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The Children and Sunscreen Study

A Crossover Trial Investigating Children's Sunscreen Application Thickness and the Influence of Age and Dispenser Type

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Objectives: To measure the thickness at which primary schoolchildren apply sunscreen on school day mornings and to compare it with the thickness (2.00 mg/cm²) at which sunscreen is tested during product development, as well as to investigate how application thickness was influenced by age of the child (school grades 1-7) and by dispenser type (500-mL pump, 125-mL squeeze bottle, or 50-mL roll-on).

Design: A crossover quasiexperimental study design comparing 3 sunscreen dispenser types.

Setting: Children aged 5 to 12 years from public primary schools (grades 1-7) in Queensland, Australia.

Participants: Children (n=87) and their parents randomly recruited from the enrollment lists of 7 primary schools. Each child provided up to 3 observations (n=258).

Intervention: Children applied sunscreen during 3 consecutive school weeks (Monday through Friday) for the first application of the day using a different dispenser each week.

Main Outcome Measure: Thickness of sunscreen application (in milligrams per square centimeter). The dispensers were weighed before and after use to calculate the weight of sunscreen applied. This was divided by the coverage area of application (in square centimeters), which was calculated by multiplying the children's body surface area by the percentage of the body covered with sunscreen.

Results: Children applied their sunscreen at a median thickness of 0.48 mg/cm². Children applied significantly more sunscreen when using the pump (0.75 mg/cm²) and the squeeze bottle (0.57 mg/cm²) compared with the roll-on (0.22 mg/cm²) ($P < .001$ for both).

Conclusions: Regardless of age, primary schoolchildren apply sunscreen at substantially less than 1.00 mg/cm², similar to what has been observed among adults. Some sunscreen dispensers seem to facilitate thicker application than others.

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EXPOSURE TO UV RADIATION from the sun is the leading environmental cause of melanoma and nonmelanoma skin cancers.¹ Childhood sun exposure is thought to be a key risk factor for future skin cancer development.^{2,3} Incidence rates of skin cancer continue to rise globally.⁴ Australia, particularly Queensland, has the highest rates of skin cancer in the world,^{4,5} and the treatment of these cancers costs the Australian health care system approximately A\$300 million annually.⁶ Primary prevention of skin cancer remains a public health challenge.

Common recommendations for primary prevention include the following: (1) avoiding peak UV sun exposure; (2) wearing sun-protective clothing, in-

cluding broad-brim hats; (3) staying in the shade whenever possible; and (4) using broad-spectrum water-resistant sunscreen with a high (≥ 30) sun protection factor (SPF), a measure of the product's effectiveness at preventing UVB-induced sunburn.⁷⁻⁹ Regular use of sunscreen during childhood has been estimated to reduce lifetime skin cancer risk by up to 80%.¹⁰ Often used as a stand-alone primary prevention method,¹¹ sunscreen is the most common form of sun protection used by children¹¹ and by parents for children.¹²

A randomized controlled trial showed that regular sunscreen use can decrease the risk of squamous cell carcinoma, one type of nonmelanoma skin cancer,^{13,14} while it had only moderate long-term benefit for basal cell carcinoma, the other primary non-melanoma skin cancer.¹⁴ Recent 15-year fol-

