Preventive Medicine Reports 11 (2018) 305–311

Contents lists available at ScienceDirect

Preventive Medicine Reports

journal homepage: www.elsevier.com/locate/pmedr

Daily Minutes of Unprotected Sun Exposure (MUSE) Inventory: Measure description and comparisons to UVR sensor and sun protection survey data

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ARTICLE INFO

Keywords:
Measurement
Sun protection
Concurrent validity
Self-report assessment
UVR
Skin cancer

ABSTRACT

One in five US adults will be diagnosed with skin cancer. As most skin cancers are attributable to sun exposure, this risk factor is an important target for research and intervention. Most sun exposure measures assess frequency of specific sun-protection behaviors, which does not account for the use of multiple, potentially overlapping sun-protection methods. In contrast, the Daily Minutes of Unprotected Sun Exposure (MUSE) Inventory assesses sun-protection behavior during self-reported activities, providing several useful metrics, including duration of unprotected sun exposure on 17 body sites, combined to yield an overall MUSE score weighted by percent of body exposed. The present study was conducted July–September 2017, in Chicago, IL USA. For 10 days, participants (39 melanoma survivors; $M_{age} = 58.59$, 64.5% female) wore an ultraviolet radiation (UVR) sensor and completed the Daily MUSE Inventory each evening. The Sun Habits Survey was completed at the end of the study. Outdoor time reported in the MUSE Inventory significantly predicted outdoor time recorded by UVR sensors, $B = 0.53, p < .001$. For all sun-protection behaviors except shade, reports from the Daily MUSE Inventory (i.e., percentage of outdoor time a particular strategy was used) correlated with frequency ratings of the same strategy from the Sun Habits Survey ($rs = 0.66$–0.75, $p < .05$). In sum, the Daily MUSE Inventory corresponds with sensor and survey data, and provides a novel metric of unprotected sun exposure that will be useful for evaluating overall extent of sun exposure, including exposure on several smaller body sites that are at high risk for skin cancer.

1. Introduction

One in five US adults will be diagnosed with skin cancer in their lifetime (Stern, 2010) and rates continue to rise (Rogers et al., 2015; Glazer et al., 2016). The primary method to prevent skin cancer is reducing sun exposure (Koh et al., 1996; Parkin et al., 2011; Armstrong and Kricker, 2001). Despite improved public knowledge about skin cancer in the last few decades (Baum and Cohen, 1998), unprotected sun exposure, and even sunburn, remain frequently reported (Bränström et al., 2010), with 37.1% of US adults reporting a sunburn in the past year (Holman et al., 2014). Thus, there is a need for additional research and interventions on sun protection.

For this research, valid measures of unprotected sun exposure are necessary. The most objective measure of real-time personal ultraviolet radiation (UVR) exposure – electronic UVR dosimetry – assesses exposure duration and intensity, but it cannot account for sun protection without self-reports. Currently, the most widely used self-report measure of personal sun protection and exposure in the US is the Sun Habits Survey, which assesses the frequency of sun-protection behaviors on warm summer days (Glanz et al., 2008). Diary measures have also been developed to capture daily-level sun behavior and have taken various forms, including asking about outdoor time during specific windows of time (Cust et al., 2018; O'Riordan et al., 2009; Cargill et al., 2013; Chodick et al., 2008) or asking the length of time participants were

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https://doi.org/10.1016/j.pmedr.2018.07.010
Received 16 March 2018; Received in revised form 20 June 2018; Accepted 21 July 2018
Available online 24 July 2018

engaged in specific sun-protection behaviors (Hillhouse et al., 2012).

An important limitation of these measures is that they do not provide a score representing overall sun protection. Because effective sun protection can be achieved by using any of several sun-protection methods, simply summing or averaging frequency-based measures may misrepresent extent of sun protection. For example, a person who "always" uses protective clothing, but "never" uses sunscreen could inappropriately receive a lower score than a person who "often" (but not "always") practices several methods and remains unprotected some of the time. Similarly, use of individual sun-protection methods is often inconsistent and there is great variability in sun-protection behaviors both within and between persons (Hay et al., 2017). This variability makes it difficult to assess change over time in overall UVR exposure because it is unclear whether changes to individual methods result in changes in overall protection – for instance, a person may reduce their sunscreen use but still retain the same level of protection if using protective clothing to cover exposed areas.

