The Children and Sunscreen study: a cross over trial investigating children's sunscreen application thickness and the influence of age and dispenser type

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Keywords: sunscreen, skin cancer, prevention, thickness, children

Abstract

Objective: To measure the thickness at which primary school children apply sunscreen on school day mornings and compare it to the 2mg/cm^2 at which sunscreen is tested during product development. We also sought to investigate how application thickness was influenced by age of the child (School-Grade 1 to 7) and dispenser type (500ml pump, 125ml squeeze or 50ml roll-on).

Design: A cross-over quasi-experimental study design comparing three sunscreen dispenser types.

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

Other Participants: Children (n = 87) and their parents randomly recruited from the enrolment lists of seven primary schools. Each child provided up to three observations (n = 258).

Intervention: Children applied sunscreen over three consecutive school weeks (Monday to Friday) for the first application of the day, using a different dispenser each week.

Main Outcome Measure: Thickness of sunscreen application (mg/cm^2). The dispensers were weighed before and after use to calculate weight of sunscreen applied. This was divided by the coverage area of application (cm^2), 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 0.48mg/cm^2. Children applied significantly more sunscreen when using the pump (0.75mg/cm^2, $p<0.001$) and the squeeze (0.57mg/cm^2, $p<0.001$) dispensers compared to the roll-on dispenser (0.22mg/cm^2).

Conclusions: Regardless of age, primary school children apply sunscreen at well less than 1 mg/cm^2, similar to what has been observed in adults. Some sunscreen dispensers appear to facilitate thicker application than others.

Introduction

Exposure to ultraviolet (UV) radiation from the sun is the leading environmental cause of melanoma and non-melanoma skin cancers (NMSC).[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, in particular 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 AUD 300 million annually.[6] Primary prevention of skin cancer thus remains a public health challenge.

Common recommendations for primary prevention include: (1) avoiding peak-UV sun exposure; (2) wearing sun-protective clothing, including 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 percent.[10] Of used as a stand-alone primary prevention method[11], sunscreen is the most common form of sun-protection used by children[11] and by parents for children.[12]

A randomised-controlled trial has shown that regular sunscreen use can decrease risk of squamous cell carcinoma, one type of NMSC,[13, 14] while it only had moderate long-term benefit for basal cell carcinoma, the other primary NMSC skin cancer.[14] Recent results after 15-years follow-up of trial participants showed that those randomised to daily sunscreen use had a significantly lower risk of melanoma than those randomised to discretionary sunscreen use (Hazard ratio 0.50, $p = 0.05$).[15]

The SPF of sunscreens is tested at a thickness of $2mg/cm^2$. Adults, including those in the trial above[16] tend to wear between one-quarter and one-half of this.[17-27] As there is a linear

relation between the thickness of application and SPF, this may result in a substantially lower SPF than stated on the bottle.[28] Previous studies suggest that sunscreen application thickness may differ when using sunscreen for recreational[18, 19, 22] or for daily use[16] and that the type and size of the sunscreen dispenser may influence the amount of sunscreen used.[29] For example, in one study participants used 24g per application on average when using a large open-mouthed jar but only 10g when using a tube with a narrow opening.[29]

It is not currently known at what thickness children apply sunscreen, and whether this is influenced by the type of sunscreen dispenser that is used. Therefore, the primary aims of the present study were to measure the thickness at which primary school children apply their sunscreen for daily use and to investigate the influence of age group and dispenser type on application thickness. As a secondary study aim, this study also explored other potential determinants of sunscreen application thickness, such as skin cancer risk factors and typical sun exposure behaviours.

Methods

Ethics

Ethical clearance to conduct the Children and Sunscreen Study was granted by the Queensland University of Technology Ethics Committee (Number EC00171) and informed consent was obtained from participating schools, parents, and, whenever possible, children.

Participants

Nine schools from a list of eligible schools (n = 20) from one Brisbane education region were randomly selected. Eligible schools had to be located within a 20 kilometres radius from the research office. Colleges that also enrolled high school students were excluded. One of the selected schools was excluded due to language barriers inhibiting informed consent, and one declined participation. Seven schools participated in the current study.