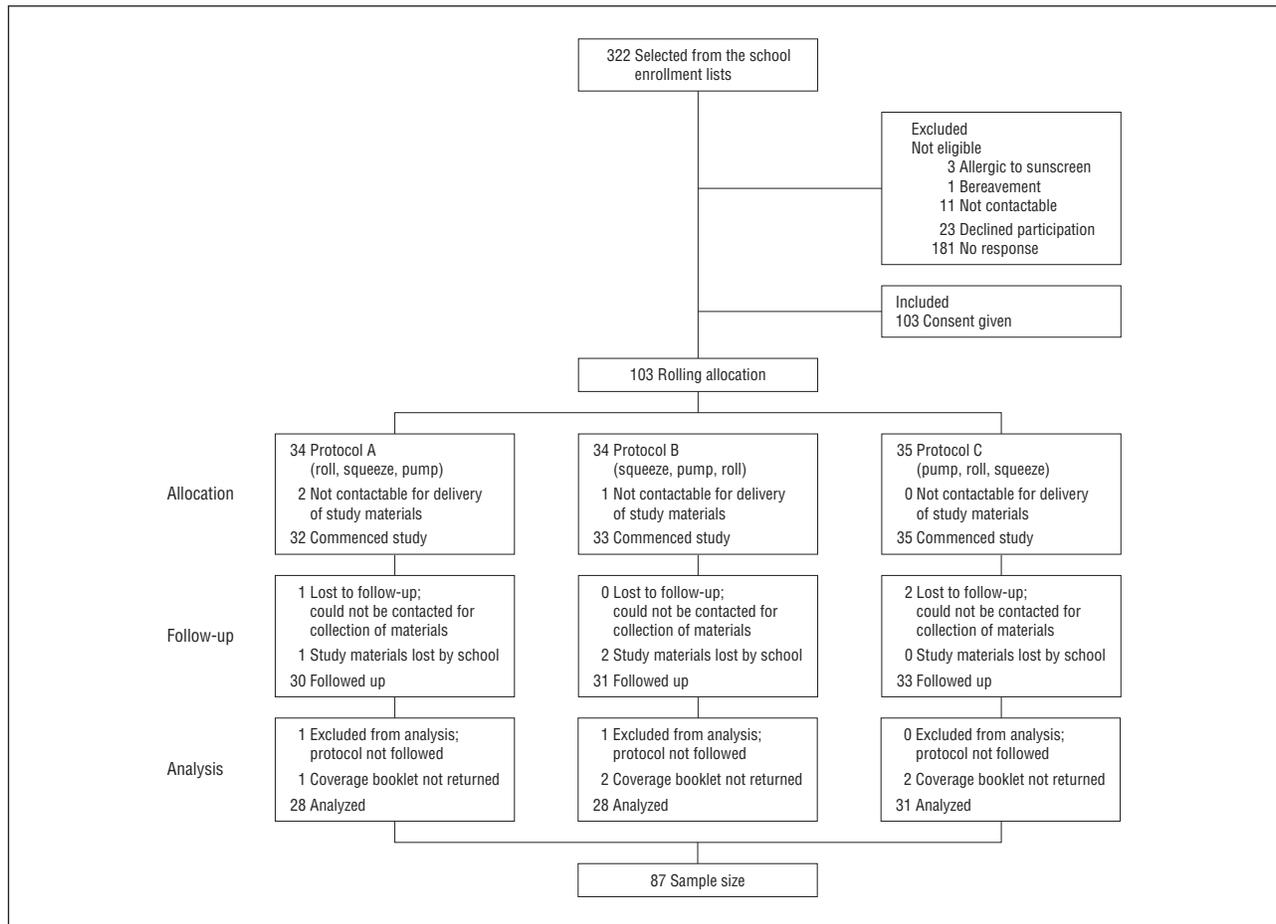


Figure 1. Consolidated Standards of Reporting Trials flowchart of the Children and Sunscreen Study.

low-up results of trial participants demonstrated that those randomized to daily sunscreen use had a significantly lower risk of melanoma than those randomized to discretionary sunscreen use (hazard ratio, 0.50; $P = .05$).¹⁵

The SPF of sunscreens is tested at a thickness of 2.00 mg/cm². Adults tend to wear between one-quarter and one-half of this thickness.¹⁶⁻²⁷ Because there is a linear relationship between the thickness of application and the SPF, this may result in a substantially lower SPF than that stated on the bottle.²⁸ Results of previous studies suggest that sunscreen application thickness may differ when using sunscreen for recreational use^{18,19,22} or for daily use¹⁶ and that the type and size of the sunscreen dispenser may influence the amount of sunscreen used.²⁹ For example, in one study²⁹ participants used 24 g per application on average when using a large open-mouthed jar but only 10 g when using a tube with a narrow opening.

It is unknown at what thickness children apply sunscreen and whether this is influenced by the type of sunscreen dispenser that is used. Therefore, the primary objectives of this study were to measure the thickness at which primary schoolchildren apply their sunscreen for daily use and to investigate the influence of age group and dispenser type on application thickness. A secondary study objective was to explore other potential determinants of sunscreen application thickness, such as skin cancer risk factors and typical sun exposure behaviors.

