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Research and Applications

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Toward a precision behavioral medicine approach to addressing high-risk sun exposure: a qualitative analysis

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ABSTRACT

Objectives: Precision behavioral medicine techniques integrating wearable ultraviolet radiation (UVR) sensors may help individuals avoid sun exposure that places them at-risk for skin cancer. As a preliminary step in our patient-centered process of developing a just-in-time adaptive intervention, this study evaluated reactions and preferences to UVR sensors among melanoma survivors.
Materials and Methods: Early stage adult melanoma survivors were recruited for a focus group ($n = 11$) or 10-day observational study, which included daily wearing a UVR sensor and sun exposure surveys ($n = 39$). Both the focus group moderator guide and observational study exit interviews included questions on UVR sensing as a potential intervention strategy. These responses were transcribed and coded using an inductive strategy.
Results: Most observational study participants (84.6%) said they would find information provided by UVR sensors to be useful to help them learn about how specific conditions (eg, clouds, location) impact sun exposure and provide in-the-moment alerts. Focus group participants expressed enthusiasm for UVR information and identified preferred qualities of a UVR sensor, such as small size and integration with other devices. Participants in both studies indicated concern that UVR feedback may be difficult to interpret and some expressed that a UVR sensor may not be convenient or desirable to wear in daily life.
Discussion: Melanoma survivors believe that personalized UVR exposure information could improve their sun protection and want this information delivered in a method that is meaningful and actionable.
Conclusion: UVR sensing is a promising component of a precision behavioral medicine strategy to reduce skin cancer risk.

Key words: sun protection, just-in-time adaptive intervention, mobile health, precision medicine, ultraviolet radiation

INTRODUCTION

One in five adults in the United States will be diagnosed with skin cancer sometime in their lifetime, making skin cancer the most commonly diagnosed cancer.[1,2] This malignancy is largely preventable through sun protection (eg, sunscreen).[3] Although public sun protection knowledge has improved in recent decades[4], unprotected sun exposure and sunburn, are frequently reported,[4,5] even among at-risk populations.[6]

Precision behavioral medicine may help to address unprotected sun exposure. Drawing on the promise of precision medicine to improve outcomes by providing medical treatment that fits with highly specific biological characteristics (eg, genetic mutations), precision *behavioral* medicine is a burgeoning area of research focused on delivering effective behavioral interventions based on precisely measured participant characteristics, contexts, moods, and behavior.[7,8] Accordingly, the goal of precision behavioral medicine is to use known predictors of behavior, such as genetic predisposition, biology, environment, and past behavior to determine *who* benefits most from an evidence-based intervention and *when* and *how* such interventions should be delivered.[9]

Precision behavioral medicine can take the form of "just-in-time" adaptive interventions (JITAIs), which apply detailed information about an individual's context and behavior in order to deliver the most effective in-the-moment intervention.[10] Development of JITAIs requires extensive preliminary work, including evaluation of the mechanisms underlying the targeted health behavior and intervention adherence, ecological momentary assessment (EMA) studies to identify the timing and context of a behavior, and micro-randomized trials (MRTs)[11] to determine the appropriate timing and type of in-the-moment interventions to deliver. For instance, in a JITAI for sedentary behavior, the current amount of participant sedentary time (the tailoring variable) is evaluated at various decision points throughout the day using decision rules that determine whether and how an intervention will be delivered.[12] In this example, users who have been sedentary for 30 minutes or longer as determined by a personal monitoring device, and for whom contextual information (eg, schedule) indicate they are able to move from a sitting position, may be sent a prompt to take a walk. The goal of this intervention is to influence a proximal outcome (ie, immediate walking behavior), which in turn influences a more distal outcome (ie, total daily minutes spent on walking breaks).