While diary measures provide more specific information about sun-protection behaviors, current versions do not yield sufficient data on the overall thoroughness of these behaviors (e.g., body sites to which sunscreen is applied). The Daily Minutes of Unprotected Sun Exposure (MUSE) Inventory uses an activity-based recall method (Hillhouse et al., 2012) to address these limitations and provide scores representing duration of unprotected sun exposure after accounting for whether any sun-protection method was used to protect specific body sites during outdoor activities. The present study assessed concurrent validity of the MUSE Inventory with both the Sun Habits Survey and UVR sensors among a sample of melanoma survivors in the US.

2. Method

2.1. Participants

Participants were adult melanoma survivors who had previously enrolled in a study that provided skin self-examination to adults following treatment for melanoma stage IIb or lower (Robinson et al., 2016). Participants were required to have daily access to a computer and wireless internet. They received a $100 gift card as compensation.

2.2. Procedures

All study visits were completed between July and September 2017 in Chicago, IL, USA. At baseline, participants provided informed consent and received instruction on using the UVR sensor and study smartphone. Participants were instructed to wear the sensor near their left collar during daylight hours and to use the smartphone to download the sensor data each evening. Each evening for 10 days, participants were emailed a link containing the MUSE Inventory, reminders and instructions for performing the device download, and an online form to record any download or device problems. Participants then returned to the laboratory and completed a single administration of the Sun Habits Survey referring to the last 10 days.

2.3. Measures

2.3.1. Sun Habits Survey

Using the Sun Habits Survey (Glanz et al., 2008), participants rated their frequency of using specific sun-protection methods (e.g., shirt with sleeves) on a warm, sunny day, using 5-point Likert scales ranging from 1 (Never) to 5 (Always). Participants indicated duration of outdoor time during peak hours (10 AM–4 PM) on weekdays and weekend days, using a rating scale ranging from 1 (30 min or less) to 8 (> 6 h).

2.3.2. Daily MUSE Inventory

The Daily MUSE Inventory is a computerized measure, currently administered via REDCap (Harris et al., 2009), which assesses sun exposure based on the outdoor activities that a participant completes during a particular reporting window (Appendix A). This measure was initially developed and pilot-tested among 128 individuals with a familial history of melanoma (Aspinwall et al., 2018). The daily version of the measure was administered in a 14-day study of 50 participants with elevated melanoma risk (Stump & Aspinwall, 2017). Following the study, participants were interviewed about their use of the measure, including any aspects of the measure they found confusing or burdensome, which resulted in additional refinements (e.g., instruction clarification). In the present study, participants were asked to report details of all outdoor activities performed for > 15 min between 6 AM and 6 PM. Participants first entered an activity description, added start and end times, and then reported the clothing they were wearing by selecting pictures of clothing options with varying coverage, represented by 5 pictures each, for four separate body regions (head, torso, legs, and feet). Additional items assessed shade, whether they sweated or got wet, and use of accessories (e.g., sunglasses, gloves). Participants then reported all instances of sunscreen use, including time of day applied (or reapplied), body sites covered, and the SPF of the sunscreen. The Daily MUSE Inventory yields several sun exposure metrics, summarized in Table 1.

2.3.3. Sun-protection behavior percentages

To enable analysis of the association between measures, percentages of outdoor time participants employed each of several main sun-protection strategies (wearing hat, sunglasses, sunscreen, shirt with sleeves, or seeking shade) were computed based on MUSE Inventory responses. Specifically, for each behavior assessed by the Sun Habits Survey, the durations of all activities during which the behavior was performed were summed and then divided by total duration of all activities reported during the 10-day period. For sunscreen use, duration of use was computed by determining how long an activity time overlapped the two-hour window beyond initial sunscreen application. The effective time of the sunscreen was shortened to 80 min if the participant reported sweating or getting wet "a lot" during an activity, consistent with US Food and Drug Administration regulations indicating that 80 min is the maximum effective time for water-resistant sunscreens following heavy sweating or submersion (US Food and Drug Administration, 2017).