METHODS

ETHICS

Ethical clearance to conduct the Children and Sunscreen Study was granted by the Queensland University of Technology Ethics Committee (No. EC00171), Kelvin Grove, Australia. Informed consent was obtained from participating schools, parents, and, whenever possible, children.

PARTICIPANTS

Nine schools from a list of 20 eligible schools from a Brisbane, Australia, education region were randomly selected. Eligible schools had to be located within a 20-km radius from the research office. Colleges that also enrolled high school students were excluded. One of the selected schools was excluded because of language barriers inhibiting informed consent, and another school declined participation. Seven schools participated in the present study.

A computerized number generator was used to select 322 children from the enrollment lists of these 7 primary schools. Reasons for ineligibility ($n = 15$) included parent-reported allergy to sunscreen or current psychological distress and incorrect address information that prevented the family from receiving an invitation. Of 307 eligible students (95.3%), 126 (41.0%) replied. Of these, 23 children (18.3%) declined to participate, and 103 (81.7%) provided consent. As shown in **Figure 1**, 16 chil-



Figure 2. The 3 sunscreen dispensers used in this study (from left to right, 125-mL squeeze bottle, 500-mL pump, and 50-mL roll-on).

dren were lost to follow-up, did not follow study instructions, or did not return completed study materials and were excluded from the analysis. Results are based on the remaining 87 children, each providing up to 3 observations (n=258).

STUDY DESIGN

This study used a crossover quasiexperimental design. Each participant (n=87) was given 3 sunscreen dispensers, a 500-mL pump, a 125-mL squeeze bottle, and a 50-mL roll-on, free of charge (**Figure 2**). Each was to be used for 1 week during 3 consecutive study weeks. To avoid an order effect, children were consecutively allocated to a study protocol on a rolling basis, stratified by age group (junior, middle, and senior grades), that determined the order in which the dispensers were to be used (Figure 1). Sunscreen texture, consistency, ingredients, and their relative proportions were the same for each dispenser type.

Parents were advised that (only the participant could use the study-provided sunscreen (extra sunscreen was made available for other family members), that it must be self-applied by the child without physical assistance from others, and that the sunscreen must be used only for the first application on school days (Monday through Friday). No specific instructions were given as to coverage or quantity of the application.

DATA COLLECTION

Along with the dispensers, participants received an instruction sheet, parent questionnaire, coverage diary, and parent calendar. Study materials were labeled with the participant's name and were color coded so that all first-week materials were labeled green, second-week materials were labeled yellow, and third-week materials were labeled red (traffic light system). At the end of each week, a text message or e-mail reminder was sent to parents advising them to change to the next dispenser.

The mean sunscreen application thickness for each child was calculated by dividing the total weight of sunscreen used (in mil-

ligrams) by the total area of body that received sunscreen (in centimeters). Therefore, these 2 variables needed to be captured.

WEIGHT OF SUNSCREEN USED

Precise (0.0001 g) pharmaceutical-grade scales were used to weigh sunscreen bottles before and after use. The difference in these weights was assumed to be the weight of sunscreen applied during the study by the participant.

COVERAGE AREA

The body surface area (BSA) that was covered with sunscreen for each application was measured in 4 steps. First, the children's total BSA was calculated using the formula by Mosteller³⁰ because it has been previously validated for children³¹ with a representative sample³² as follows:

$$\text{BSA (in Square Meters)} = \{[\text{Weight (in Kilograms)} \times \text{Height (in Meters)}] / 3600\}^{0.5}$$

Children's weight and height measurements were reported by parents according to detailed study instructions. Second, to identify the areas of the body where each child applied sunscreen, children marked on a pictogram the areas of the body to which sunscreen had been applied or ticked a box to indicate that study sunscreen had not been used that day. The pictogram of the child had lines segmenting the different areas of the body (eg, upper arms from lower arms). Third, published age- and sex-specific body proportion data were used to estimate the proportion of the body that received sunscreen at each application.³³ Fourth, the sum of the daily proportions for each study week was multiplied by the total BSA to give a total area that received sunscreen each week. The weight of sunscreen used was divided by the total coverage area to estimate the weekly mean thickness of application (in milligrams per square centimeter) for each child.

