morning walking and short (15-min) post-meal walking improved 24-hr glucose profile in inactive older adults without diabetes [18]. Multiple behavioral theories (eg, self-determination theory, social cognitive theory) address the importance of perceived benefits and outcome expectancy in influencing changes in dietary and physical activity behaviors [22-24]. Since glucose is a biological marker that could be acutely impacted by diet and physical activity, the richness of data collected from CGM could potentially be used in health behavior interventions in a way to illustrate the immediate physiological consequences of one’s behavior and subsequently encourage behavioral changes (eg, biologically-based behavioral feedback).

Despite the growing utilization of CGM in diet and physical activity research beyond the diabetic population and its potential as a tool to promote diet and physical activity behavior change, questions have remained about the acceptability of CGM to non-diabetic individuals. As such, the goal of the current study was to describe the acceptability of CGM and compared it to other widely used mobile diet and physical activity data collection methods (ie, MyFitnessPal and an accelerometer) from a sample of non-diabetic individuals. Knowledge gained from these results intends to support the
use of CGM in diet and physical activity research and could inform the planning and development of future diet and physical activity studies that use CGM.

**Methods**

**Study Overview**

Data used for this study was from Project SENSE, an observational study aimed at testing the feasibility and utility of CGM to detect and characterize consummatory (eating and drinking) events in free-living adults without diabetes. All study participants gave their written informed consent. Project SENSE was approved by the Institutional Review Board at The University of Texas MD Anderson Cancer Center.

**Participants**

Adults were recruited through public and private announcements (e.g., email listserv, word-of-mouth) around the Texas Medical Center. Interested individuals contacted the study team to assess their eligibility to participate in the study. Eligible individuals were between 21-65 years old; able to speak, read, and write in English; and have a smartphone with Internet access. Individuals were excluded if they reported being diagnosed with diabetes, reported use of any medication known to affect glucose levels (eg, corticosteroids, anti-depressants, metformin), had fasting blood glucose >125 mg/dL as measured by glucometer, were pregnant or lactating, had a reported diagnosis of a chronic condition with dietary restrictions, eating disorder, or were unable or unwilling to use CGM.

**Procedures**

Interested individuals, who passed the initial eligibility screening, were invited for an in-person visit to have their fasting blood glucose measured by a commercially-available glucometer to confirm their eligibility and enroll in the study. Upon enrollment,
participants were introduced to the study equipment, which included a CGM system (Dexcom G4 Platinum, San Diego, CA), a glucometer for CGM calibration, a mobile app to track dietary intake (MyFitnessPal), and an accelerometer to measure physical activity. The 7-day self-monitoring period started after the completion of the in-person visit. Participants were asked to track all dietary intake and exercise events using both the CGM receiver and the MyFitnessPal app. Participants were told not to change their usual behaviors during the monitoring period. Participants came back for another in-person visit on day 8 to return the CGM system and the accelerometer and to complete an exit survey.

**Study Tools**

**CGM:** The Dexcom G4 Platinum CGM system included a sensor, transmitter, and receiver (Figure 1). Upon insertion and activation of the sensor, glucose levels were recorded every 5 minutes. The receiver screen displayed the real-time glucose reading, a trend arrow indicating rate-of-change, and a graph showing the glucose trend in the past 24 hours. In addition, the receiver had the function to mark (ie, time-stamp) eating events and exercise sessions. Additionally, participants were asked to record all eating and drinking of calorie-containing beverages using the receiver within 5 minutes of initiating the consummatory event. To ensure proper data transmission between the CGM transmitter and receiver, participants were asked to keep the receiver within 18 feet of them at all times. Lastly, with the Dexcom G4 Platinum CGM system, participants were
required to perform a finger prick calibration using the supplied glucometer set at least every 12 hours.