2.3.4. MUSE scores

MUSE scores represent the duration of unprotected sun exposure an individual received in a single day. Scores were computed separately for individual body sites and as an overall MUSE score, which considers both the total percentage of the body's surface area that was unprotected and duration of exposure. Body site surface area was estimated by referencing charts used to characterize the extent of burns (see Fig. 1) (Wedro, 2012; Zinn, n.d.). All clothing was considered equally effective at blocking UVR to simplify scoring algorithms and prevent the respondent burden of answering additional questions about fabric characteristics for each clothing item. To illustrate these calculations, we provide an example of a woman doing yardwork for 4 h while wearing a brimmed hat, T-shirt, shorts, and tennis shoes (see Fig. 2). Assuming no additional sun-protection strategies are used, this clothing combination leaves parts of her arms and legs exposed, which comprise 38.5% of her body. The scoring algorithm adjusts time outdoors (240 min) for this percentage of unprotected body surface area by multiplying these values, yielding an overall MUSE score of 92.4. In variations 1, 2, and 3, the protection provided by sunscreen with reapplication after 2 h, protective clothing (long sleeves, long pants, gloves), and deep shade, respectively, reduces MUSE scores to 0, while sunscreen that is not reapplied during this lengthy exposure provides sun protection for only the first 2 h (variation 4).

2.3.5. UVR sensor

The Shade UVR sensor assessed minutes of outdoor exposure

Table 1
Metrics derived from the Daily Minutes of Sun Exposure (MUSE) Inventory as implemented in this study.[a]

	Possible range	Summary
Summary metrics		
Overall MUSE score	0–676.8[a]	Minutes outdoors per day, weighted by percentage of body that was unprotected from sun exposure
Average % body exposed	0–94%	During time spent outdoors, average percentage of total body surface area exposed to the sun
Time outdoors	0–720	Minutes outdoors per day, regardless of sun protection use
Specific metrics		
Sun-protection behavior percentage	0–100%	Percentage of outdoor time during which use of specific sun-protection methods (brimmed hat, shirt with sleeves, sunglasses, sunscreen, and shade) was reported
Body-site MUSE scores	0–720	Minutes of Unprotected Sun Exposure calculated for individual body sites, from scalp to feet

The maximum body exposure is 94% because the MUSE Inventory does not assess protection of the genital and buttocks regions.
[a] For this study, the reporting window was restricted to 6 AM to 6 PM; the use of different reporting windows would alter these values.

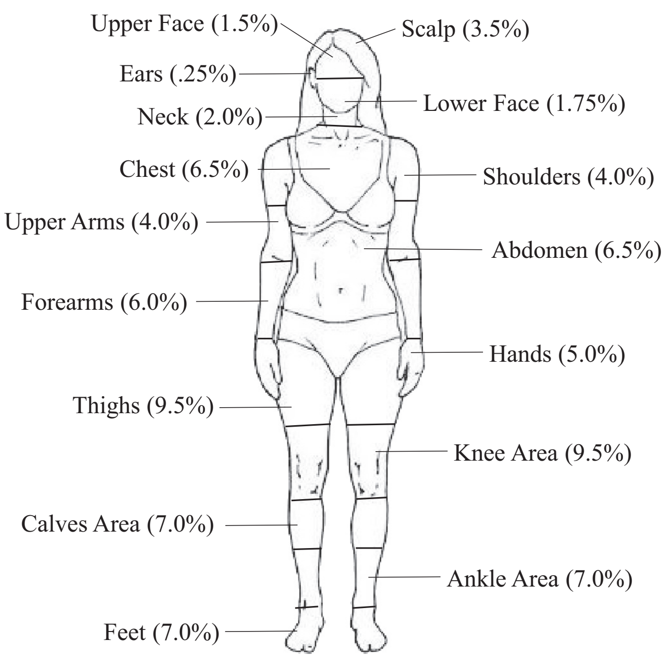


Fig. 1. Body site labels and surface-area percentages used for Daily MUSE Inventory scoring.

(Banerjee et al., 2017). The Shade UVR sensor (model V1.00, YouV Labs Inc., New York, NY) is a wearable, patented system that connects to the Shade mobile app (iOS version > 7.7, Android version > 4.4) via Bluetooth Low Energy. This device maintains an internal data log of accumulated UVR dose (J/m^2) every 6 min; estimates of exposure minutes are rounded up to the closest multiple of 6. Because the Daily MUSE Inventory instructed participants to report only activities that were 15 min or longer and between the hours of 6 AM and 6 PM, all instances of exposure that occurred outside of those daylight hours or for a shorter duration (i.e., 6 or 12 min) were excluded. For each day, the minutes of each instance of exposure were summed. Data were treated as missing for 15.1% of days due to technical issues (e.g., dead battery) and on an additional 3.3% of days during which the participant did not confirm having worn the device.