EXPLORING OTHER DETERMINANTS OF CHILDREN'S SUNSCREEN APPLICATION THICKNESS

To explore associations between sunscreen application thickness and other behaviors and characteristics, parents were asked to complete a questionnaire. Included were questions about parents' and children's demographic characteristics (eg, age, number of siblings, and annual gross household income), phenotypic characteristics (eg, hair color, skin color, and tendency to burn), sun exposure behaviors (time spent in the sun), sun protection behaviors (eg, frequency of sunscreen, hat, and shade use), usual household sunscreen use (eg, SPF and dispenser type), children's attitudes about the study-provided sunscreen (eg, smell, look, and feel), and parents' knowledge, beliefs, and attitudes about skin cancer, sun protection, and sunscreen.

VALIDITY OF SELF-REPORTED MEASUREMENTS USED TO CALCULATE APPLICATION THICKNESS

A separate sample of parents (n=30) and children (n=30) from a state primary school in the same geographic area participated in a validity study during which children's height and weight were measured and children's sunscreen applications were covertly observed. Parents reported height (intraclass correlation coefficient [ICC], 0.95; 95% CI, 0.90-0.98) and weight (ICC, 0.99; 95% CI, 0.97-0.99) accurately, and children's reported coverage of application strongly correlated with the coverage area observed by the researcher (A.D.) (ICC, 0.89; 95% CI, 0.78-0.95).

STATISTICAL ANALYSIS

Commercially available statistical software (SPSS, version 14-18; SPSS, Inc) was used to complete all statistical analyses. Simple descriptive statistics (counts and percentages) were used to describe participant characteristics.

Each child provided 3 separate thickness measurements (1 for each of the dispensers used). The data set was initially arranged so that all thickness measurements (n=258) were combined into one outcome variable, with dispenser type as an index variable. The median (range) was used to describe children's sunscreen application thickness overall. The data set was rearranged so that the thicknesses obtained from each dispenser type formed separate outcome variables. From this data set, the medians (ranges) of thicknesses were presented to describe differences between dispenser types. The mean of the 3 thickness measurements was used to create a fourth outcome variable, mean thickness (n=87). To describe differences in application between school grades, the medians (ranges) of the mean thickness were used.

Wilcoxon signed rank test was used to determine whether there was a statistically significant difference between the median thicknesses obtained and the 2.00 mg/cm² at which SPF testing is performed. Kruskal-Wallis test was used to test for differences in the median thickness between dispenser types and between school grades, and post hoc Mann-Whitney test was used to identify which groups were significantly different from one another.

To address the secondary aim of this study, bivariate associations between sunscreen thickness and parent-reported child and parent sociodemographic and phenotypic characteristics, typical sun exposure and sun protection behaviors, sunscreen-related attitudes, and beliefs and purchasing behaviors were described (using medians and ranges) and were tested using Mann-Whitney test or Kruskal-Wallis test. Linear mixed models were then used to adjust significant bivariate associations for dispenser type and school grade, considering the intraperson correlations of the crossover study design by including dispenser type in the model as a repeated measure. Variables that remained significant after adjustment for dispenser type and school grade were included in a final linear mixed model. The log of sunscreen application thickness (in milligrams per square centimeter) was used as the outcome variable in these models because thickness was not normally distributed. Results were back-transformed to obtain the geometric means, which approximate the medians. Statistical significance was set a priori at $P \leq .05$ (2-tailed).

RESULTS

Table 1 summarizes the participants' sociodemographic and phenotypic characteristics and their typical sun exposure and sun protection behaviors. Boys (51.7%) and girls (48.3%) were about equally represented. Their mean age was 8.7 years (age range, 5-12 years). Forty-three children (49.4%) were in school years 3 to 5. Children commonly had light hair and eye color. Forty-eight children (55.2%) had previously experienced 3 or more sunburns. Most children had 1 sibling (37 participants [42.5%]) or more (40 participants [46.0%]). Thirty-two parents (37.2%) had not continued their education beyond secondary school. Fifty-three of 86 parents (61.6%) were employed full-time or part-time. Forty-three of 75 families (57.3%) reported an annual gross household income exceeding A\$60 000.