A computerised number generator was used to select 322 children from the enrolment lists of these seven 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 the eligible students (n = 307, 95%), 126 (40%) replied. Of these, 23 children (19%) declined to participate, and 103 (81%) provided consent. As shown in **Figure 1**, 16 children were lost to follow-up, did not follow study instructions, or did not return completed study materials, and thus were excluded from analysis. Results are based on the remaining 87 children, each providing up to three observations (n = 258).

Study Design

This study employed a cross-over quasi-experimental design. Each participant (n = 87) was given three sunscreen dispensers, a 500ml pump dispenser, a 125ml squeeze dispenser and a

50ml roll-on dispenser, free of charge (**Figure 2)**. Each were to be used for one week over three 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 only be used for the first application on school days (Monday to 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 labelled with the participant's name and were colour coded so that all first week materials were labelled green, second week materials were yellow and third week materials were labelled red (traffic light system). At the end of each week we sent a text message or e-mail reminder to parents advising them to change to the next dispenser.

The average sunscreen application thickness for each child was calculated by dividing the total weight of sunscreen used (mg) by the total area of body that received sunscreen (cm^2), and therefore needed to capture these two parameters.

<u>Weight of sunscreen used</u>

Precise (0.0001g) 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 over the course of the study by the participant.

Coverage Area

The body surface area (BSA) that was covered with sunscreen for each application was measured via the following steps. First, the children's total BSA was calculated, using the Mosteller formula,[30] as it has been previously validated for children[31] with a representative sample:[32]

$$\text{BSA } (m^2) = [(\text{weight [kg]} \times \text{height } [m^2])/3600]^{0.5}$$

Children's weight and height measurements were reported by parents following detailed study instructions.

Second, to identify the areas of the body that each child applied sunscreen to, , children either marked on a pictogram the areas of the body to which sunscreen had been applied or ticked a box to indicate study sunscreen had not been used that day. The pictogram of the child had lines segmenting the different areas of the body (e.g. 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] Then, 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 average thickness of application (mg/cm^2) for each child.

Exploring other determinants of children's sunscreen application thickness

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

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 geographical 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 (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 researchers (ICC 0.89, 95%CI: 0.78-0.95).

Statistical Analysis

The statistical software package SPSS v. 14-18 (SPSS Inc, Chicago, IL) was used to complete all statistical analyses. Simple descriptive statistics (counts and percentages) were used to describe participant characteristics.

Each child provided three separate thickness measurements (one for each of the dispensers used). The dataset 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 dataset was rearranged so that the thicknesses obtained from each dispenser type formed separate outcome variables. From this dataset, medians (ranges) of thicknesses were presented to describe differences between dispenser types. The mean of the three thickness measurements was used to create a fourth outcome variable, "average thickness" (n = 87). To describe differences in application between school grades, medians (range) of "average thickness" were used.

Wilcoxon signed-rank tests were used to determine whether there was a statistically significant difference between the median thicknesses obtained and the 2mg/cm^2 at which SPF is tested. Kruskal-Wallis tests were performed to test for differences in median thickness between dispenser types and between school grades, and post-hoc Mann-Whitney tests employed 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 socio-demographic and phenotypic characteristics, typical sun-exposure and sun-protection behaviours, sunscreen-related attitudes, and beliefs and purchasing behaviours were described (median, range) and tested using Mann-Whitney or Kruskal-Wallis tests. Linear mixed models (LMM) were then used to adjust significant bivariate associations for dispenser type and school grade, taking into account 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 were included in a final LMM model. The log of sunscreen application thickness (mg/cm^2) was used as the outcome variable in these models as thickness was not normally distributed. Results were back-transformed to obtain the geometric means, which approximate medians. Statistical significance was set *a priori* at $p \leq 0.05$ (2-tailed).

Results

Table 1 describes the participants' socio-demographic and phenotypic characteristics, and typical sun-exposure and sun-protection behaviours. Boys (52%) and girls (48%) were about equally represented. The mean age was 8.7 years (range 5 -12 years). Approximately half of the children (n = 43, 49%) were in school years 3 to 5. Children commonly had light hair and eye colour. Approximately half of the children had previously experienced three or more sunburns (n = 48, 55%). Most children had one (n = 37, 43%) or more (n = 40, 46%) siblings. Over one-third (n = 32, 37%) of parents had not obtained an education beyond secondary school. Almost two-thirds (n=53, 62%) were full- or part-time employed. Over half of families (n = 43, 57%) reported a household income of over AUD 60,000 gross annually.

