



UV detection stickers can assist people to reapply sunscreen

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ABSTRACT

Sunscreen when applied at the recommended concentration (2 mg/cm²) has been shown to block the harmful molecular effects of ultraviolet radiation (UVR) in vivo. In real world conditions, however, sunscreen is often not applied/reapplied sufficiently to yield protection. This field study tested the effectiveness of UV detection stickers to prevent sunburn and improve reapplication of sunscreen. During the Ashes Cricket Test match event (November 2017) in Brisbane, Australia interested spectators were recruited into the control group on DAY-1 and during subsequent days (DAY-2, DAY-3, DAY-4) new participants were recruited into the UV-Sticker group. Participants in both groups were provided with free sunscreen and participants in the UV-Sticker group were additionally provided with a UV detection sticker. Primary outcomes were self-reported sunburns and re-application of sunscreen. Secondary endpoints included satisfaction with the UV detection stickers. 813 participants enrolled in the study, and complete data is available for 428 participants (52.6% response rate, $n = 369$ UV detection sticker, $n = 59$ control). Participants provided with a UV detection sticker were more likely to re-apply sunscreen than controls (80% vs 68%, $p = 0.04$); but do not reduce sunburn rates. UV detection stickers may improve sunscreen re-application in a high UV-environment.

Trial registration: Australian and New Zealand clinical trials register (ACTRN12617001572358).

1. Introduction

Australia, has one of the highest rates of melanoma in the world, which are at least double those of high risk countries such as the US and UK (Ferlay et al., 2013; Australian Institute of Health and Welfare, 2013). Melanoma is the most common cancer in people 15 to 44 years (Australian Institute of Health and Welfare, 2013). Keratinocyte skin cancers also have very high incidence rates in Australia (1170 per 100,000) and were estimated to cost \$703 million to diagnose and treat in 2015 (excluding out-of-pocket or societal costs) (Staples et al., 2006; Gordon and Rowell, 2015). All skin cancers together in Australia are more common than all other cancers combined, are very costly overall (treating keratinocyte cancers alone was estimated at 8.1% of all health system spending on cancer), and place a significant and increasing burden on the health care system. There is also a large societal impact from skin cancer with many individuals affected by multiple skin cancers, which need to be managed as a chronic disease (Gordon et al.,

2018). Skin cancer prevention initiatives are very important for Australia and have been shown to be highly cost-effective, with every dollar invested in sun protection programs returning an estimated \$2.30 to \$3.20 in cost savings (Gordon and Rowell, 2015; Shih et al., 2009; Shih et al., 2017).

Sunscreen is an important line of defence against skin damage and results from the Nambour Skin Cancer Prevention Trial, have shown regular sunscreen application can reduce the incidence of squamous cell carcinoma (SCC) (van der Pols et al., 2006) and may reduce melanoma (Green et al., 2011). Molecular findings also support a protective role for sunscreen when applied at the correct concentration (2 mg/cm²) (Olsen et al., 2017). Under such conditions, sunscreen is effective at blocking the harmful effects of ultraviolet radiation (UVR) (Hacker et al., 2013); however, many people do not apply sunscreen at such thickness, and the concentration applied in real life conditions provides less protection (Autier et al., 2007; Diaz et al., 2012). A randomized, split-face double-blind study has shown the impact actual use of SPF100

Abbreviations: UVR, Ultraviolet radiation

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and SPF50 sunscreens had on sunburn rates (Williams et al., 2018). Following an average 6.1 h of sun exposure, 40.7% of the participants (81/199) exhibited increased erythema scores on the SPF50 protected side as compared with 13.6% (27/199) on the SPF100 protected side (Williams et al., 2018). In Queensland during 2015–16, almost 54% of adults (> 18 years) reported being sunburnt in the last 12 months (Queensland Government, 2016) and in an Australian nationwide survey conducted in 2016–17, 17% of adults reported being sunburnt on an average summer weekend (Cancer Council Australia, 2017).

New technologies may assist people in determining how long they can safely stay in the sun after applying sunscreen. Several mobile phone applications are available with sunscreen volume calculators and/or sunscreen re-application reminders. However, these apps will not provide user feedback on whether the correct amount of sunscreen was applied. To overcome this challenge, new products have been developed, which incorporate UV sensitive dyes into a sticker that can be used as an indicator to signal sunscreen efficiency. The US patent (20,020,022,008 A1) describes a photochromic molecule, which changes color when exposed to UVR and the potential application of this photochromic molecule as an indicator of reduced sunscreen efficiency. Zou et al. have further described the methodology for creating ink and the fabrication of low-cost sensors that provide naked-eye monitoring of UVR, even at low doses typically encountered during solar exposure (Zou et al., 2018). The UV detection sticker technology alleviates the discrepancy between sunscreen concentration applied and changes color as soon as the sunscreen filter is no longer blocking UVR illustrating to the user they are no longer protected.

Several UV detection sticker products are available using various photochromic molecules including the “Sundicator” (Treadley Pty Ltd., Australia), the “My UV” heart shaped patch (La-Roche-Posay, France) and the SPOTMYUV™ sticker (Suncayr LTD, Australia). The “My UV” heart shaped patch is water resistant and can be applied to skin for up to 5 days. The “My UV” patch links with an app, which scans the sticker and provides messages about personal UVR exposure (Shi et al., 2018). A limitation of this device is the requirement of a mobile phone to provide user feedback which are commonly unavailable during outdoor activities. The Sundicator and the SPOTMYUV™ sticker are water resistant and highlight the need for reapplication by changing color in response to UV. The SPOTMYUV™ sticker has the capability of customizing the design on the sticker and costs below \$1 USD per sticker.