Similarly, adaptive interventions may be developed for unprotected sun exposure among people at-risk to develop skin cancer. Personal UVR monitoring using an application-connected wearable sensor is a technological solution that may be well-suited for providing information needed to conduct JITAIs. Electronic UVR dosimeters provide time-stamped readings of the UVR reaching the device in the unit of joules/m^2 and have been used in several large studies.[13,14] Technology now exists to deliver UVR sensor data to connected smartphone applications (apps), but very little research has addressed patient preferences on methods to understandably present this data, at what times personal UVR data would be helpful, and how individuals anticipate taking action based on personal UVR data. In the present study, which is a starting point for developing a sun exposure JITAI (Figure 1), we analyze qualitative data on participants' reactions to the use of precision behavioral medicine techniques, including the use of UVR sensors for addressing sun exposure. Qualitative data were derived from focus groups and exit interviews of melanoma survivors following a 10-day observational study using UVR sensors.

METHOD

Participants

All participants were adult melanoma survivors who had previously participated in a study on skin self-examinations and resided in the greater Chicago area.[15] All participants had completed treatment for melanoma stage 0-IIb. Participants were recruited by phone or email. Eligibility criteria did not differ between the focus groups and observational study.

Procedure

Focus groups and exit interviews were used to assess patient preferences. Procedures were reviewed and approved by the Institutional Review Board at Northwestern University. Participants who enrolled in the focus group participated in one of two moderated discussions after providing informed consent. Focus groups took place in person and were moderated by the lead author. Prior to the session, participants provided informed consent. SMH was also present during the focus groups to take notes. The moderator guide included a section on preferences for technology-based intervention strategies. Intervention strategies evaluated included: print-based education modules, texts/emails, passive monitoring using UVR sensors, high UVR alerts, online sun protection "diaries," and feedback on sun protection on specific body sites. For each strategy, the group was asked open-ended questions.

Focus groups were conducted to allow for the efficient collection of viewpoints from multiple individuals and to support interaction among members of the group that may identify concerns and elicit reflection from other members. Two focus groups were conducted to allow iterative changes in the probes used by the moderator while also identifying most important themes.[16] The focus group study occurred earlier in the summer than the observational study.

For the observational study later that year, we aimed to recruit 40 participants in order to reach power requirements for our primary analyses on measurement validation;[17] far fewer participants are typically needed for interview research.[18] Participants in the 10-day observational study first attended a baseline session in which they provided informed consent, completed surveys (analyzed elsewhere),[17] and learned about the UVR sensor they would wear over the next 10 days. Participants were asked to wear the sensor on their shirt near their left collar during daylight hours. The UVR sensor used in this study was Shade® model V1.00, YouV Labs Inc., NY, which at the time of this study was commercially available for $250 and was the most accurate device available to consumers (Supplementary Figure 2s).[19] It was connected to a smartphone app that synced with the UVR sensor at least once each day. The app displayed UVR received each day. Each evening, participants were reminded to use their smartphone to download their sensor data and to complete online surveys on their outdoor activities and sun exposure. After 10 days, participants returned to the laboratory to complete additional surveys on sun exposure as well as an audio-recorded exit interview on their experiences with the UVR sensors. The relevant focus group and exit interview questions are listed in a Supplementary file.

Analysis plan

Interviews were transcribed and then reviewed by TKS, JKR, and SMH. Open-ended questions in both focus groups and exit interviews were coded using an inductive strategy. The authors first generated a list of codes to summarize content pertaining to opinions and reactions to personalized information about sun exposure. These lists were then reviewed with conceptually meaningful codes merged or grouped into a general theme. TKS used this coding scheme to code each transcript and report the presence or absence of each code (see Table 1). SMH reviewed both focus group transcripts and randomly selected exit interview transcripts. Double-coding proceeded until the coders reached 80% agreement; 33% of the exit interview transcripts were coded by both TKS and SMH.