The overall median thickness at which children applied their sunscreen was 0.48mg/cm^2 (range 0.00 – 8.72mg/cm^2) which was significantly less ($p<0.001$) than 2mg/cm^2, as was the median application thickness for each school grade group. Thickness achieved with all three bottles was well below 2mg/cm^2. The median application thickness was highest for the pump (0.75mg/cm^2, range 0.00-8.72); intermediate for the squeeze (0.57mg/cm^2, range 0.15-5.10); and lowest for the roll-on (0.22mg/cm^2, range 0.01-1.58). Children used significantly less sunscreen when using the roll-on dispenser compared to the pump ($p<0.001$) or the squeeze dispenser ($p<0.001$). In contrast, the difference between the pump and squeeze dispensers was not significant. The median application thickness for week 2 was 0.11mg/cm^2 less than week 1 (median 0.47mg/cm^2, $p = 0.643$), and week 3 was 0.05mg/cm^2 less than week 2 ($p = 175$). The difference in application thickness from week 1 to week 3 was not significant ($p = 0.070$).

In contrast to *a-priori* expectations, phenotype, usual time in the sun and frequency of sun-protection behaviours (such as, frequency of wearing sunscreen) were not significantly associated with sunscreen application thickness. Parent's and children's sunburn history and their attitudes regarding sunscreen fragrance were associated with application thickness, at the bivariate level. When adjusting for dispenser type and school grade, however, these associations were no longer significant (**Table 2**).

Socio-demographic factors, specifically the number of siblings and the household annual income, were significantly associated with sunscreen application thickness. Children with two siblings (n = 27) applied sunscreen at a significantly greater thickness (median 0.68 mg/cm^2) than those with fewer (n = 47, median 0.48 mg/cm^2) or more (n = 13, median 0.35 mg/cm^2) siblings (overall significance p = 0.003). Number of siblings remained significantly associated with sunscreen application thickness when adjusting for dispenser type and school grade (p = 0.015). Children residing in households earning less than AUD 60,000 gross per annum (n = 32) applied sunscreen at a significantly lesser thickness than those in higher income families (n = 43) (difference in median 0.24mg/cm^2, p = 0.011). This association remained significant when adjusted for dispenser type and school grade (p = 0.003) (**Table 2**).

When entered together into the final model, dispenser type (p<0.001), school grade (p=0.020), household income (p=0.001) and the number of children in the household (p=0.005) remained significantly associated with sunscreen application thickness.

Comment

A number of previous studies have investigated the thickness at which sunscreen is applied; however, all have been conducted with adults.[16-27] The Children and Sunscreen Study measured the average thickness at which primary school children apply their sunscreen at home and found the application thickness to be similar to that reported in adults. Children applied less than one-quarter (median 0.48mg/cm^2) the quantity of sunscreen used during SPF testing. Due to the quasi-linear relationship between thickness and the SPF,[28] these results suggest 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 children;[11] thus, children may be less well sun-protected 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 a number of 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 with sun protection practices decreases.[34-37] It was anticipated, therefore, that older children may apply the least sunscreen, but there was no significant difference between children in grades 3-5 and those grades 6-7.

While the average application thickness was significantly less than 2mg/cm^2 regardless of dispenser type used, the roll-on dispenser yielded particularly poor results (median thickness 0.22mg/cm^2), across all age groups. None of the children applied sunscreen at 2mg/cm^2 thickness with the roll-on, although some children did when using the pump or squeeze dispensers. These results suggest that without specific instructions the roll-on dispenser may