While the idea of UV detection stickers is intuitively appealing no data exist as to whether it assists people in knowing when to reapply sunscreen or reduces sunburn incidence. Here, we present the findings of a field study to assess the effectiveness of UV detection stickers to improve sunscreen re-application and reduce sunburn.

2. Materials & methods

2.1. Subjects

Eligible participants were healthy residents or visitors of greater Brisbane, Australia aged > 18 years with no history of allergy to sunscreen. Demographic and phenotypic data were collected from participants through a structured questionnaire (Table S1) described previously (Whiteman et al., 2003a). Participants ($n = 813$) were recruited at the GABBA stadium in Brisbane, Australia (latitude 27°S, 153°E) by research staff during the Ashes cricket test match event (23–26th November 2017; Spring in Australia), who outlined the project and determined eligibility (Fig. 3). The study was approved by the Human Research Ethics Committee of the Queensland University of Technology (#1700000992) and prospectively registered with the Australian and New Zealand clinical trials register (ACTRN12617001572358). Participants were emailed the follow-up survey up to three times. Upon completion of all study activities participants could enter the draw to win one of five \$200 AUD gift vouchers. The study complied with the Declaration of Helsinki, and all

participants gave their written, informed consent to take part.

2.2. Treatment regimen and outcome measures

During DAY-1, the control group was recruited, completed the baseline questionnaire and provided with a free sunscreen (Cancer Council SPF 30+, 35 mL tube) for use during the day's play. During subsequent days (DAY-2, DAY-3, DAY-4) new participants were recruited and completed the same baseline questionnaire and were provided with one UV detection sticker SPOTMYUV™ (Suncayr, LTD, Australia, <https://spotmyuv.com/>) as well as a free sunscreen for use during the day's play. Participants were advised to place the UV detection sticker which lasts for one day on an exposed body part, such as their hand, to use at their discretion. To ensure the designs of the UV detection stickers resonated with participants, designs were created for the Australian supporters using the social media campaign #BeatEngland and for the other supporters the movermer logo (a charity supporting Men's Health (Fig. 2). Participants could participate in the study on only one day, even if they attended multiple days at the cricket. Control group participants were recruited on a separate day to the intervention group to avoid treatment crossover. The UV detection stickers were not commercially available at the time of data collection. Follow-up post-test measurements were collected via email up to seven days after the participant attended the event. All participants completed an online questionnaire recording sunburn and sunscreen use and intervention group participants also reported satisfaction with the intervention device.

2.3. Weather measurements

UVR data was recorded using a UV-Biometer model 501 (Solar Light Co, Philadelphia, PA) and data was displayed using the UV index scale. The standard erthermal dose (SED) was also calculated with daily summaries and hourly observations at 10 am and noon recorded. The UVR data was captured by the Australian Radiation Protection and Nuclear Safety Agency detector (Brisbane, latitude 27°S, 153°E). The proportion of cloud cover in the sky above the stadium was recorded hourly during each measurement day from 9 am until 4 pm. Images of the sky above the stadium were captured using a fixed camera maintained by Queensland Government, Department of Transport and Main Roads (Traffic Cam, 4172). The proportion of cloud cover in each image was counted using ImageJ software (Rueden et al., 2017). The scale was set using the known road lane width of 3.5 m and the sky (region of interest) selected using the polygon tool with the RGB image split to black and white and threshold adjusted to 220 and 255 respectively. The ‘analyse particles algorithm’ was used to count positive pixels > 0.5m² with the area of clouds calculated as a percentage of total area of sky (Fig. S1). All field trial image analysis and quantification procedures were performed blind to the image ID.

Temperature data was recorded in degrees Celsius and data was reported for the daily minimum and maximum as well as observations at 9 am and 3 pm each day. The temperature data was captured by the Bureau of Meteorology weather station (040913 Brisbane, latitude 27°S, 153°E).

2.4. Statistical analysis

Pearson's chi-squared and/or Fisher's exact test was used to detect the statistical significance in the difference between the control group and the UV detection sticker group. Logistic regression models were used to examine the difference in outcome variables (sunburn and re-apply sunscreen) between groups while adjusting for age and sex. Analyses were performed using SAS and JMP statistical software package (SAS institute, Cary, NC). Likelihood Ratio chi-squared tests were used to assess associations between categorical variables. The JMP uplift model was used to find subgroups for whom the intervention

Table 1
Participant characteristics.

	Total N = 428		UV sticker n = 369		Control n = 59		p-value
	n	(%)	n	(%)	n	(%)	
Age mean (range)	41.68 (18–72)		41.03 (18–72)		45.66 (20–65)		p = 0.01
Data missing	10						
Gender							
Female	119	(27.8)	109	(29.5)	10	(16.9)	p = 0.05
Male	309	(72.2)	260	(70.5)	49	(83.1)	
Visiting Australia							
Yes	25	(5.8)	20	(5.4)	5	(8.5)	p = 0.35
No	403	(94.2)	349	(94.6)	54	(91.5)	
Skin color							
Very fair/fair	273	(63.8)	238	(64.5)	35	(59.3)	p = 0.21
Medium	116	(27.1)	101	(27.4)	15	(25.4)	
Olive/dark	39	(9.1)	30	(8.1)	9	(15.3)	
Hair color							
Red/auburn/blonde	103	(24.1)	93	(25.3)	10	(16.9)	p = 0.09
Light brown/dark brown	306	(71.7)	257	(69.8)	49	(83.1)	
Black	18	(4.2)	18	(4.9)	0	(0)	
Data missing	1		1				
Skin burn in strong summer sun for 30 min without protection?							
My skin would not burn at all	8	(1.8)	7	(1.9)	1	(1.7)	p = 0.95
My skin would burn lightly	127	(29.7)	110	(29.8)	17	(28.8)	
My skin would burn moderately	160	(37.4)	137	(37.1)	23	(39.0)	
My skin would burn severely	133	(31.1)	115	(31.2)	18	(30.5)	
Previous skin cancer BCC, SSC or melanoma							
Yes	82	(19.2)	71	(19.2)	11	(18.6)	p = 0.52
No	339	(79.2)	293	(79.4)	46	(78.0)	
Unsure/don't know	7	(1.6)	5	(1.4)	2	(3.4)	

Table 2
Weather data.

