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A comprehensive approach to evaluating and classifying sun-protective clothing

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ABSTRACT

Background: National standards for clothing designed to protect the wearer from the harmful effects of solar ultraviolet radiation (UVR) have been implemented in Australia/New Zealand, Europe, and the USA. Industry standards reflect the need to protect the skin by covering a considerable proportion of the potentially exposed body surface area (BSA) and by reducing UVR-transmission through fabric (the Ultraviolet Protection Factor; UPF).

Objectives: This research aimed to develop a new index for rating sun-protective clothing that incorporates the BSA coverage of the garment in addition to the UPF of the fabric.

Methods: A mannequin model was fixed to an optical bench and marked with horizontal lines at 1 cm intervals. An algorithm (the Garment Protector Factor; GPF) was developed based on the number of lines visible on the clothed versus unclothed mannequin and the UPF of the garment textile. This data was collected in 2015-16 and analysed in 2016.

Results: The GPF weights fabric UPF by BSA coverage above the minimum required by international sun-protective clothing standards for upper-body, lower-body and full-body garments. GPF increases with BSA coverage of the garment and fabric UPF. Three nominal categories are proposed for the GPF: $0 \leq GPF < 3$ for garments that 'meet' minimum standards; $3 \leq GPF < 6$ for garments providing 'good' sun-protection; and $GPF \geq 6$ indicating 'excellent' protection.

Conclusions: Adoption of the proposed rating scheme should encourage manufacturers to design sun-protective garments that exceed the minimum standard for BSA coverage, with positive implications for skin cancer prevention, consumer education and sun-protection awareness.

Keywords: Sun-protective clothing, UPF, standard, skin cancer

What's already known about this topic?

National standards for clothing labelled as sun-protective are based on the clothing fabric exceeding a minimum ultraviolet protection factor (UPF). Standards vary on the minimum body surface area required to be covered.

What does this study add?

A new clothing classification system is introduced utilising an easy to calculate metric that incorporates both the fabric ultraviolet protection factor and protected body surface area. The new metric termed Garment Protection Factor (GPF) provides a mechanism for the fair assessment of apparel of different types and size categories aimed to encourage better sun-protective clothing design for the prevention of skin cancer.

INTRODUCTION

It is well established that ultraviolet radiation (UVR) is a human carcinogen[1]. Sunlight is the major environmental risk-factor for cutaneous melanoma, keratinoctye skin cancers, actinic keratoses, and pigmented moles[1,2,3,4,5] as well as causing or exacerbating several eye diseases, some of which can result in blindness[2,6].

In addition to being the most expensive cancer in Caucasian populations world-wide, skin cancer is highly preventable[7-9]. Estimates for the Australian population suggest that 80% of melanoma, the skin cancer with the highest malignant potential, could be prevented by reducing sun-exposure[10]. Consequently, the prevention of skin cancer has been the focus of important public health interventions aimed at reducing sun-exposure in at-risk populations over the past three decades[11-14].

In 1996, Australia pioneered a method for evaluating the UV-protective capabilities of clothing based on the transmission of UVR through fabric[15]. This research led to the development and implementation of the Australian and New Zealand Standard for the evaluation and classification of sun-protective clothing, AS/NZS 4399:1996[16]. It documented standardized Ultraviolet Protection Factor (UPF) measurement procedures and associated labeling specifications. As the first industry standard for sun-protective clothing to be introduced, it was widely adopted[17]. However, the original Australian/New Zealand Standard did not consider garment design in relation to body surface area (BSA) coverage[18,19]. This requirement was incorporated into a subsequent revision of the standard (AS/NZS 4399:2017)[18] and other international standards on sun protective clothing, such as those of the European Union[20].

We propose a comprehensive index for quantifying the sun-protective capabilities of clothing that takes into account both the BSA coverage afforded by the design of the garment and the UPF of the fabric. This index could be incorporated universally in industry standards for sun-protective clothing and could form the basis of a new rating and labelling scheme (the Garment Protection Factor, GPF) that is more informative for consumers.

METHODS

Derivation of the Garment Protection Factor

The GPF is designed to inform consumers about the benefits of garments that provide physical protection to as much of the skin surface as practical, and to encourage fashion designers/manufacturers to strive to improve the design and BSA coverage of sun-protective clothing. The GPF rates both the BSA coverage, determined by the design of the garment,

and the UPF of the fabric of which it is comprised. The GPF determines if an item of clothing meets or exceeds minimum international standards for sun-protective clothing[18,20] by the inclusion of two linear variables for the UPF and relative BSA covered as follows:

$$GPF = 3\left(\frac{UPF-15}{15}\right)\left(2\left(\frac{P-\mu}{U-\mu}\right)+1\right). \qquad (1)$$

In the equation, UPF is weighted relative to a minimum standard UPF of 15 (the lowest published international standard required for a sun protective garment)[18] and expressed as a fraction. The relative BSA coverage of the garment is expressed relative to the minimum number of horizontal bands (surface contours drawn onto a body model or mannequin) that must be protected to achieve the minimum BSA coverage stipulated in the standard, for an (i) upper-body garment, (ii) a lower-body garment, or (iii) an all-in-one garment. The contours represent the maximum practical surface area able to be covered from the neck to the hip-line, and across the shoulders to the wrists for upper-body garments, from the hip-line to the ankle for lower-body garments, and from the neck-line, shoulder to wrist and the ankle for all-in one garments.