be unsuitable for children's use. Some parents may prefer to use a roll-on as it does not necessarily require getting sunscreen on the hands, it is compact and has a screw-on-lid that makes it suitable for transporting in children's school bags.[38] However given the results of this study, parents may be advised to provide sunscreen in pump or squeeze bottles, at least for the morning home application, with roll-ons being 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 application thickness. Two studies have shown that specific information about the amount of sunscreen used in SPF testing, and discussion or demonstration of techniques to estimate 2mg/cm^2, may improve median sunscreen application thickness.[26, 27] However, these studies were both limited either by lack of pre-measurements or lack of a control group. Both studies were conducted in adults and may not apply to children's sunscreen application behaviours. Future educational interventions may utilise modern communication technology, which has been shown to effectively assist in improving 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. Several factors were identified at the bivariate level, however, that may be important for children's sunscreen application behaviour. These warrant further investigation in larger studies Low consent rate (32%) was also a limitation of this current study. If those children who took part were particularly motivated regarding sun protection, our study may have over-estimated 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 between brands; however, consistency of our findings with previous

results where other brands of sunscreen were tested indicates that application thickness would be low regardless of brand used. Further, as the current study was conducted in a high ambient UV- environment, amongst a pre-dominantly fair-skinned population, the participants may have been more familiar with sunscreen applications than those in low UV-environments. This could indicate that our findings may over-estimate the sunscreen children would usually apply.

In summary, this study confirms previous findings in adult populations. Applying sunscreen at a thickness of $2mg/cm^2$ is not feasible; however, there is still room for improvement in the way sunscreen is used. Educational interventions, along with availability of sunscreens that are highly accepted, easily dispensed, and encourage uniform coverage of sunscreen at greater thickness may maximise the protection received from sunscreen. These results highlight the need for continued recommendations that sunscreens be combined with other forms of sun-protection, such as hats, clothing and shade, to achieve optimal sun-protection.

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Figure Legends:

Figure 1: Children and Sunscreen Study using the CONSORT flow chart

Figure 2: Photograph of the three sunscreen dispensers used in this study (500 ml pump; 125ml squeeze and 50ml roll-on)

Table 1. Key participant characteristics [a b]

Characteristic	n	%
TOTAL	87	100.0
Gender		
Female	45	51.7
Male	42	48.3
Age	87	8.7 years (mean)
Grade		
Junior (grades 1-2)	20	23.0
Middle (grades 3-5)	43	49.4
Senior (grades 6-7)	24	27.6
Hair colour		
Red, fair or blonde	22	25.3
Light or mouse brown	39	44.8
Dark Brown or black	26	29.9
Eye colour		
Blue or grey	35	41.2
Green or hazel	20	23.5
Brown or black	30	35.3
Skin colour		
Fair	44	50.6
Medium	24	27.6
Olive or brown	19	21.8
Number of lifetime sunburns		
< 3 times	39	44.8
>= 3 times	48	55.2
Time outside on week days		
1 to 30 minutes	8	9.4

Table 1. Key participant characteristics [a b]

Characteristic	n	%
30 minutes to 2 hours	67	78.8
2 hours or more	10	11.8
Days sunscreen used (Monday to Friday)		
None	31	36.1
1 or 2 days	18	20.9
3 or 4 days	13	15.1
5 days	24	27.9
Number of siblings		
None	10	11.5
1	37	42.5
2 or more	40	46.0
Parent's Highest Education Level^		
Primary or Secondary School	32	37.2
Trade cert./college diploma	33	38.4
University degree or higher	21	24.4
Parent's employment status^		
Full-time	24	27.9
Part-time	29	33.7
Home-carer	26	30.2
Student, unemployed, or other	7	8.1
Annual gross household income*		
AUD 60,000 or less	32	42.7
AUD 60,001 or more	43	57.3

[a] *numbers and participants based on number of respondents for each item*

[b] *parent-reported*

Table 2: Summary of significant bivariate associations, unadjusted and adjusted for dispenser type and school grade[d]