Date	Group	Event day	Start of day	End of day	Temperature				UV daily ^b dose	UV 10-11am ^c dose	UV 12-1pm ^d dose
					Min	Max	9 AM	3 PM			
					°C	°C	°C	°C			
23-Nov-17	Control	DAY 1	10:00	17:30	16.4	26.5	23.5	25.9	43.3	4.4	8.4
24-Nov-17	UV sticker	DAY 2	9:00	17:30	17.4	28.8	24.9	27.1	58.3	8.0	7.7
25-Nov-17	UV sticker	DAY 3	9:30	17:30	18.6	28.7	25.3	26.8	43.8	6.4	8.4
26-Nov-17	UV sticker	DAY 4	10:00	17:30	19.7	29.5	25.6	28.3	54.0	7.3	10.4

^a SEDs = standard erythemal dose.^b Daily dose calculated from 6:00–16:00.^c Morning dose calculated from 10:00–11:00.^d Midday dose calculated from 12:00–13:00.

would most likely benefit in terms of the reapplying sunscreen outcome. Inductive thematic analysis was used to group open-ended answers into themes by two researchers (CH and HF).

Sample size calculations were based on an expected difference in the sunburn rates between the control group and the treatment group. We assumed the control group rate would be around 17% based on our literature review. With significance level $\alpha = 0.05$, and 3:1 allocation ratio, with $N = 300$ in intervention group and $N = 100$ in the control group, this study was expected to have 80% power to detect a reduction of sunburn to 7% or less in the intervention group.

3. Results

3.1. Subject characteristics

Over the four days of cricket, 813 volunteers were enrolled (98 on the first day were assigned to the control group; 715 on the subsequent days were sequentially assigned to the intervention group) and completed the baseline survey. The evaluation survey was completed by 428 (52.6%) participants ($n = 369$ UV detection sticker group, $n = 59$ control group) (Table 1). There were significant differences between

those who completed the study ($n = 428$) and those who did not ($n = 385$), in terms of gender (28% vs 17% females, $p < 0.001$), previous history of skin cancer (19% vs 13%, $p \leq 0.001$) and residing in Australia (94% vs 82% vs, $p \leq 0.001$) (Fig. S2).

The 428 participants who completed the study had a mean age of 42 years (range 18–72) and 72% (309/428) were male (Table 1). Most participants had very fair or fair skin 63% (273/428). The characteristics of participants in the control and UV detection sticker group were similar for skin color, hair color, skin sensitivity to sunburn and previous history of skin cancer but differed for age with median 46 years in the control group compared to 41 years in the UV detection sticker group ($p = 0.01$) and gender with 83% male in the control group versus 71% in the UV detection sticker group ($p = 0.05$, Table 1).

3.2. Weather conditions during treatment regimen

The length of each measurement day was consistent and ranged from 7.5 h to 8.5 h (Table 2, Fig. 1A). The UVR exposure level was consistently high during the four measurement days with daily SEDs ranging from 43.3 SEDs to 58.3 SEDs (Table 2). The UV index level was above 3, requiring sun protection from 9 am to after 3 pm each day. The