**Diet Tracking App:** Participants kept a detailed food log (ie, food and caloric-beverage consumed, portion size, time of consumption) using the MyFitnessPal mobile app. In addition, participants were asked to take a time-stamped photo of all food and caloric beverages consumed using their smartphone and email the images to the study coordinator at the end of each day. Food photos were used to confirm the time stamp marked in the CGM receiver for each of the recorded consummatory events. The MyFitnessPal app was also used by participants to enter all exercise events (ie, time, duration, and type).

**Accelerometer:** The ActiGraph GT3X was used to objectively measure physical activity. Participants wore the accelerometer on their waist during all waking hours, except when bathing or swimming.

**Measures**

**Acceptability:** A 10-item survey was developed to assess the acceptability of all study tools used in Project SENSE. The survey items were based on barriers and facilitators in the use of mHealth tools [25-28] such as convenience, value, and relevance. The response options were on a 5-point Likert scale, ranging from “Strongly disagree” to “Strongly agree.” All participants completed the survey during their exit visit. Two additional questions were later added to the survey to specifically ask about participants’ opinions on using CGM for health and wellness purpose: “How likely or willing are you to use a wearable glucose sensor, like the one you used in this study, to help you achieve your health and wellness goals (healthy eating or weight management)?” and “How likely or willing would you be to use a wearable glucose sensor to help you achieve your
health and wellness goals (healthy eating or weight management), if the sensor did not have to be inserted under your skin (i.e., non-invasive)?” The response options were on a 5-point Likert scale, ranging from “Very unlikely” to “Very likely.” Half of the participants answered these two questions.

**Statistical Analysis**

Statistical analyses were conducted using the Statistical Package for Social Sciences, version 24.0 (IBM Corp., Armonk, NY). Descriptive statistics were generated for all variables, including the mean and standard deviation for continuous variables and percentages for categorical variables. The Cronbach’s alpha ranged from $\alpha = .757$ (CGM sensor) to $\alpha = .853$ (MyFitnessPal). A summary score of acceptability was created for each study tool (i.e., CGM sensor, CGM receiver, MyFitnessPal, and accelerometer) by calculating the mean of the 10 survey items (the Privacy item was reverse-coded). Two-tailed paired-samples t-tests were used to examine whether the acceptability score was comparable between CGM sensor, CGM receiver, MyFitnessPal, and accelerometer. A p-value of .05 was considered significant.

**Results**

**Participant Characteristics**

A total of 66 individuals completed the eligibility screening. Eight were ineligible due to having been diagnosed with diabetes (type I or II); 4 were taking medication that would impact glucose levels; 2 had dietary intake restrictions due to health conditions, 1 was unwilling to have the sensor inserted; and 9 were due to other reasons (eg, age, time commitment, pregnancy, other health reasons). A total of 42 individuals, who passed the initial eligibility screening, were scheduled for an in-person visit to determine final
eligibility. Of these individuals, 8 did not attend their appointment and were unable to be rescheduled, and 4 had elevated fasting blood glucose levels.

A total of 30 participants enrolled in Project SENSE. They were on average 38 years old (SD = 13.2, range = 24-64). Seventy-three percent of the participants were female, 17% were Hispanic, and 64% were overweight or obese. Table 1 shows the detailed demographic characteristics of the participants.

Table 1. Participant characteristics (n=30).

<table>
<thead>
<tr>
<th></th>
<th>Mean (SD)</th>
<th>Percentage (n)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>37.9 (13.2)</td>
<td>-</td>
</tr>
<tr>
<td>Female</td>
<td>-</td>
<td>73.3 (22)</td>
</tr>
<tr>
<td>Hispanic</td>
<td>-</td>
<td>16.7 (5)</td>
</tr>
<tr>
<td>Overweight</td>
<td>-</td>
<td>46.7 (14)</td>
</tr>
<tr>
<td>Obese</td>
<td>-</td>
<td>16.7 (5)</td>
</tr>
<tr>
<td>College graduated</td>
<td>-</td>
<td>93.3 (28)</td>
</tr>
<tr>
<td>Full-time employed</td>
<td>-</td>
<td>73.3 (22)</td>
</tr>
</tbody>
</table>

Of the 30 participants, 3 participants experienced an unexpected failure of their CGM adhesive, which caused the sensor to be removed prematurely (2 participants had 4 wear days and 1 participant had 5 wear days). All other participants wore the CGM for the entire 7-day observational period.