			Unadjusted		Adjusted [a]		
Variable	***n***	**Median**	**Range**	***p-value*** [b]	**GM** [c]	**95% CI**	***p-value***
Dispenser				<0.001			<0.001
Pump	86	0.75	0.00-8.72		0.72	0.59-0.88	
Squeeze	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	
Age group (school grade)				0.032			0.034
Year 1	12	0.69	0.44-2.79		0.62	0.43-0.89	
Year 2	8	0.93	0.23-2.73		0.65	0.41-1.12	
Year 3	18	0.48	0.17-4.39		0.45	0.33-0.61	
Year 4	13	0.58	0.32-2.49		0.48	0.34-0.69	
Year 5	12	0.40	0.11-0.90		0.28	0.20-0.41	
Year 6	12	0.51	0.37-1.93		0.54	0.38-0.78	
Year 7	12	0.43	0.18-1.68		0.37	0.26-0.53	
Annual household gross income				0.011			0.003
$60,000 or less	32	0.67	0.15-4.39		0.65	0.53-0.84	
More than $60,000	43	0.49	0.11-2.49		0.41	0.33-0.50	

Table 2: Summary of significant bivariate associations, unadjusted and adjusted for dispenser type and school grade[d]

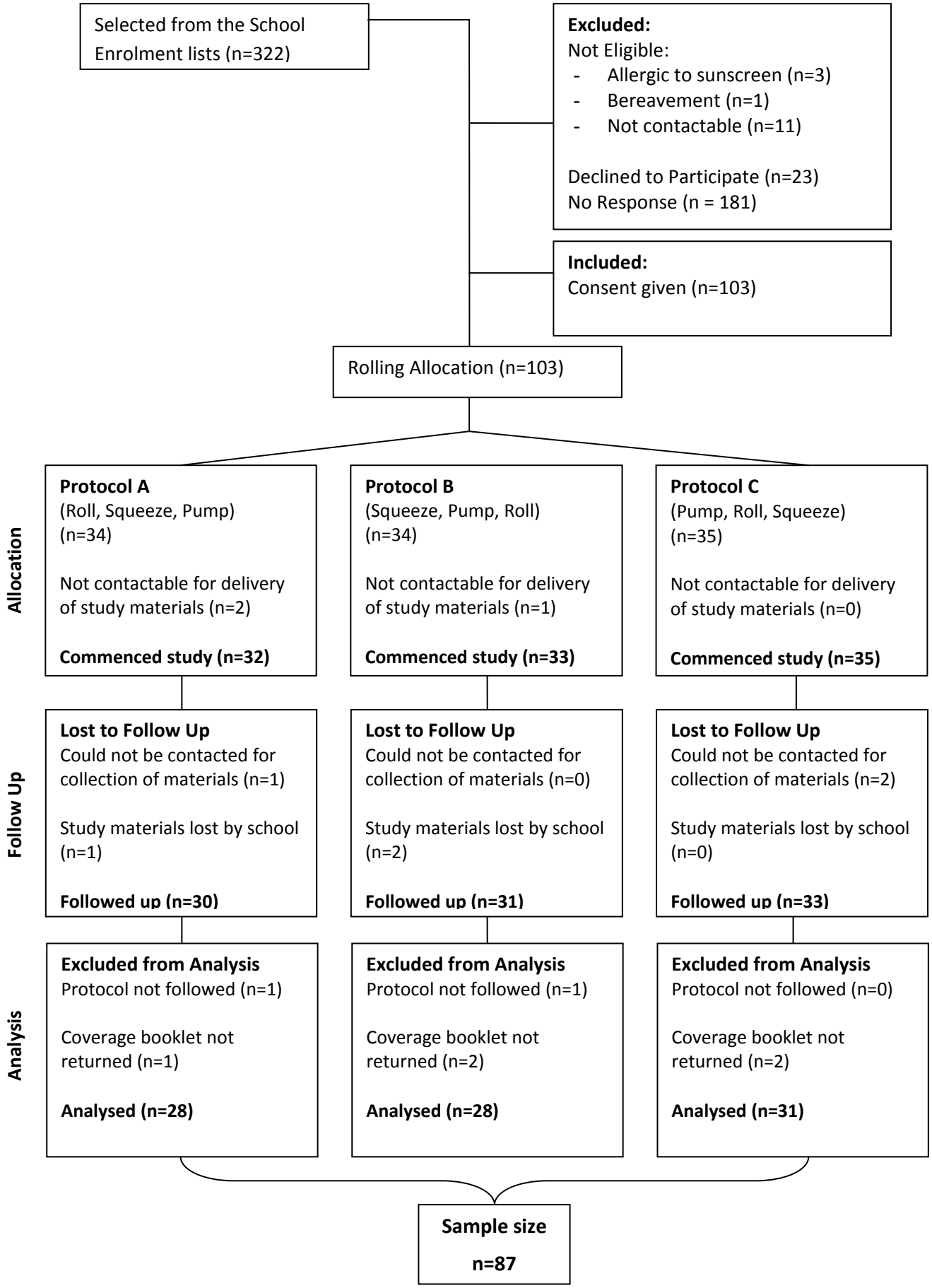
		Unadjusted			Adjusted [a]		
Variable	***n***	**Median**	**Range**	***p-value*** [b]	**GM** [c]	**95% CI**	***p-value***
Number of siblings				0.003			0.015
Zero or one	47	0.48	0.11-2.73		0.44	0.37-0.53	
Two	27	0.68	0.29-4.39		0.61	0.48-0.78	
Three or more	13	0.35	0.23-1.38		0.34	0.24-0.48	
Number of lifetime sunburns				0.028		0.27-0.51	0.057
Less than 3	39	0.49	0.15-2.79		0.47	0.38-0.58	
3 to 5	31	0.66	0.18-4.39		0.59	0.47-0.75	
6 or more	17	0.39	0.11-4.53		0.37		
Parent's number of lifetime severe sunburns				0.016			0.138
Less than 3	11	0.35	0.15-1.74		0.36	0.24-0.53	
3 to 5	24	0.55	0.18-4.39		0.57	0.44-0.74	
6 or more	52	0.55	0.11-2.54		0.48	0.40-0.57	
How important is fragrance to parents when purchasing sunscreen				0.009			0.057
Very Important or important	16	0.58	0.42-0.80		0.57	0.41-0.79	
Somewhat important	19	0.82	0.22-2.73		0.57	0.43-0.76	