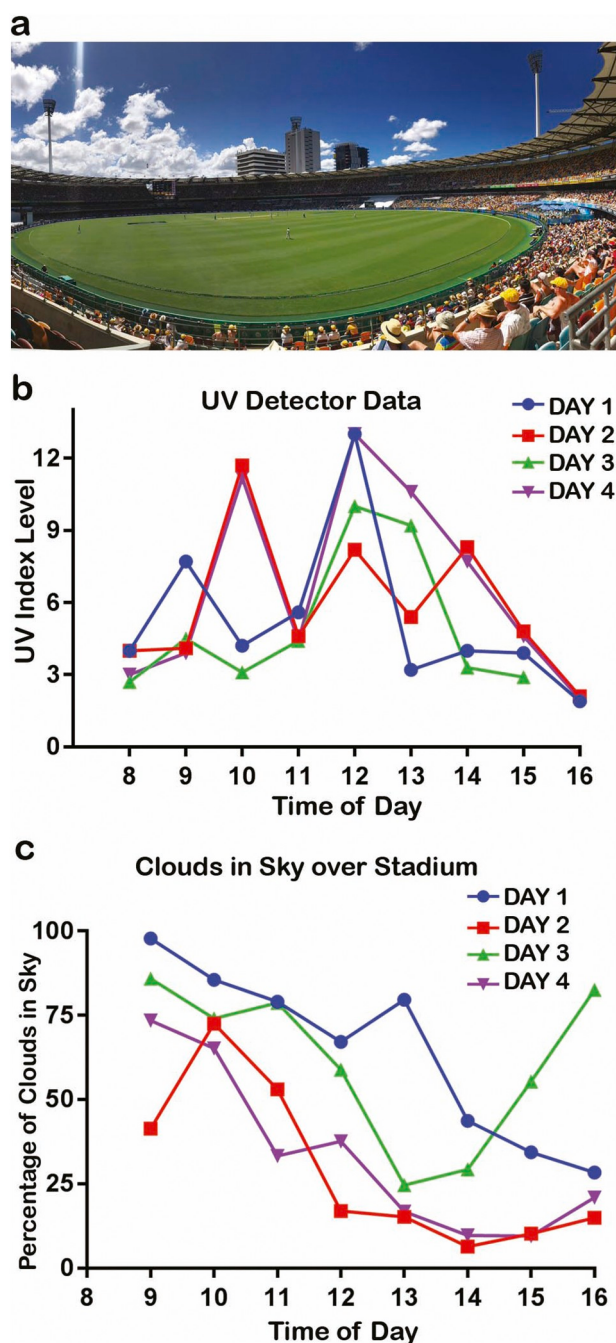


Fig. 1. Weather data for testing venue. A) The GABBA stadium in Brisbane (latitude 27°S), Australia was the testing venue for this study during November 2017. B) The UVR levels were captured each measurement day and intensity graphed using the UV index scale. C) The proportion of cloud cover in the sky above the stadium were recorded hourly during each measurement day from 9 am until 4 pm.

UV index in the hour noon–1 pm ranged from 7.7 to 10.4 (Table 2, Fig. 1B). The cloud cover above the stadium venue did vary throughout the day with cloudy conditions before 8 am clearing throughout the day (Fig. 1C). The temperature between 9 am and 3 pm ranged from 23.5 to 28.3° Celsius during the measurement period (Table 2).

3.3. Sunburn, sunscreen usage and sun protection intention

Sun protection behaviors were high among all participants ($n = 813$) at the beginning of the day with 84% ($n = 656$) bringing a

Table 3

Sunburn and Sunscreen usage on the event days.

	UV sticker $n = 369$		Control group $n = 59$		p-value
	n	(%)	n	(%)	
Did you experience one or more sunburns?					
Yes	39	(10.6)	2	(3.4)	0.08
No	330	(89.4)	57	(96.6)	
Was the sunburn ^a					
Mild (pink to light redness)	36	(70.5)	1	(50)	
Moderate (red skin)	15	(29.5)	1	(50)	
Severe (deep redness, blisters may develop)	–	–	–	–	
Location of sunburn ^a					
Face	13	(25.5)	1	(50)	
Neck	15	(29.5)	–	–	
Shoulders	2	(3.9)	–	–	
Chest	4	(7.8)	–	–	
Hands/arms	7	(13.7)	1	(50)	
Legs	10	(19.6)	–	–	
Did you apply sunscreen on the day of the cricket?					
Yes	354	(95.9)	54	(91.5)	0.14
No	15	(4.1)	5	(8.5)	
Did you re-apply sunscreen					
Yes	295	(79.9)	40	(67.8)	0.04
No	74	(20.1)	19	(32.2)	
Do you need a reminder to help with applying and reapplying sunscreen?					
Yes	106	(28.7)	2	(3.4)	< 0.001
No/unsure	263	(71.3)	57	(96.6)	

^a 41 people were sunburnt on multiple areas therefore 53 sunburn events were recorded.

hat, 84% ($n = 656$) wearing sunglasses and 64% ($n = 509$) bringing sunscreen while only 16% ($n = 113$) wore a long-sleeve shirt (Table S2).

During the study 41 participants reported being sunburnt, with a higher proportion of the intervention group reporting sunburn than the control group (11%, $n = 39$ vs 3%, $n = 2$ respectively, $p = 0.08$, Table 3). The majority of sunburns reported were of mild intensity on the face/neck with no reports of severe sunburn (Table 3). Within the UV detection sticker group, those who reported a sunburn were more likely to be male (87% vs 69%, $p = 0.02$) and reported they needed a reminder to help with applying and reapplying sunscreen (44% vs 27%, $p = 0.03$, Table S3). The majority of participants within the UV detection sticker group who reported being sunburnt also reported applying sunscreen 95% (37/39) and re-applying sunscreen 85% (33/39) (Table S3). There was no difference between those who purchased public seating in the shade and the sunburn rate for participants within the UV detection sticker group ($p = 0.26$, Table S3).

The attitudes of participants towards the use of sunscreen were similar with 63% ($n = 231/369$) of participants in the UV detection sticker group agreeing sunscreen is ‘greasy’ compared with 64% (38/59) in the control group (Table S4). The majority of participants in both groups agreed sunscreen use is ‘important’ (UV detection sticker group 97% ($n = 359/369$); control group 98% ($n = 58/59$). In the UV detection sticker group 54% ($n = 198/369$) of participants applied sunscreen ‘before they go outside or in the car’, similar to the control group (58%, $n = 34/59$) (Table S5).

Sunscreen use was commonly reported in the follow-up survey with 96% (354/369) of participants in the UV detection sticker group and 92% (54/59) of participants in the control group applying sunscreen during the event (Table 3, $p = 0.14$). The re-application of sunscreen was higher for participants in the UV detection sticker group 80% (295/369) compared to 68% (40/59) in the control group (Table 3,