2.4. Analysis plan

To compare daily time outdoors reported in the MUSE Inventory and assessed by the UVR sensors, a mixed-model analysis was conducted. Subsequent models evaluated whether the association between these measures was moderated by age, gender, and time since diagnosis by adding cross-level interaction terms. For time outdoors, a Bland Altman plot was constructed to display measure agreement. To evaluate correspondence between MUSE percentages and Sun Habits Survey responses for each sun-protection behavior, Spearman's correlations were computed.

3. Results

Thirty-nine melanoma survivors enrolled in the study. The sample ranged in age from 28 to 84 (M_{age} = 58.59) and was predominantly female and college-educated (see Table 2). All participants returned for the follow-up appointment. Participants completed an average of 9.59 (SD = 1.23) of 10 daily surveys and wore the sensor an average of 8.69 (SD = 2.08) days. Completion times for the MUSE Inventory were recorded by the online form and ranged from < 1 to 18 min, M = 3.97, SD = 2.54. Descriptive statistics for all measures of sun protection and exposure are reported in Table 3, and activity descriptions are provided in Supplementary Table 1. The frequencies with which individual clothing options in the MUSE Inventory were selected are listed in Appendix A.

3.1. MUSE score descriptive statistics

Body-site specific MUSE scores indicate the minutes of exposure after subtracting the time during which any sun-protection method was used at that site. Mean body-site MUSE scores ranged from 0 to 95.63 min, and were highest for the lower face, neck, ears, scalp, and hands (see Table 4). Reflecting that the sites typically left unprotected were relatively small compared to total body surface area, the average overall MUSE score in this sample was 8.70 (SD = 7.55), which is equivalent, for example, to being outside for 31 min while wearing no sunscreen, no hat, a T-shirt, long pants, and shoes (thus, exposing 28% of the body).

3.2. Daily MUSE Inventory and UVR sensor measures of time outdoors

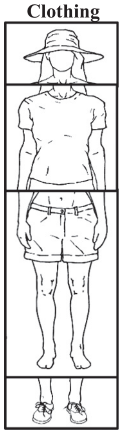
Minutes outdoors reported in the MUSE Inventory significantly predicted minutes outdoors recorded by the UVR sensor, B = 0.53, t = 11.69, p < .001, accounting for 28.9% of the variance in the UVR sensor data. Analysis of cross-level interactions did not reveal any significant difference in associations between these measures based on age, gender, or time since diagnosis (see Supplementary Table 2).

For average outdoor time during peak hours, the MUSE Inventory appeared to more closely match the UVR sensor than did the Sun Habits Survey (see Table 3), but still exceeded these estimates. In contrast, for average total outdoor time, the time recorded by the UVR sensor exceeded time outdoors reported in the MUSE Inventory. Likewise, as shown in the Bland Altman plot (Fig. 3), on average participants reported 35.81 fewer minutes of sun exposure per day in the MUSE Inventory than was recorded by the UVR sensor. Further, this plot shows that large discrepancies between the measures were predominantly comprised of greater reports of time outdoors on the MUSE Inventory than the UVR sensor.

Example Scenario

Yard Work – 9 AM - 1 PM

Clothing



Additional options
- No use of gloves, scarf, umbrella, sunglasses
- No shade use
- Did not sweat or get wet
- Sunscreen not applied

Variations

Variation 1 – Clothing
- Long sleeves, gloves, long pants worn

Variation 2 – Shade
- Shade use reported all the time

Variation 3 – Sunscreen 1
- Sunscreen applied at 9 AM and again at 11 AM to face, arms, legs

Variation 4 – Sunscreen 2
- Sunscreen applied at 9 AM to face, arms, legs, and no subsequent application

MUSE Metrics from Example Scenario and Variations (Var.)