Table 2: Summary of significant bivariate associations, unadjusted and adjusted for dispenser type and school grade[d]

		Unadjusted			Adjusted [a]		
Variable	***n***	**Median**	**Range**	***p-value*** [b]	**GM** [c]	**95% CI**	***p-value***
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? [e]				0.029			0.059
Yes	29	0.66	0.17-4.39		0.50	0.38-0.65	
No	10	0.39	0.11-1.07		0.28	0.17-0.48	

[a] *Adjusted for dispenser type and child's school grade*
[b] *Unadjusted associations*
[c] *GM: Geometric Mean*
[d] *With the exception of dispenser type, data was parent-reported*
[e] *Parents were asked to obtain this information from their child and report on the Questionnaire*

Figure 1


Selected from the School Enrolment lists (n=322)
Excluded:
Not Eligible:
- Allergic to sunscreen (n=3)
- Bereavement (n=1)
- Not contactable (n=11)
Declined to Participate (n=23)
No Response (n = 181)
Included:
Consent given (n=103)
Rolling Allocation (n=103)
Allocation
Protocol A
(Roll, Squeeze, Pump)
(n=34)
Not contactable for delivery of study materials (n=2)
Commenced study (n=32)
Protocol B
(Squeeze, Pump, Roll)
(n=34)
Not contactable for delivery of study materials (n=1)
Commenced study (n=33)
Protocol C
(Pump, Roll, Squeeze)
(n=35)
Not contactable for delivery of study materials (n=0)
Commenced study (n=35)
Follow Up
Lost to Follow Up
Could not be contacted for collection of materials (n=1)
Study materials lost by school (n=1)
Followed up (n=30)
Lost to Follow Up
Could not be contacted for collection of materials (n=0)
Study materials lost by school (n=2)
Followed up (n=31)
Lost to Follow Up
Could not be contacted for collection of materials (n=2)
Study materials lost by school (n=0)
Followed up (n=33)
Analysis
Excluded from Analysis
Protocol not followed (n=1)
Coverage booklet not returned (n=1)
Analysed (n=28)
Excluded from Analysis
Protocol not followed (n=1)
Coverage booklet not returned (n=2)
Analysed (n=28)
Excluded from Analysis
Protocol not followed (n=0)
Coverage booklet not returned (n=2)
Analysed (n=31)
Sample size
n=87