RESULTS

Participants

All study participants identified as White/Non-Hispanic. Among the eleven participants in two focus groups, 55% were female, and ages

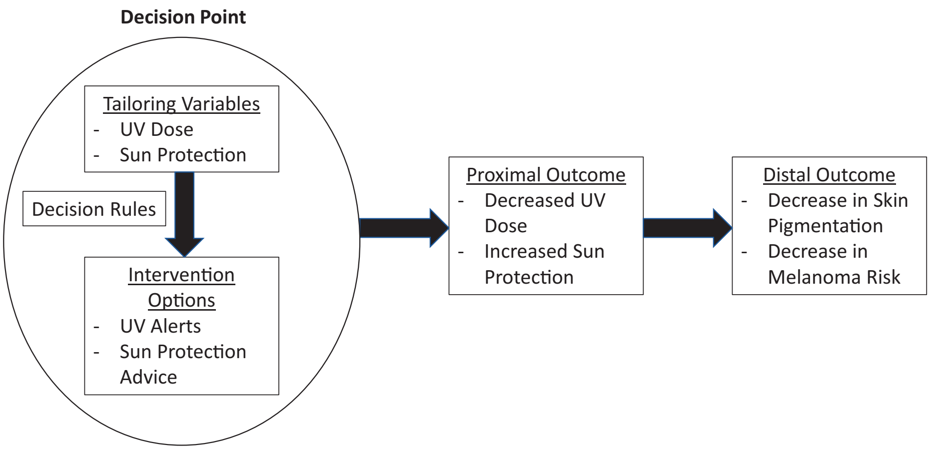

Figure 1. Basic components of a just-in-time adaptive intervention for high-risk sun exposure.

Table 1. UVR sensor usage and notification suggestions (in response to open-ended questions), $n = 39$

Exit interview category	Code	*n* (%)
Duration of wear and feedback timing		
	Longer-term: Display of trends or averages over time (months)	11 (28.2)
	Shorter-term: Use as a temporary learning tool or to learn about how new activities affect sun exposure (days/weeks)	2 (5.1)
Impact of specific conditions on UVR		
	Cloudy days	3 (7.7)
	Shade	3 (7.7)
	Different locations and activities	4 (10.3)
	Time of day	4 (10.3)
In-the-moment alerts		
	Sunscreen reapplication	2 (5.2)
	Current high UVR/Out too long	10 (25.6)
Other responses		
	UVR data would be more informative if it incorporated sun protection	8 (20.5)
	Wearing sensor makes more conscious of sun protection	11 (28.2)
	UVR sensors would help to be less worried when outdoors	4 (10.3)

ranged from 28 to 65 ($M = 46.82$, $SD = 13.08$). Of the 39 observational study participants, 61.5% were female, and ages ranged from 28 to 84 ($M = 58.59$).

Focus group themes

Greater enthusiasm for UVR information compared to other intervention strategies

In general, participants were not interested in logging their sun protection on an online or paper log. For instance, one participant said: "I think it's just like calorie counting, when you're at it, you just don't record. That's reality. I just wouldn't do that log when it's a bad day." (F6) Likewise, participants were also not particularly interested in feedback on their use of sun protection. Many expressed that they already should know how well they were doing with sun protection. Others mentioned that their indicator of sun protection quality would simply be how much their skin had changed color: "Like if I was out in the sun for an hour, I'm going to have a different skin color." (F2)

When presented with printed education on sun protection, participants expressed that this information was too basic to be useful. For instance, participants statements included that "everyone knows this" (F4) and that it was "preaching to the choir" (F5). In contrast, information on UVR was perceived as more interesting and useful. For instance, after viewing the other intervention strategies, a participant noted,

> "I think what would be helpful is stuff you're not aware of, so if there was some kind of chip or something that gauges when you're outside and getting sun when you don't remember … then you don't have to think about it or report it, you know … it just comes back and you plug your phone in and it says oh, you know, here's your weekly log for you." (F11)

When presented with the screenshot of an app, which showed the Ultraviolet Index forecast for Chicago, a participant said, "This is kind of interesting to me… .maybe you don't think about reapplying or, so this to me would get my attention and serve as a reminder. Yeah and it's just presented in a way that I haven't seen before." (F10) Participants indicated that this information could capture their attention and be something that they check daily, similar to a weather forecast. Participants were enthusiastic about the use of UVR sensors, saying it was "very cool" (F10) and suggesting that it would be most useful if it were connected to a mobile application.