	Example Scenario	Var. 1 - Clothing	Var. 2 – Shade	Var. 3 – Sunscreen 1	Var. 4 – Sunscreen 2
Overall MUSE	92.4	0	0	0	46.2
Time Outdoors (minutes)	240	240	240	240	240
Average % Body Exposed	38.5%	0%	0%	0%	19.25%
Sun-Protection Behavior Percentage					
Brimmed Hat	100%	100%	100%	100%	100%
Shirt with Sleeves	100%	100%	100%	100%	100%
Sunglasses	0%	0%	0%	0%	0%
Sunscreen	0%	0%	0%	100%	50%
Shade	0%	0%	100%	0%	0%
Body-Site MUSE (minutes exposed)					
Scalp	0	0	0	0	0
Upper Face	0	0	0	0	0
Lower Face	0	0	0	0	0
Ears	0	0	0	0	0
Neck	0	0	0	0	0
Shoulders	0	0	0	0	0
Upper Arm	240	0	0	0	120
Forearms	240	0	0	0	120
Hands	240	0	0	0	120
Chest	0	0	0	0	0
Abdomen	0	0	0	0	0
Back	0	0	0	0	0
Thighs	0	0	0	0	0
Knee Area	240	0	0	0	120
Calves Area	240	0	0	0	120
Ankle Area	240	0	0	0	120
Feet	0	0	0	0	0

Fig. 2. Illustration of sample metrics derived from the Daily MUSE Inventory based on an example scenario and several variations.

3.3. *Daily MUSE Inventory and Sun Habits Survey measures of sun-protection behavior*

For this analysis only, data from one individual who completed the Daily MUSE Inventory for only three days, and two who reported no outdoor time during the study, were excluded. As shown in Table 5, Spearman's correlations between MUSE and Sun Habits Survey data indicated a strong association for hat, sleeved shirt, sunglasses, and sunscreen use.

3.4. *Follow-up analyses of reported sunscreen use*

The observation of a low MUSE percentage for sunscreen despite a frequency rating exceeding the midpoint of the scale on the Sun Habits Survey (see Table 3) prompted follow-up analyses. These analyses revealed that the frequency of sunscreen use reported in the Sun Habits Survey correlated strongly with the number of days sunscreen use was reported in the MUSE Inventory ($r = 0.80, p < .001$). However, among the subset of 16 participants who indicated on the survey that they always used sunscreen, percentage of outdoor time sunscreen was reported in the MUSE ranged from 3.0% to 36% ($M = 21.02\%$, $SD = 12.52\%$). These respondents reported an average daily number of body sites covered by sunscreen ranging from 1.5 to 7.90 ($M = 3.70$, $SD = 1.60$) with facial application being most common and reported on most days ($M_{\text{days}} = 7.63$, $SD = 2.80$). Thus, even among the participants who reported the highest compliance with sunscreen use in the Sun Habits Survey, MUSE Inventory data showed substantial variability.

4. Discussion

The Daily MUSE Inventory measured sun exposure by assessing sun exposure and protection based on specific activities performed, yielding scores representing duration of unprotected sun exposure. Analyses indicated moderate correspondence between the Daily MUSE Inventory and both UVR sensors and the widely-used Sun Habits Survey. For estimates of time outdoors, discrepancies were identified which warrant further investigation, but overall agreement was comparable to past studies (Cust et al., 2018; Cargill et al., 2013; Glanz et al., 2010).

For sunscreen, the Daily MUSE Inventory accounts for the timespan of effectiveness and reapplication. The MUSE percentages obtained for sunscreen use among melanoma survivors was considerably lower than what would be suggested by the average frequency rating for sunscreen use from the Sun Habits Survey. We found high correspondence between frequency of sunscreen use and number of days sunscreen was reported in the Daily MUSE Inventory, suggesting that Sun Habits Survey responses may reflect whether sunscreen was applied at all on a given day and that participants may not consider timespan of effectiveness when providing frequency ratings. Analyses also revealed considerable variability in the number of body sites to which sunscreen was applied even among the subset of participants who indicated they “always” wore sunscreen. The results suggest that responses about frequency of application may often be driven by daily application (mainly to the face) rather than by the duration of use or thoroughness of application. Thus, the MUSE Inventory may be more sensitive to variation in these aspects of sunscreen use than a frequency-based measure. This level of specificity may be especially important for high-risk populations, such as those with a personal or familial history of melanoma, who have the greatest need to engage in effective sun protection and may benefit from detailed information on body sites that are not well-protected.