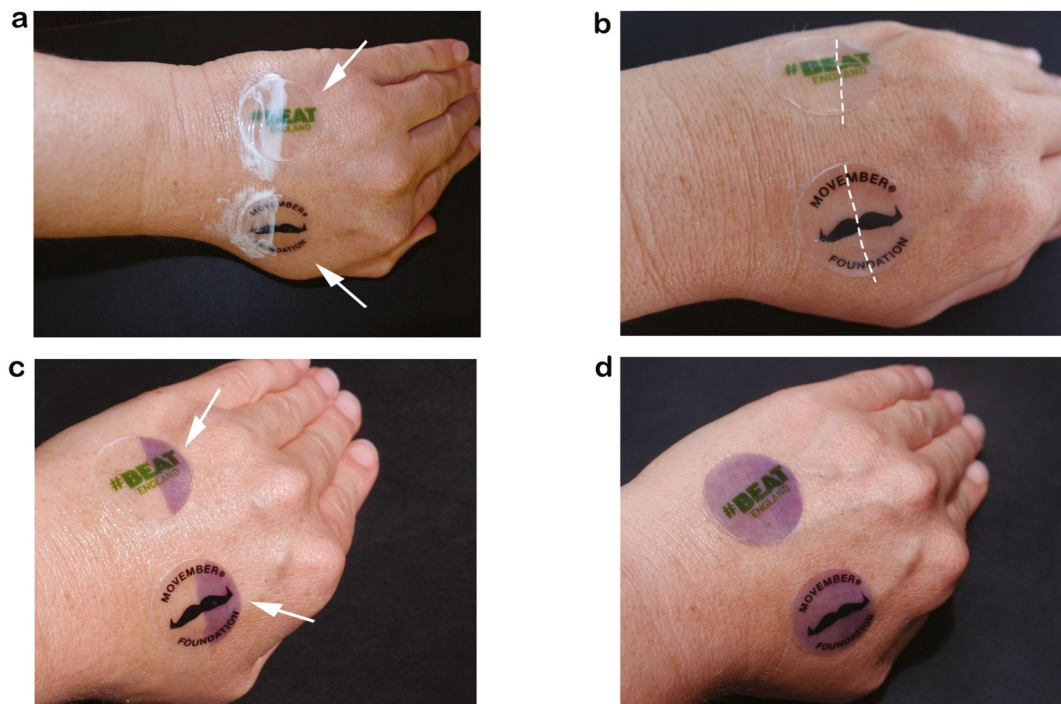


Fig. 2. SPOTMYUV™ sticker device. A) Sunscreen SPF30+ was applied to half of the sticker (arrows indicate area sunscreen was not-applied). B) The sunscreen applied to half of the sticker was rubbed-in and the dotted-line indicates the right hand-side of the sticker remained sunscreen-free. C) The sticker was exposed to sunlight and the sunscreen-free area changed color from clear to purple. The section of the sticker which had sunscreen applied protected the UV sensitive dyes in the sticker and remained clear. D) Several hours post-sunscreen application the sunscreen UV filters have degraded and are no longer blocking UV light the whole sticker is purple. The SPOTMYUV™ sticker is clear when protected from UV light and changes to purple when not protected indicating sunscreen application or re-application is required. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

$p = 0.04$). After adjusting for age and gender, the UV detection sticker group was almost twice as likely as the control group to re-apply sunscreen (OR 1.91; CI 1.03–3.55, $P = 0.04$). Participants in the UV detection sticker group were over ten-folds more likely than those in the control group to report needing a reminder to help with applying and reapplying sunscreen (29% vs. 3%, respectively; $p < 0.001$), and this difference was statistically significant after adjusting for age and sex (OR 10.89; CI 2.60–45.61, $P = 0.001$). The JMP uplift model analysis revealed participants who agreed they needed a reminder to apply and reapply sunscreen had the greatest benefit from the intervention with 82.6% ($n = 132$) reapplying sunscreen compared to 33.3% ($n = 6$) in the control group (Fig. S3). The reapplication rate among participants who stated they did not need a reminder was 78.5% ($n = 237$) in the intervention group and 71.7% ($n = 53$) in the control group.

3.4. Satisfaction with UV detection sticker

Adherence to the intervention device was high with 95% (349/369) of participants in the UV detection sticker group using the stickers (Table S6, Fig. 2). Seventy-five percent (276/369) of participants found the UV detection sticker helpful to remind them to apply sunscreen (Table S6). Three quarters (74%, 274/369) of participants in the UV detection sticker group agreed with the statement ‘you could better manage your health when outdoors using the UV detection stickers’, and 86% (317/369) would like to have the UV detection stickers included with tickets for outdoor events in the future.

Open-ended responses were completed by 55% (204/369) of participants in the UV detection sticker group. Participants commented the stickers were helpful, educational, a good reminder and a useful initiative 35% (72/204). With comments reporting “*This initiative is great, it is time (once again) that we start understanding the importance of applying sunscreen*” and “*I would say I topped my sunscreen up [reapplied] at least one more time than I would have done normally*” [ID:AS530]. Some

participants (9%, 19/204) commented the UV detection sticker would be beneficial particularly for children “*I can see the benefit of stickers for kids, as kids normally associate stickers with fun. Thus making fun of applying sunscreen*” [ID:ZR751]. Barriers reported by participants included problems with sticker adhesion 35% (72/204) including tendency to fall off when sweating or they extracted hair when removed from skin, and confusion around the meaning of the color change 22% (45/204).

4. Discussion

To investigate the impact of UV detection stickers we undertook a field trial in human volunteers exposed to a high UVR environment and found providing people with a UV detection sticker increased sunscreen re-application. To our knowledge, this is the first study to show the benefits of UV detection stickers. Previous studies investigated sunscreen reapplication prompts via SMS or mobile app platforms. Armstrong and colleagues have shown the effectiveness of text messages as a reminder tool for improving daily sunscreen adherence, which increased from 30% (12/35) in the control group to 56% (19/35) in the SMS group (Armstrong et al., 2009). In contrast RCTs examining the impact of using sun safe apps, which provide sunscreen re-application alerts, have found no improvement in sunscreen use and no difference in the number of sunburns between app users and the control group (Hacker et al., 2018; Buller et al., 2015).