Acceptability

Overall, more than 90% of participants agreed with the statements regarding usability, value, relevance, and confidence for both the CGM sensor and the CGM receiver. Table 2 shows the results from the acceptability survey for all tools used in Project SENSE. Of the 15 participants who answered the additional questions regarding using CGM for health and wellness purpose, 6 (40%) indicated that they were likely to do so using a similar CGM system, and 12 (80%) indicated that they were likely to do so if the CGM system become non-invasive.
<table>
<thead>
<tr>
<th>Acceptability Survey Item</th>
<th>CGM Sensor n (%)</th>
<th>CGM Receiver n (%)</th>
<th>MyFitnessPal n (%)</th>
<th>Accelerometer n (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Usability: This tool is easy to use and user friendly</td>
<td>28 (93%)</td>
<td>27 (90%)</td>
<td>28 (93%)</td>
<td>28 (93%)</td>
</tr>
<tr>
<td>Convenience: This tool is convenient for me to use in my everyday lives</td>
<td>22 (73%)</td>
<td>19 (63%)</td>
<td>22 (73%)</td>
<td>18 (60%)</td>
</tr>
<tr>
<td>Value: This tool is useful and beneficial</td>
<td>28 (93%)</td>
<td>29 (97%)</td>
<td>28 (93%)</td>
<td>23 (77%)</td>
</tr>
<tr>
<td>Relevance: This tool provides information that is of interest to me</td>
<td>27 (90%)</td>
<td>28 (93%)</td>
<td>27 (90%)</td>
<td>13 (43%)</td>
</tr>
<tr>
<td>Motivating: I am motivated to use this tool to track my daily behaviors</td>
<td>19 (63%)</td>
<td>20 (67%)</td>
<td>24 (80%)</td>
<td>11 (37%)</td>
</tr>
<tr>
<td>Tech Support: There is adequate availability and quality of professional assistance throughout use of this tool</td>
<td>21 (70%)</td>
<td>20 (67%)</td>
<td>21 (70%)</td>
<td>18 (60%)</td>
</tr>
<tr>
<td>Confidence: I feel confident that I use this tool correctly</td>
<td>29 (97%)</td>
<td>28 (93%)</td>
<td>27 (90%)</td>
<td>28 (93%)</td>
</tr>
<tr>
<td>Privacy: I am concerned about my privacy when using this tool</td>
<td>1 (3%)</td>
<td>1 (3%)</td>
<td>4 (13%)</td>
<td>1 (3%)</td>
</tr>
<tr>
<td>Recommend: I would recommend this tool to my friends and family</td>
<td>19 (63%)</td>
<td>20 (67%)</td>
<td>28 (93%)</td>
<td>14 (47%)</td>
</tr>
<tr>
<td>Like: I like using this tool</td>
<td>20 (67%)</td>
<td>23 (77%)</td>
<td>24 (80%)</td>
<td>17 (57%)</td>
</tr>
</tbody>
</table>

*aValues are number of participants who agreed or strongly agreed with the statement.*
Figure 2 shows the mean summary acceptability score for each data collection tool. The summary acceptability score was comparable between the CGM sensor and MyFitnessPal (mean diff. = -.04, n.s.), and the CGM receiver and MyFitnessPal (mean diff. = -.05, n.s.). Compared to the accelerometer, participants perceived a higher acceptability for both CGM sensor (mean diff. = .33, p < .01) and receiver (mean diff. = .32, p < .01).