In addition to the overall MUSE score, other metrics derived from the MUSE Inventory will be useful for research and interventions (see Table 1). Percentage of sun-protection strategy use, average percent of

Table 2
Sample characteristics. This study was conducted July–September 2017, in Chicago, IL.

	Percentage of sample (N = 39)
Gender	
Male	38.5%
Female	61.5%
Age	
20–39 years	12.8%
40–59 years	35.9%
60–79 years	48.7%
80 years and older	2.6%
Race and ethnicity	
White, Non-Hispanic	100.0%
Fitzpatrick skin type	
I	35.9%
II	28.2%
III	28.2%
IV	7.7%
Stage at diagnosis	
Melanoma-in-situ	38.5%
Stage IA	30.8%
Stage IB	17.9%
Stage IIA	10.3%
Stage IIB	2.6%
Years elapsed from initial diagnosis	
0–1	28.2%
2–3 years	0.0%
4–6 years	20.5%
7–9 years	25.6%
10 years and longer	25.6%
Education	
Some post-high school education	2.6%
College graduate	53.8%
Graduate degree	43.6%
Annual household income	
$20,000–$34,999	2.6%
$35,000–$50,999	2.6%
$51,000–$100,000	28.2%
Over $100,000	66.7%

body exposed, and average total duration of exposure at specific body sites provide information on methods through which individuals change sun exposure (that is, by increasing body coverage, decreasing exposure time, or both). Body-site-specific MUSE scores can also serve as an informative outcome measure. For instance, in the present study, evaluation of these scores revealed higher levels of exposure on the lower face, neck, ears, scalp, and hands, which are common sites for skin cancer (Youl et al., 2011). Through the various MUSE metrics, researchers can attain a better understanding of how individuals deploy sun-protection behaviors and can explore questions related to what patterns of sun exposure are most common during specific activities and their relative effectiveness.

Table 4
Descriptive statistics for average Daily MUSE scores representing Minutes of Unprotected Sun Exposure for separate body sites (from scalp to feet) and overall.

	% of body[a]	MUSE scores (mins)		
		Mean	*SD*	Maximum
Scalp	3.5	18.71	22.45	95.63
Upper face	1.5	14.24	20.31	88.13
Lower face	1.75	25.35	23.04	88.13
Ears	0.25	24.67	24.69	88.13
Neck	2.0	26.39	22.96	88.13
Shoulders	4	2.94	8.95	48.50
Upper arm	4	14.78	18.18	76.75
Forearms	6	18.43	18.94	76.75
Hands	5	30.89	23.60	95.63
Chest	6.5	3.76	9.97	48.50
Abdomen	6.5	0.98	5.04	30.75
Back	13.0	0.00	0.00	0.00
Thighs	9.5	0.72	3.67	22.25
Knee area	9.5	4.07	9.66	48.50
Calves area	7	13.52	19.14	76.75
Ankle area	7	17.23	20.40	76.75
Feet	7	8.95	12.88	58.13
Overall MUSE	–	8.70	7.55	29.70

[a] This column presents the percentage surface area used to weight body-site scores in order to calculate the overall MUSE scores.

4.1. Relative strengths and uses of the MUSE Inventory, Sun Habits Survey, and UVR sensors

While the MUSE Inventory is a useful measure for obtaining detailed information about personal sun-protection behaviors, other measures of sun exposure remain valuable. Short, frequency-based measures, such as Sun Habits Survey, are useful for cross-sectional studies of sun exposure or estimating the frequency of particular behaviors in the general population. This survey has been embedded in several national surveys, including the Health Information National Trend Survey (HINTS) (Nelson et al., 2004), allowing analysis of population-level

Table 3
Sun protection and exposure descriptive statistics for average daily values from the Daily MUSE Inventory, Sun Habits Survey, and UVR sensor.