Compared to a sunscreen only control group, this study found no benefit for UV detection stickers in preventing sunburn. Most participants reporting a sunburn during this study also reported wearing and re-applying sunscreen. This may suggest these participants did not apply sufficient sunscreen or used application techniques that did not provide full protection. Application techniques are a challenge that should be addressed in future studies. Previous work has demonstrated sunscreen is applied insufficiently at thickness ranging between 0.39 and 1.0 mg/cm, less than half of the recommended 2.0 mg/cm²

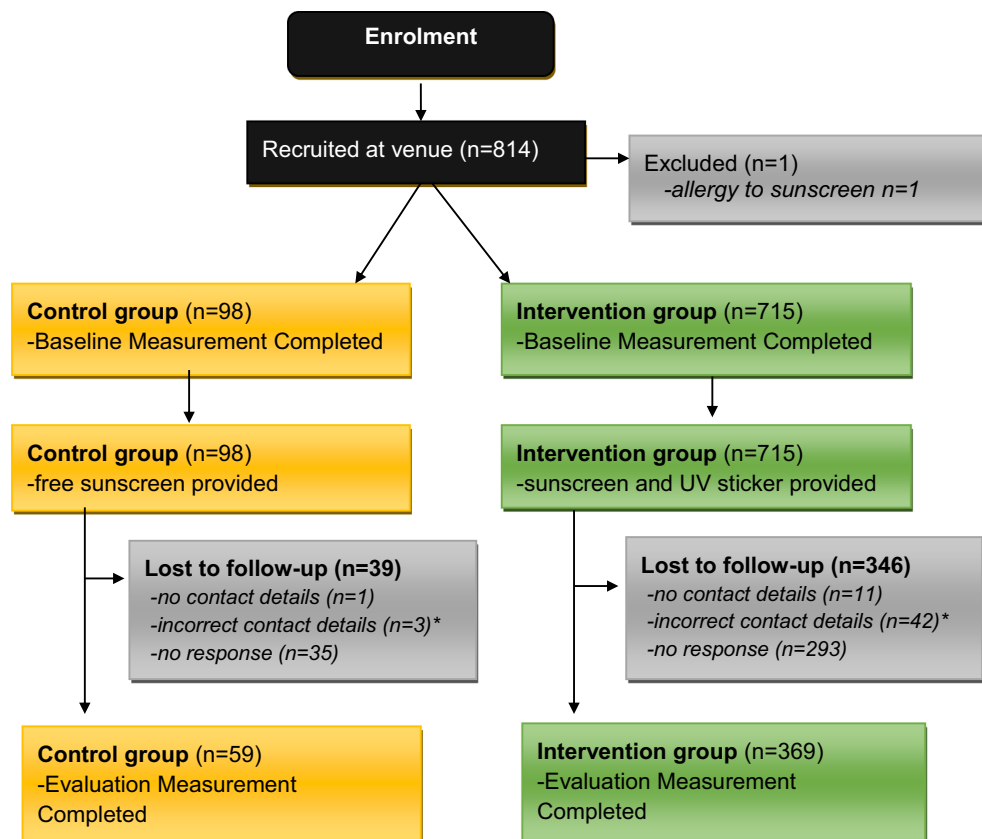


Fig. 3. Flow chart of study recruitment. During recruitment participant's completed contact details and some information was not decipherable, *incorrect contact details = email bounced back to sender and evaluation questionnaire was not received by participant.

(Petersen and Wulf, 2014). This study did not measure the thickness of sunscreen applied by participants. Future studies could address this limitation by using the non-invasive skin swabbing technique (O'Riordan et al., 2005; Bauer et al., 2010; Whiteman et al., 2003b) to explore if UV detection stickers can improve the thickness of sunscreen applied. UV cameras which visualize the sunscreen layer and highlight areas missed may also assist to improve people's understanding of sunscreen thickness with portable UV cameras currently under development (Pratt et al., 2017). Although participants reported sunscreen feels greasy on their skin, the majority of participants reported it was 'important' and 'healthy' to use. Improving sunscreen texture and aesthetics, as well as application techniques needs to be a focus of future research programs.

Another potential reason for increased sunburn may have been increased awareness and therefore reporting bias among the intervention group. The Hawthorne effect may have been heightened in the intervention compared to the control group as they were asked to regularly observe the sticker's color. Future studies could address this limitation by objectively assessing the degree of erythema on the day following exposure. The relatively small sample size of participants who reported sunburn means we cannot rule out the possibility the differences in results are attributable to chance alone. To address this floor effect, future studies need to enrol a substantially larger sample to clarify the possible relationship between UV detection stickers and sunburn.

The UV detection sticker technology resonated with participants in this study as evidenced by their high adherence (95%) and satisfaction rates (86% would like to have the UV detection stickers at future outdoor events). They further recommended creative designs such as supporter slogans would be engaging; this should be considered when designing future interventions using this technology. The context relevant high UVR environment where this study was undertaken is also an important factor with previous research illustrating tailoring health

information to each user "in-the-moment" where it is most meaningful and ecologically valid has the most potential to be beneficial (Heron and Smyth, 2010). The UV detection sticker provides personalized information regarding sunscreen protection and does not require any companion device. This overcomes limitations when conducting mobile phone-based health interventions, which include costs and mobile phone availability, and the congestion of mobile towers during peak periods impairing connectivity. Barriers identified for the UV detection stickers included confusion around the color change, which could be overcome by clear labelling instructions.