**Figure 2.** Mean and standard deviation of acceptability score for each data collection tool

Discussion

Principal Findings

Results from the current study suggested high acceptability of using a CGM in a sample of free-living, non-diabetic adults. The overall acceptability for CGM sensor and receiver was comparable to the diet tracking app MyFitnessPal, and was higher than the waist-worn accelerometer. After wearing the CGM sensor and using the CGM receiver for one week, more than 90% of the study participants agreed that the CGM sensor and receiver
were easy to use, useful, and provided relevant information that was of interests to them. These results demonstrate a great potential for using CGM in non-diabetic adults as previous research has suggested that individuals will not engage with technology that is challenging to use or perceived as irrelevant to their needs [27,29].

Percent agreement was low for the statement regarding motivating for CGM sensor (63%) and receiver (67%). However, a post-hoc analysis showed that these scores were comparable to the one for MyFitnessPal (80%, p n.s.) and significantly higher than the one for the accelerometer (37%, p < .01). Potentially contributing to this finding is that both the CGM and the MyFitnessPal app provide feedback to the user regarding their glucose dynamics and their dietary intake, respectively; whereas, the accelerometer does not. Feedback that is person-specific, actionable, and goal-related tends to improve outcomes in interventions [30]. Furthermore, for Project SENSE, no specific explanations were given to participants about how their glucose pattern might reflect their behaviors (e.g., dietary intake or physical activity). Therefore, this lack of knowledge of how data from CGM might be related with their behaviors might have contributed to a low motivation score. To increase motivation, future studies considering the use of CGM might want to provide a few examples of the potential effects of dietary intake and physical activity on glucose levels (e.g., glucose will rise sharply after consuming high carbohydrate food; the more you move the more glucose you burn).

The CGM receiver also had lower percent of agreement (63%) for the statement regarding convenience. It is worth noting that the CGM model used in the current study (Dexcom G4) required the receiver to be within 18 feet of the sensor at all times to ensure proper data transmission. Therefore, participants might have found it burdensome to always carry an additional device with them. Nevertheless, the need of having a receiver is being phased out in newer CGM models. For example, Dexcom G5 and G6 users can have the option to download a mobile app and use their smartphone.
to receive and view glucose data instead of the receiver. For FreeStyle Libre CGM users (Abbott, Alameda, CA), a receiver (ie, reader) is only needed at the time of retrieving glucose data (through scanning the reader over the sensor). Hence, as the technology for CGM system keeps advancing, it is expected that the concern regarding convenience will be minimized.

**Limitations**

Although the current study was among the few that used CGM in a sample of non-diabetic adults and was the only one that assessed participant acceptability, it had some limitations. First, the study was not powered to formally test any difference in acceptability across different study tools (i.e., CGM, mobile app, and accelerometer). Second, majority of the study participants were highly educated and female. Therefore, findings from this study might not be generalizable to individuals with lower socioeconomic status.

**Implications and Conclusions**

The continued advancement in technology will further diversify the use of wearable devices and foster innovative approaches in diet and physical activity research. CGM represents one type of biological sensor that has the potential to provide personalized physiological data for a biomarker that is closely related to dietary and physical activity behaviors. These data could potentially be used to present the immediate or short-term (eg, past 24 hours) physiological consequences of dietary and physical activity behaviors as a strategy to encourage positive changes in those behaviors [21]. The ability to frequently assess a marker related to a behavioral goal is the foundation for providing just-in-time feedback that could ultimately optimize strategies for impactful behavioral changes [30].
Results from the current study suggested that although healthy individuals did not mind wearing a minimally invasive CGM device for one week, the motivation for wearing was moderate, possibly due to the lack of ability to interpret or make sense of all the data that was available to them. As the barriers to tracking and collecting health behavior data are overcome by technological advancements, the challenges ahead will be determining how to most efficiently and effectively use these data to provide meaningful insights and useful feedback to users. Thus, more behavioral research that utilizes CGM and other biological sensors is needed to offer evidence-based recommendations that assist individuals with their behavior change goals.

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**Conflicts of Interest**

None declared.

**Abbreviations**

CGM: continuous glucose monitors
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