Sun exposure metrics	MUSE Inventory		Sun Habits Survey[a]		UVR sensor	
	Mean	*SD*	Mean	*SD*	Mean	*SD*
Sun protection methods						
Brimmed hat	49.80%	37.84%	3.49	1.38	–	–
Shirt covering shoulders	91.95%	19.72%	4.53	0.85	–	–
Shade	27.01%	27.69%	3.17	0.94	–	–
Sunscreen	15.58%	17.04%	3.64	1.53	–	–
Sunglasses	70.60%	37.95%	4.09	1.42	–	–
Time outdoors (minutes)						
Peak time outdoors (weekday)	46.67	47.33	80.83	57.63	31.16	25.12
Peak time outdoors (weekend)	64.09	42.90	132.50	89.82	42.98	29.51
Total time outdoors (daily average)	87.36	55.12	–	–	120.89	70.11
Overall exposure score[b]	8.70	7.55	–	–	–	–
Average % body exposed	11.94%	8.90%	–	–	–	–
UVR dose (J/m^2)	–	–	–	–	45.43	42.93

Blank cells indicate that a particular sun exposure metric is unavailable for that measure.
[a] Sun Habits Survey items were rated on Likert scales. For sun-protection methods, response scales ranged from 1 (Never) to 5 (Always). For time outdoors, response scales were converted to minutes of exposure (e.g., a response of “1 to 2 h” was assigned a value of 90 min).
[b] Overall exposure scores are uniquely computed by the MUSE Inventory. These scores represent minutes of unprotected sun exposure, adjusted for the percentage of the body that was exposed.

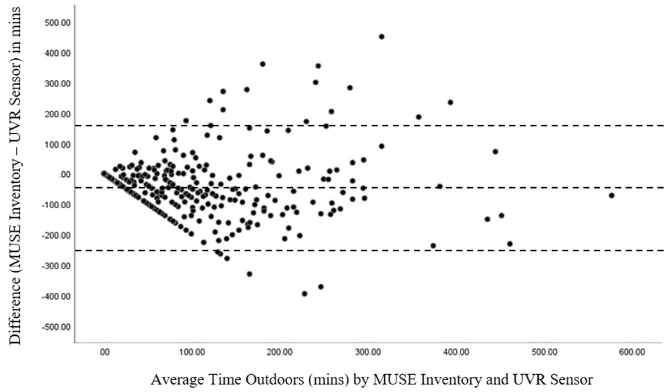


Fig. 3. Bland Altman plot displaying measurement differences between time outdoors measured by the UVR sensor and MUSE Inventory, with 95% confidence intervals indicated.

Table 5
Spearman's correlations between average sun-protection behavior percentages from MUSE Inventory and corresponding Sun Habits Survey items for individual sun-protection methods.

Sun protection methods	Spearman's correlation with corresponding Sun Habits Item	
	rho	*p*
Brimmed hat	0.75	< .001
Shirt covering shoulders	0.66	< .001
Shade	0.11	.49
Sunscreen	0.69	.002
Sunglasses	0.68	< .001

change in reported use of specific sun-protection strategies over decades. As epidemiological research must reach a large and diverse population, use of simpler items is necessary to reduce burden and enable the inclusion of other health-related survey items.

In contrast to self-report measures, UVR sensors provide an objective measure of sun exposure that does not rely on participant memory. UVR sensors have been used to assess sun exposure in several studies (Idorn et al., 2014; Autier et al., 2000; Thieden et al., 2005) and are particularly useful for obtaining objective information about exposure intensity. However, UVR sensors present several limitations, including that the amount of sun exposure the sensors measure depends on where it is attached to the body and participant compliance. Further, UVR sensors are an imperfect measure of time outdoors because shade can block the device, resulting in a zero reading that is interpreted as indoor time. This measurement limitation likely contributed to the discrepancies observed in the present study. Most importantly, UVR sensors do not assess concurrent sun-protection behaviors; thus, additional measures are needed to capture the extent to which sun exposure assessed by the sensor actually reaches the skin (Idorn et al., 2014). A potential strategy for obtaining more accurate and detailed information about sun exposure would be to integrate diary measures, such as the Daily MUSE Inventory, with UVR sensors. For instance, data from UVR sensors can be used to automatically generate a list of outdoor times for which participants then complete sun-protection measures.

4.2. Limitations

While the Daily MUSE Inventory is a promising tool for providing detailed data on unprotected sun exposure, this measure and the present study are not without limitations. The sample size was relatively small and homogenous regarding race and ethnicity, melanoma history, income, and education level. Melanoma survivors may be more tolerant of the respondent burden and more motivated to provide detailed reports of their behavior than individuals with a lower risk of melanoma, and they may more accurately recall sun-protection behavior and outdoor time due to their heightened awareness and concern. Compliance to study procedures was also likely enhanced by the sample's high level of education and affluence.