Strengths of our study include recruitment of a large sample in a realistic field setting, exposed to high UVR, and the high adherence of the intervention device. The consistent weather conditions across the four-day measurement period provided comparable data across intervention and control groups. Another strength of the study was the recruitment of a large proportion of male participants (72%), who are commonly underrepresented in prevention studies. Limitations of this study included the self-reported outcome measures, which could have been subject to recall and social desirability biases, and the smaller number of participants in the control group. The retention rate of 53% (428/813) reduced our sample size significantly and may have led to low statistical power contributing to non-significant findings. Retention rates for research studies have dropped dramatically over the past several decades and a previous study testing the use of the Solar Cell mobile app reported a similar retention rate of 57% (454/794) (Buller et al., 2015). Similar to reported and expected trends (Olsen et al., 2012), we observed female participants, those with a previous history of skin cancer, and Australian residents were more likely to remain in the study.

Sunburn prevalence was low (< 10%) in this study limiting the sample size for meaningful analysis of this outcome measure. However, the self-reported sunburn rate for both the intervention and control

group was lower than the Australian national sun protection survey data from 2016 to 2017 indicating 17% of adults reported a sunburn on the previous weekend (Cancer Council Australia, n.d.).

A further limitation of this study was the convenience sampling in an event setting and using a sequential rather than randomized assignment. Reflecting the sporting event, participants were mainly male (> 70%) and the results may not be generalizable to other subgroups of the population. The lack of randomization means there may also be other unmeasured differences between the groups. Improving sunscreen use among men is important for skin cancer prevention. In Queensland men have higher rates of sunburn than women (Queensland Government, 2016), which was also observed in our study and are twice as likely as women to be non-adherent to daily sunscreen application (Neale et al., 2002). Men also have a higher rate of death (9.4 deaths per 100,000) from melanoma than women (3.6 deaths per 100,000) (Australian Institute of Health and Welfare, 2016). The results from this study demonstrate the potential UV detection stickers may have in improving sunscreen reapplication in a less sun aware population, with greater improvement observed among people who reported needing a reminder.

5. Conclusion

This study tested the effectiveness of UV detection stickers to reduce sunburn and improve reapplication of sunscreen in a high UV-environment. We found increased re-application of sunscreen among participants provided with a UV detection sticker. However, sunburn rates remain unchanged.

Declaration of Competing Interest

EH has previously received funding from Suncayr Ltd. to undertake contract research projects. Authors CH, HF, GH, CO, NP, MJ state no conflict of interest.

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Author contributions

EH contributed to conceptualization, funding acquisition, investigation, methodology, project administration, resources, data curation, formal analysis, supervision, visualization, and writing, reviewing and editing the manuscript. CH contributed to project administration, investigation, formal analysis and writing, reviewing and editing the manuscript. HF contributed to project administration, investigation, and reviewing and editing the manuscript. GH contributed to the sample size and power calculations and logistical regression analysis, CO contributed to formal analysis, NP contributed to sample

size estimates. GH, CO and NP all provided discussion, review and editing of the manuscript. MJ contributed to the methodology and reviewing and editing the manuscript.

Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.ypmed.2019.05.005>.