Table 1. Parent-Reported Key Characteristics of Participants

Characteristic	Value (n = 87)
Sex, No. (%)	
Female	45 (51.7)
Male	42 (48.3)
Age, mean (SD), y	8.7 (2.07)
School grade, No. (%)	
Junior, grades 1-2	20 (23.0)
Middle, grades 3-5	43 (49.4)
Senior, grades 6-7	24 (27.6)
Hair color, No. (%)	
Red, fair, or blonde	22 (25.3)
Light or mouse brown	39 (44.8)
Dark brown or black	26 (29.9)
Eye color, No. (%)	(n = 85)
Blue or gray	35 (41.2)
Green or hazel	20 (23.5)
Brown or black	30 (35.3)
Skin color, No. (%)	
Fair	44 (50.6)
Medium	24 (27.6)
Olive or brown	19 (21.8)
Lifetime sunburns, No. (%)	
<3	39 (44.8)
≥3	48 (55.2)
Time outside on weekdays, No. (%)	(n = 85)
1-30 min	8 (9.4)
>30 min to <2 h	67 (78.8)
≥2 h	10 (11.8)
Days sunscreen used on weekdays, No. (%)	(n = 86)
0	31 (36.0)
1-2	18 (20.9)
3-4	13 (15.1)
5	24 (27.9)
Siblings, No. (%)	
0	10 (11.5)
1	37 (42.5)
≥2	40 (46.0)
Parent's highest educational level, No. (%)	(n = 86)
Primary or secondary school	32 (37.2)
Trade certificate or college diploma	33 (38.4)
≥University degree	21 (24.4)
Parent's employment status, No. (%)	(n = 86)
Full-time	24 (27.9)
Part-time	29 (33.7)
Home care provider	26 (30.2)
Student, unemployed, or other	7 (8.1)
Annual gross household income, A\$, No. (%)	(n = 75)
≤60 000	32 (42.7)
≥60 001	43 (57.3)

The overall median thickness at which children applied their sunscreen was 0.48 mg/cm² (range, 0.00-8.72 mg/cm²), which was significantly less than 2.00 mg/cm² ($P < .001$), as was the median application thickness for each school grade group. Thickness achieved with all 3 dispensers was substantially less than 2.00 mg/cm². The median application thickness was highest for the pump (0.75 mg/cm² [range, 0.00-8.72 mg/cm²]), intermediate for the squeeze bottle (0.57 mg/cm² [range, 0.15-5.10 mg/cm²]), and lowest for the roll-on (0.22 mg/cm² [range, 0.01-1.58 mg/cm²]). Children used significantly less sunscreen when using the roll-on compared with the pump or the squeeze bottle ($P < .001$ for both). In contrast, the

Table 2. Significant Bivariate Associations of Sunscreen Application Thickness, Unadjusted and Adjusted for Dispenser Type and School Grade^a