Achieving a UVR sensor size, position, and qualities that are functional for daily life

Participants questioned the appropriate body location for a UVR sensor: "Is the idea that you only wear one of them, like for example, this hand is my golf hand when I used to play golf, but it's always covered up by a glove, right? … [M]aybe your shoulder blades, get it a lot, you know…"(F8). This participant also added that by placing the sensor on more than one body site "[i]t's also an educational tool, over time, you figure out that one part of your body might get more." (F6). Participants indicated that they would be more interested in UVR-sensing devices that are "waterproof and sunscreen-proof" (F10) and "sand-proof" (F3). Appearance was also a concern, with several participants expressing a desire for a small device in attractive colors.

Several participants indicated interest in adding a UVR sensors to products they were already wearing or using, such as "adher[ing] it to the side of your sunglasses." (F10) Participants suggested a wrist-worn version of the device, and several expressed interest in integrating a UVR sensor into a fitness tracker they were already using. For instance, one said, "if it could be integrated in a Fitbit with a sensor, that's like a real sweet spot. So multipurpose like that, I think that would be much more realistic and more functional." (F2)

UVR sensor timespan of use and feedback

Participants provided mixed input on how long they would want to use a UVR sensor. Some viewed it as a temporary learning tool. For instance, one participant said, "I might do it as a short-term experiment…[j]ust to kind of get a sense, I know that you can adjust accordingly." (F11). Another added, "we'll just say you wear it for a month. Over this, June or July or whatever it is, and I think getting that data back would give you a pretty good idea how long, in other words, you wouldn't always wear that, wear it for three years." (F5) Likewise, other suggestions included that it would be useful "if you change up routines. Let's say you haven't been on a rafting trip before or you move, so something is different" (F10). In contrast, others expressed interest in learning their longer-term trends in UVR exposure. One participant said, "And I'm young enough where I would be wearing it for many, many years… [S]ay you did it for two years, and you're constantly wearing the device, you would really get to know the numbers and like, you would start to understand." (F2).

Preference for meaningful and actionable information

The above participant further elaborated that this timespan would give an opportunity to more fully understand the kind of information provided by the device: "Like now it wouldn't make much sense to me if I just started getting numbers of what kind of UV I was getting, doesn't make sense, I have no benchmark for that. But over a long period of time, maybe it would be interesting to, you know, wear it and see the numbers." (F2) Likewise, another participant had concerns about understanding the data, indicating she would likely not wear the device "…unless there was an app or some tool that would help you interpret the data, and what is, then is it not just like each of us have different sensitivities?" (F11)

Participants valued the real-time feedback that a UVR monitoring system could provide and believed it should ideally have the ability to log and provide reminders of sunscreen application times, ideally on the actual device—"Yeah, just like a button" (F11)—and suggested that the device could chime, speak, or change colors to indicate reapplication time.

Observational study

Table 2 quantifies the responses to close-ended questions asked during exit interviews following the 10-day observational study. Although only about half of the participants indicated that they would be willing to wear the UVR sensor in their daily life, the vast majority believed that personal information of UVR exposure would be helpful. Those who did not believe this information would be useful tended to be of an older age ($M = 68.5$, $SD = 13.44$), and expressed

Table 2. Responses to close-ended interview questions on wearing the sensor during daily life ($n = 38$), whether participants were surprised by result ($n = 33$), and whether UVR information would be useful ($n = 39$)

Exit interview category	Responses	n (%)
Wear in daily life	Yes	19 (50.0)
	Maybe	8 (21.1)
	No	11 (28.9)
Surprised by results		
	Yes	13 (39.4)
	No	20 (60.6)
	Found metric unclear[a]	23 (59.0)
UVR information would be useful		
	Yes	33 (84.6)
	No	6 (15.4)

Note: Due to device malfunctions with the UVR sensor, not all questions were asked of all participants. Percentages are calculated among those who were asked the relevant question.