References

- Armstrong, A.W., Watson, A.J., Makredes, M., Frangos, J.E., Kimball, A.B., Kvedar, J.C., 2009. Text-message reminders to improve sunscreen use: a randomized, controlled trial using electronic monitoring. *Arch. Dermatol.* 145, 1230–1236.
- Australian Institute of Health and Welfare, 2013. GRIM (General Record of Incidence of Mortality) Books. AIHW, Canberra.
- Australian Institute of Health and Welfare, 2016. Skin Cancer in Australia. Cat. No. CAN 96. AIHW, Canberra.
- Autier, P., Boniol, M., Dore, J.F., 2007. Sunscreen use and increased duration of intentional sun exposure: still a burning issue. *Int. J. Cancer* 121, 1–5.
- Bauer, U., O'Brien, D.S., Kimlin, M.G., 2010. A new method to quantify the application thickness of sunscreen on skin. *Photochem. Photobiol.* 86, 1397–1403.
- Buller, D.B., Berwick, M., Lantz, K., Buller, M.K., Shane, J., Kane, I., et al., 2015. Smartphone mobile application delivering personalized, real-time sun protection advice: a randomized clinical trial. *JAMA Dermatol.* 151, 497–504.
- Cancer Council Australia, 2017. The National sun Protection Survey. <https://www.cancer.org.au/news/media-releases/we%E2%80%99re-still-a-sunburnt-country.html> (Accessed November 2017).
- Cancer Council Australia National sun survey data 2016–2017 2018. <https://www.sunsmart.com.au/about/media-campaigns/media-releases/2018-media-releases/record-high-numbers-of-sunburns-treated-at-victorian-hospital-emergency-departments.html>, Accessed date: 8 August 2018.
- Diaz, A., Neale, R.E., Kimlin, M.G., Jones, L., Janda, M., 2012. The children and sunscreen study: a crossover trial investigating children's sunscreen application thickness and the influence of age and dispenser type. *Arch. Dermatol.* 148, 606–612.
- Ferlay J, Soerjomataram I, Ervik M, Forman D, Bray F, Dikshit R et al. GLOBOCAN 2012 v1.0, Cancer incidence and mortality worldwide: IARC CancerBase No. 11. 2013. <http://globocan.iarc.fr>. Accessed 18 November 2015.
- Gordon, L.G., Rowell, D., 2015. Health system costs of skin cancer and cost-effectiveness of skin cancer prevention and screening: a systematic review. *Eur. J. Cancer Prev.* 24, 141–149.
- Gordon, L.G., Elliott, T.M., Olsen, C.M., Pandeya, N., Whiteman, D.C., 2018. Multiplicity of skin cancers in Queensland and their cost burden to government and patients. *Aust. N. Z. J. Public Health* 42, 86–91.
- Green, A.C., Williams, G.M., Logan, V., Strutton, G.M., 2011. Reduced melanoma after regular sunscreen use: randomized trial follow-up. *J. Clin. Oncol.* 29, 257–263.
- Hacker, E., Boyce, Z., Kimlin, M.G., Wockner, L., Pollak, T., Vaartjes, S.A., et al., 2013. The effect of MC1R variants and sunscreen on the response of human melanocytes in vivo to ultraviolet radiation and implications for melanoma. *Pigment Cell Melanoma Res.* 26, 835–844.
- Hacker, E., Horsham, C., Vagenas, D., Jones, L., Lowe, J., Janda, M., 2018. A mobile technology intervention in skin cancer prevention with UVR dosimeters and smartphone applications in young adults: a randomised controlled trial. *JMIR mHealth UHealth* 6 (11), e199.
- Heron, K.E., Smyth, J.M., 2010. Ecological momentary interventions: incorporating mobile technology into psychosocial and health behaviour treatments. *Br. J. Health Psychol.* 15, 1–39.
- Neale, R., Williams, G., Green, A., 2002. Application patterns among participants randomized to daily sunscreen use in a skin cancer prevention trial. *Arch. Dermatol.* 138, 1319–1325.
- Olsen, C.M., Green, A.C., Neale, R.E., Webb, P.M., Cicero, R.A., Jackman, L.M., et al., 2012. Cohort profile: the QSkin sun and health study. *Int. J. Epidemiol.* 41, 929–i.
- Olsen, C.M., Wilson, L.F., Green, A.C., Biswas, N., Loyalka, J., Whiteman, D.C., 2017. Prevention of DNA damage in human skin by topical sunscreens. *Photodermatol. Photoimmunol. Photomed.* 33, 135–142.
- O'Riordan, D.L., Lunde, K.B., Urschitz, J., Glanz, K., 2005. A noninvasive objective measure of sunscreen use and reapplication. *Cancer Epidemiol. Biomark. Prev.* 14, 722–726.
- Petersen, B., Wulf, H.C., 2014. Application of sunscreen—theory and reality. *Photodermatol. Photoimmunol. Photomed.* 30, 96–101.
- van der Pols, J.C., Williams, G.M., Pandeya, N., Logan, V., Green, A.C., 2006. Prolonged prevention of squamous cell carcinoma of the skin by regular sunscreen use. *Cancer Epidemiol. Biomark. Prev.* 15, 2546–2548.
- Pratt, H., Hassanin, K., Troughton, L.D., Czanner, G., Zheng, Y., McCormick, A.G., et al., 2017. UV imaging reveals facial areas that are prone to skin cancer are disproportionately missed during sunscreen application. *PLoS One* 12, e0185297.
- Queensland Government, 2016. Queensland survey analytics system (QSAS), sunburn in Queensland-regional detailed data, 16 November 2016. https://www.health.qld.gov.au/_data/assets/file/0028/538336/qsas-sun.xls, Accessed date: November 2017.
- Rueden, C.T., Schindelin, J., Hiner, M.C., DeZonia, B.E., Walter, A.E., Arena, E.T., et al., 2017. ImageJ2: ImageJ for the next generation of scientific image data. *BMC Bioinf.* 18, 529.

- Shi, Y., Manco, M., Moyal, D., Huppert, G., Araki, H., Banks, A., et al., 2018. Soft, stretchable, epidermal sensor with integrated electronics and photochemistry for measuring personal UV exposures. *PLoS One* 13, e0190233.
- Shih, S.T., Carter, R., Sinclair, C., Mihalopoulos, C., Vos, T., 2009. Economic evaluation of skin cancer prevention in Australia. *Prev. Med.* 49, 449–453.
- Shih, S.T., Carter, R., Heward, S., Sinclair, C., 2017. Economic evaluation of future skin cancer prevention in Australia. *Prev. Med.* 99, 7–12.
- Staples, M.P., Elwood, M., Burton, R.C., Williams, J.L., Marks, R., Giles, G.G., 2006. Non-melanoma skin cancer in Australia: the 2002 national survey and trends since 1985. *Med. J. Aust.* 184, 6–10.
- Whiteman, D.C., Watt, P., Purdie, D.M., Hughes, M.C., Hayward, N.K., Green, A.C., 2003a. Melanocytic nevi, solar keratoses, and divergent pathways to cutaneous melanoma. *J. Natl. Cancer Inst.* 95, 806–812.
- Whiteman, D.C., Brown, R.M., Xu, C., Paterson, C.L., Miller, D., Parsons, P.G., 2003b. A rapid method for determining recent sunscreen use in field studies. *J. Photochem. Photobiol. B* 69, 59–63.
- Williams, J.D., Maitra, P., Atillasoy, E., Wu, M.M., Farberg, A.S., Rigel, D.S., 2018. SPF 100+ sunscreen is more protective against sunburn than SPF 50+ in actual use: results of a randomized, double-blind, split-face, natural sunlight exposure clinical trial. *J. Am. Acad. Dermatol.* 78, 902–910 (e2).
- Zou, W., Gonzalez, A., Jampaiah, D., Ramanathan, R., Taha, M., Walia, S., et al., 2018. Skin color-specific and spectrally-selective naked-eye dosimetry of UVA, B and C radiations. *Nat. Commun.* 9, 3743.