Variable	No.	Unadjusted		Adjusted	
		Median (Range), mg/cm ²	P Value	GM (95% CI), mg/cm ²	P Value
Dispenser type					
Pump	86	0.75 (0.00-8.72)	<.001	0.72 (0.59-0.88)	<.001
Squeeze bottle	85	0.57 (0.15-5.10)		0.63 (0.51-0.76)	
Roll-on	87	0.22 (0.01-1.58)		0.22 (0.18-0.26)	
School grade					
1	12	0.69 (0.44-2.79)	.03	0.62 (0.43-0.89)	.03
2	8	0.93 (0.23-2.73)		0.65 (0.41-1.12)	
3	18	0.48 (0.17-4.39)		0.45 (0.33-0.61)	
4	13	0.58 (0.32-2.49)		0.48 (0.34-0.69)	
5	12	0.40 (0.11-0.90)		0.28 (0.20-0.41)	
6	12	0.51 (0.37-1.93)		0.54 (0.38-0.78)	
7	12	0.43 (0.18-1.68)		0.37 (0.26-0.53)	
Annual gross household income, A\$					
≤60 000	32	0.67 (0.15-4.39)	.01	0.65 (0.53-0.84)	.003
≥60 001	43	0.49 (0.11-2.49)		0.41 (0.33-0.50)	
Siblings, No.					
0-1	47	0.48 (0.11-2.73)	.003	0.44 (0.37-0.53)	.02
2	27	0.68 (0.29-4.39)		0.61 (0.48-0.78)	
≥3	13	0.35 (0.23-1.38)		0.34 (0.24-0.48)	
Lifetime sunburns, No.					
<3	39	0.49 (0.15-2.79)	.03	0.47 (0.38-0.58)	.06
3-5	31	0.66 (0.18-4.39)		0.59 (0.47-0.75)	
≥6	17	0.39 (0.11-4.53)		0.37 (0.27-0.51)	
Parent's lifetime severe sunburns, No.					
<3	11	0.35 (0.15-1.74)	.02	0.36 (0.24-0.53)	.14
3-5	24	0.55 (0.18-4.39)		0.57 (0.44-0.74)	
≥6	52	0.55 (0.11-2.54)		0.48 (0.40-0.57)	
How important is fragrance to parents when purchasing sunscreen?					
Very important or important	16	0.58 (0.42-0.80)	.009	0.57 (0.41-0.79)	.06
Somewhat important	19	0.82 (0.22-2.73)		0.57 (0.43-0.76)	
Not important	52	0.48 (0.11-2.49)		0.40 (0.34-0.48)	
Did the child like the smell of the study-provided sunscreen? ^b					
Yes	29	0.66 (0.17-4.39)	.03	0.50 (0.38-0.65)	.06
No	10	0.39 (0.11-1.07)		0.28 (0.17-0.48)	

Abbreviation: GM, geometric mean.

^aParent reported except for dispenser type.

^bParents were asked to obtain this information from their child and report it on the questionnaire.

difference between the pump and the squeeze bottle was not significant. The median application thickness for week 2 (median, 0.47 mg/cm²) was 0.11 mg/cm² less than that for week 1 (median, 0.58 mg/cm²; *P* = .64), and the median application thickness for week 3 (0.42 mg/cm²) was 0.05 mg/cm² less than that for week 2 (*P* = .18). The difference in application thickness from week 1 to week 3 was not significant (*P* = .07).

In contrast to a priori expectations, phenotype, usual time in the sun, and frequency of sun protection behaviors (eg, frequency of application of sunscreen) were not significantly associated with sunscreen application thickness. Parents' and children's sunburn history and their attitudes about sunscreen fragrance were associated with application thickness at the bivariate level. However, when adjusting for dispenser type and school grade, these associations were no longer significant (**Table 2**).

Sociodemographic factors, specifically the number of siblings and the annual gross household income,

were significantly associated with sunscreen application thickness. Twenty-seven children with 2 siblings applied sunscreen at a significantly greater thickness (median, 0.68 mg/cm²) than 47 children with fewer siblings (median, 0.48 mg/cm²) or 13 children with more siblings (median, 0.35 mg/cm²) (overall *P* = .003) (Table 2). The number of siblings remained significantly associated with sunscreen application thickness when adjusting for dispenser type and school grade (*P* = .02). Thirty-two children residing in households with an annual gross household income of A\$60 000 or less applied sunscreen at a significantly lower thickness than 43 children residing in higher-income households (difference in median, 0.18 mg/cm²; *P* = .01). This association remained significant when adjusting for dispenser type and school grade (*P* = .003). When entered together into the final model, dispenser type (*P* < .001), school grade (*P* = .02), annual gross household income (*P* = .001), and the number of siblings (*P* = .005) re-

mained significantly associated with sunscreen application thickness.

COMMENT

Previous studies¹⁶⁻²⁷ have investigated the thickness at which sunscreen is applied; however, all investigations were performed among adults. The Children and Sunscreen Study measured the mean thickness at which primary schoolchildren apply their sunscreen at home and found the application thickness to be similar to that reported among adults. Children applied less than one-quarter (median thickness, 0.48 mg/cm²) of the quantity of sunscreen used during SPF testing. Because of the quasilinear relationship between sunscreen thickness and the SPF,²⁸ these results suggest that children's in-use SPF may be less than one-fourth of the manufacturer's SPF. Sunscreen is often the only form of sun protection used by children¹¹; therefore, they may be less well protected from the sun than parents might expect.