[a]Spontaneous response provided by several participants while elaborating on their response to the close-ended question.

that they had already established strong knowledge or habits related to sun exposure: "I can't imagine that, at this stage in my life I'm going to change my habits too much." (O16) When presented with a figure displaying their UVR dose each day during the previous 10 days, about 40% were unsurprised by the results. Even among those who were not surprised, several mentioned finding the metric of the UVR dose unclear. For instance, one participant said, "it was kind of meaningless to me" (O37). Another asked, "What is considered high, low, medium?" (O40) Exploratory analyses compared responses by gender and melanoma stage and did not reveal sizeable differences in these responses between subgroups (see Supplementary Table 1).

UVR sensor timespan of use and feedback

While most participants in exit interviews would be willing to use a UVR sensor in their daily life, participants expressed varying opinions about how long they would want to wear the device. Some viewed the device as similar to other health tracking devices, which they would wear over a long period:

> "like I keep track of how many steps I get, or how many miles I ride… It's part of health, right, so I think it could be a health application, and I think that I would use it if it was on my phone just to keep track of, you know, if I was able to download that information every night so that I could see what I was exposed to and where I could change my habits." (S19)

Others viewed the UVR sensor as a short-term learning tool. Some expressed the sensor may have been most useful during the time immediately following their melanoma diagnosis, when they were first implementing changes to their sun habits. Others mentioned that they believed the sensor would be particularly useful to learn about how changes to their outdoor activities influenced their degree of sun exposure.

Impact of specific conditions on UVR

Related to the use of the UVR sensor as a learning tool, participants expressed interest in using the UVR sensor to learn about how specific conditions (eg, cloudy days, shade, location, and time of day) impact UVR levels. For instance, one participant noted, "you realize 60 minutes in the sun between this hour and this hour, the difference is literally twice. You know, I think to quantify it, you know, it might make you think twice about [it]." (O40).

In-the-moment alerts

Participants were interested in receiving in-the-moment alerts based on the information provided by the UVR sensors. Suggested alerts included notifications about the current UVR being high, that they personally had received too much sun exposure, or that they should now reapply sunscreen. For instance, one participant mentioned that the UVR sensor would be useful "if it could tell you at what point is too much UVR, or at what point you would get a sunburn or something." (O22)

Other responses

Throughout the exit interviews, participants generated several additional ideas about how and when personalized information about sun exposure would be helpful. For instance, several mentioned that UVR information would be more informative if it incorporated sun protection; "Is there a way to quantify the fact that you had a hat, you had long pants—so, that '60' really comes down to 30. Is there something like that?" (O40). A few also expressed that the UVR sensor might make them feel comfortable going outdoors more; as one survivor explained, "I'm 8 years now of survivor. So, in the beginning I never went outside and that was prison for me because I'm an outside person, I do lots of things outside, so that information would have been really helpful to know that I could have gone outside during the times when it's not so sunny and I can also make sure I protect myself." (O19)

DISCUSSION

Personalized behavioral medicine techniques, such as JITAIs, have the potential to help individuals more effectively engage in sun protection behaviors, potentially leading to decreased risk of skin cancer. In the present study, we adopted a patient-centered approach to evaluate reactions and preferences regarding wearing and using UVR sensors to monitor sun exposure expressed by melanoma survivors—a population at risk to develop another skin cancer from unprotected sun exposure. Qualitative analysis revealed that melanoma survivors believed that personalized UVR exposure information could improve their sun protection in several ways that other strategies do not. In exit interviews, most of the sample reported they believed UVR sensors would be useful, and many expressed interest in feedback and alerts from a UVR sensor. Some participants suggested that the UVR sensor could serve as a learning tool to help them understand how changes to their habits would influence sun exposure, as well as how specific conditions, such as shade and time of day, influence sun exposure.