Another limitation is that we could not definitively validate the MUSE score metric itself, which is unique to the MUSE Inventory. Instead, this study compared individual components (e.g., outdoor time) used to calculate the MUSE scores with comparable metrics from UVR sensors and the Sun Habits Survey. Furthermore, due to differences in the metrics derived for sun protection in each measure (percentages vs. Likert scales), it was not possible to formally test agreement between these measures. Instead, Spearman's correlations were computed, which indicated that for all behaviors (except shade), there was a strong association between measures. A more definitive test of the validity of behavioral reports in the MUSE Inventory could be achieved through direct observation of sun-protection behaviors (O'Riordan et al., 2009).

Additionally, although the MUSE Inventory is one of few measures that accounts for the limited timespan of effectiveness for sunscreen and thoroughness of application, it does not account for all factors that influence the effectiveness of sun-protection efforts. For instance, the measure does not incorporate details about the weather, types of fabric worn, and details about sunscreen, including how much was applied, when it was applied relative to outdoor time, its expiration date, and whether sunscreen was stored properly (Cooley and Quale, 2013). Lastly, the MUSE Inventory measure of shade use was not significantly associated with the Sun Habits Survey measure of this behavior. Shade use may be especially difficult for individuals to quantify and recall over time because shade can be highly variable even within the same activity.

4.3. Future directions

As correspondence between time outdoors measured by the Daily MUSE Inventory and UVR sensors was imperfect, further studies should examine potential sources of discrepancies between these measures. Additional future directions include programming the MUSE Inventory in platforms other than REDCap, for instance as a smartphone application. This format would provide additional opportunities for its use in ecological momentary assessment protocols to examine in-the-moment sun-protection behavior and for its use as an intervention tool. For instance, MUSE responses could be automatically scored as part of a just-in-time adaptive intervention delivering sun-exposure alerts. The MUSE Inventory may also inform epidemiological studies of the relationship between sun protection and risk of diseases, including both cutaneous and non-cutaneous cancers (Feskanich et al., 2004; English et al., 1997).

5. Conclusions

We evaluated the concurrent validity of the newly-developed Daily MUSE Inventory with UVR sensor and Sun Habits Survey data in a sample of melanoma survivors completing these measures during the summer in Chicago, IL, USA. The Daily MUSE Inventory uniquely provides scores representing duration of unprotected sun exposure on body sites and yields an overall score representing duration of unprotected sun exposure after accounting for the proportion of the body's surface area exposed. Analyses indicated that the Daily MUSE Inventory corresponds well with the Sun Habits Survey and UVR sensors, while also providing more specific information on degree of sun exposure on several smaller body sites that are at high risk for skin cancer.

Supplementary data to this article can be found online at https://doi.org/10.1016/j.pmedr.2018.07.010.

Conflict of interest

The authors declare there is no conflict of interest.

Acknowledgments

The authors wish to thank Jamie Hauglid and Michael Brutinel for their assistance with REDCap programming and pilot testing, Bryce Billings for providing the clothing drawings for the MUSE Inventory, as well as Jennifer Taber, Wendy Kohlmann, Marjan Champine, Roger Edwards, and Sandie Edwards for their contributions to the initial development and pilot testing of the MUSE Inventory. We additionally acknowledge Jayalakshmi Jain for assistance with administrative tasks.

We acknowledge use of the REDCap Support Team at Northwestern University as well as the Health Measurement and Survey Methods core facility supported by the National Institutes of Health through National Cancer Institute Cancer Center Support Grant 5P30CA420-14 awarded to Huntsman Cancer Institute and additional support from the Huntsman Cancer Foundation. We additionally acknowledge YouV Labs Inc. (New York, NY), who donated 20 Shade® sensors for use in this study and provided data management.

Research reported in this publication was supported, in part, by the National Institutes of Health's National Center for Advancing Translational Sciences, Grant Number UL1TR001422. The content is solely the responsibility of the authors and does not necessarily represent the official views of the National Institutes of Health. This project received additional financial support from the professional development funds provided by JKR and LGA. TKS acknowledges salary support by NIH/NCI training grant T32 CA193193. During the development and testing of the MUSE Inventory, LGA, TKS, and SAL were supported in part by the National Cancer Institute of the National Institutes of Health under Award Number R01 CA158322.

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