The sunscreen application thickness was low irrespective of the children's age or the dispenser type used. However, children in the youngest school grades (1 and 2) applied significantly more sunscreen than the older children. There are several plausible explanations for this. Younger children may be more motivated to please the researcher, may be less likely to follow study protocol or spill excess sunscreen, or may receive more parent or teacher encouragement, assistance, or education about sunscreen use. During adolescence, overall adherence to sun protection practices decreases.³⁴⁻³⁷ Therefore, it was anticipated that older children may apply the least sunscreen, but there was no significant difference between children in grades 3 through 5 and those in grades 6 and 7.

Although the mean sunscreen application thickness was significantly less than 2.00 mg/cm² regardless of the dispenser type used, the roll-on yielded particularly poor results (median thickness, 0.22 mg/cm²) across all age groups. None of the children applied sunscreen at a thickness of 2.00 mg/cm² with the roll-on, although some children did with the pump or squeeze bottle. These results suggest that without specific instructions the roll-on may be unsuitable for children's use. Some parents may prefer to use a roll-on because it is compact, it does not necessarily require getting sunscreen on the hands, and it has a screw-on lid that makes it suitable for transporting in children's schoolbags.³⁸ However, given the results of this study, parents should be advised to provide sunscreen in pump or squeeze bottle dispensers, at least for the morning home application, with roll-ons reserved for supplementary applications during the day if necessary. Similarly, schools may best provide sunscreen in easy-dispensing bottles.

Educational interventions may help to improve sunscreen application thickness. Two studies^{26,27} showed that specific information about the amount of sunscreen used in SPF testing, along with discussion or demonstration of techniques to estimate 2.00 mg/cm², may improve the median sunscreen application thickness. However, these studies were limited by the absence of a control group²⁷ and by the lack of premeasurements.²⁷ Both studies were

performed among adults and may not generalize to children's sunscreen application behaviors. Future educational interventions might use modern communication technology, which has been shown to effectively assist in improving the frequency of sunscreen use.³⁹

A limitation of the Children and Sunscreen Study was the small sample size, which prevented us from generating a fully adjusted multivariable model. However, several factors were identified at the bivariate level that may be important for children's sunscreen application behavior. These warrant further investigation in larger studies. A low consent rate (32.0%) was also a limitation of this study. If those children who took part were particularly motivated about sun protection, our study may have overestimated the thickness of sunscreen application commonly achieved.

Only one brand of sunscreen was tested in this study. Thickness at which children apply sunscreen may vary across brands; however, the consistency of our findings with previous results in which other brands of sunscreen were tested indicates that application thickness would be low regardless of the brand used. Furthermore, because the present study was conducted in a high ambient UV environment among a predominantly fair-skinned population, the participants may have been more familiar with sunscreen applications than those in low ambient UV environments. This could indicate that our findings may have overestimated the amount of sunscreen that children would usually apply.

In summary, this study confirms previous findings among adult populations. Applying sunscreen at a thickness of 2.00 mg/cm² is infeasible; however, there is room for improvement in the way sunscreen is used. Educational interventions are needed to maximize the protection received from sunscreen, along with enhanced availability of sunscreens that are highly accepted, easily dispensed, and encourage uniform coverage of sunscreen at greater thickness. Our results highlight the need for continued recommendations that sunscreens should be combined with other forms of sun protection, such as hats, clothing, and shade, to achieve optimal UV protection.

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Author Contributions: Ms Diaz and Drs Neale, Kimlin, and Janda had full access to all the data in the study and take responsibility for the integrity of the data and the accuracy of the data analysis. *Study concept and design:* Diaz, Neale, Kimlin, and Janda. *Acquisition of data:* Diaz, Neale, and Janda. *Analysis and interpretation of data:* Diaz, Neale, Kimlin, Jones, and Janda. *Drafting the manuscript:* Diaz, Neale, Kimlin, Jones, and Janda. *Critical revision of the manuscript for important intellectual content:* Diaz, Neale, Kimlin, Jones, and Janda. *Statistical analysis:* Diaz, Neale, Kimlin, Jones, and Janda. *Obtained funding:* Diaz. *Administrative,*

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