Despite this enthusiasm for information about personal UVR exposure, it is important to note that melanoma survivors expressed concern that UVR information be presented in a way that is meaningful and actionable. When presented with a chart showing their UVR dose each day, over half of the participants in the observational study responded that this information metric was unclear—that they had no basis for interpreting what levels were "high" and represented a potential danger. Others added that the UVR dose displayed on the app represented the UVR received by the sensor and did not adjust for their use of sun protection. Integration of sensor data with activity-based self-reports of sun protection may help to address this limitation.

Also, many participants indicated that they would not routinely wear the device in their daily lives. Although no participants reported a high degree of distress or indicated that appearance concerns prevented them from wearing the sensor during outdoor time, the concerns about device appearance and location on the chest, near collar will be important to address. Wearable sensors that evoke perceived stigma can impact compliance with device wear.[20] The potential for this perceived stigma will be especially critical to monitor among lower risk populations, which may not be as enthusiastic about receiving feedback on UVR exposure as melanoma survivors. Manufacturers may be able to ameliorate appearance and stigma concerns by following our participants' suggestion to create a small, wrist-worn sensor, ideally integrated with another device.

Future directions in the development of a JITAI for sun exposure

While these results provide initial support and important considerations for proceeding with a JITAI targeting sun exposure (see Figure 1) among high-risk users, additional research is need to address several important issues. First, research is needed to identify the optimal tailoring variables, decision points, and intervention. For sun exposure, prior interventions have provided alerts based on time elapsed since sunscreen application and forecasted UVR levels,[21] or text or email reminders to use sun protection,[22] but these studies have not used MRT designs to evaluate the immediate impact, or optimal timing and type, of intervention. Second, effective in-the-moment intervention depends on providing understandable information about UVR exposure, which is usually communicated in terms of the UV Index.[23,24] For personal UVR exposure, the standard erythemal dose (SED[25])—a standardized measure that correlates with potential to burn depending on skin type[26]—may be a useful metric. In a prior analysis of SED values for the present sample, about 15% of participants exceeded their skin-type-specific sunburn threshold[27]; delivering a warning about reaching a UV exposure that may cause sunburn may lead to improved sun protection. Third, to develop and evaluate a JITAI, the behavior targeted must be quantifiable, ideally objectively. In contrast to physical activity research, in which objective metrics (eg, Actigraph[28] and ActivPAL[29] accelerometers) are routinely used,[30] sun exposure is more difficult to objectively assess. Existing measures—UVR photography,[31] serum measures of vitamin D, and reflectance spectroscopy[32]—are imperfectly related to sun exposure and lack the in-the-moment precision needed to provide a "just-in-time" intervention. In contrast, electronic UVR sensing can provide a precise, real-time measure of sun exposure (albeit one that does not currently account for sun protection).

LIMITATIONS

Although this study provides information that will inform future steps toward developing a JITAI for sun exposure, it is not without limitations. The study sample was restricted to white melanoma survivors, who, due to their cancer history, may have been especially receptive to UVR sensing technology. Also, participants used just one type of UVR sensor; it is possible that they would have provided different feedback if they had been exposed to other types of devices and feedback formats.

CONCLUSIONS

UVR sensing is a promising component of a precision behavioral medicine strategy to reduce skin cancer risk. Research is needed in order to further define the elements of a just-in-time adaptive intervention for sun exposure, especially optimal behavior measurement, intervention timing, and methods of providing informative feedback on UVR exposure.

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CONTRIBUTION STATEMENT

TKS: Qualitative coding; Writing—original draft, review and editing. BS: Data interpretation; Writing—review and editing. SHM: Qualitative coding; Writing—review and editing. NA: Conceptualization; Writing—review and editing. JKR: Conceptualization, Data collection, Writing—review and editing.

SUPPLEMENTARY MATERIAL

Supplementary material is available at *Journal of the American Medical Informatics Association* online.

COMPETING INTERESTS STATEMENT

The authors do not have competing interests to declare.

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