The number of body contours in Equation (1) varies depending on the aged standardized height for which the clothing is designed, however the equation evaluates the *proportion* of excess skin surface protected by clothing items beyond minimum limits required by sun-protective clothing standards. This makes the size of the mannequin model irrelevant for the purposes of calculating the relative proportion of the skin surface protected by a garment exceeding minimum standards. The maximum number of contours defined in the BSA quotient for clothing of the relevant size is U. These contours can be counted on an unclothed mannequin model for either upper- or lower-body garments, as U_U or U_L respectively. P

represents the number of surface contours protected/covered by a particular garment when the mannequin model is clothed, and is denoted as either P_U or P_L for upper- and lower-body garments respectively.

The number of body contours that must be covered by a garment to meet the minimum BSA standard is μ. In the GPF, μ may be described as μ_U or μ_L for the upper- and lower-body, respectively. For an upper-body garment, μ_U involves counting all contours from the base of the neck to the hip-line, counted down the torso and across the shoulders to three-quarters of the way down the upper-arm, consistent with sun protective clothing standard EN 13758-2:2003+A1[20], and AS/NZS 4399:2017[18]. Similarly, μ_L involves counting all contours from the hip-line to the mid-point of the crotch and the knee, based on the inner-thigh measurement and is consistent with AS/NZS 4399:2017[18].

GPF is determined separately for upper- and lower-body garments. To derive the GPF, the product of UPF, normalised to the minimum standard for sun-protective fabrics (i.e. UPF 15), and the excess BSA contour fraction expressed as the relative number of contours exceeding the minimum standard is taken after each factor is multiplied by coefficients of 3 and 2 respectively. These coefficients, and the inclusion of the term added after the BSA contour fraction adjust the nominal gradient of the derived GPF when plotted against UPF for clothing items that meet and exceed the minimum BSA Standard. This provides a unit-less GPF index that can be applied to assess the sun-protective capabilities of any (i) upper-body, (ii) lower-body or (iii) all-in-one garments designed to meet a minimum protective standard where the GPF ranges categorically from $0 \leq \text{GPF} < 3$ (garments meeting minimum

standard), from 3 ≤ GPF < 6 ('good' protection), and GPF ≥ 6 ('excellent' protection). A garment assessed using this simple linear application of UPF and BSA coverage that produces a negative result for either the weighted-UPF or BSA fraction coverage does not qualify for a GPF as both criteria must meet minimum BSA design and UPF to claim a sun-protective advantage.

Practical Testing of Clothing items

A flexible, standing, fabric-covered mannequin closely matching the median height of a 3-year-old child (as determined from the height for age percentile charts for 2-18 year-olds[21]) was used to model the BSA covered by (i) upper-body, (ii) lower-body and (iii) all-in-one UVR protective clothing. The 3 year-old mannequin was chosen as a model to demonstrate how upper, lower and all-in-one GPF is derived. The technique is applicable to mannequins of any size or gender.

The fabric covered surface of the mannequin was marked with horizontal contour bands drawn with red (anterior surface) and blue (posterior surface) indelible ink at 1 cm intervals with the aid of laser levels and a sliding assembly fixed to an optical bench. Contour lines were drawn onto the surface such that they encircled the girth of the mannequin. After contours for the mannequin were drawn from the top of the neck, through the torso, the full length of the right arm and the right lower limb, they were returned to the upright position supported by a stand and base. Test clothing was fitted to the marked mannequin to determine the proportion of body contours protected by upper, lower and all-in-one body garments.

Division of body surface and clothing limits

The implementation of GPF has been designed with current international minimum sun-protective clothing standards in mind. Upper body surface coverage eligibility criteria for GPF meets minimum international standards which currently specify the minimum acceptable BSA incorporate the area from the neck-line, down to the hip-line and across the shoulders and down to the three-quarter upper-arm length sleeve boundary[18,20] (corresponds anatomically with the area between the AC-joint and three-quarter upper-arm length shown as the uppermost and lowest green contour line on the right upper-arm of the mannequin in Figure 1). To facilitate the measurement of the BSA of upper-body garments, the neck/shoulder and hip-line were chosen as shown in Figure 1 as the maximum garment limits, U_U.

For a lower-body garment to qualify for a GPF we apply the minimum leg length surface coverage standard (AS/NZS 4399:2017)[18], such that a lower body garment must fully cover the area from the hip-line (corresponds with the uppermost yellow line in Figure 1) to at least as far as the mid-point measured between the crotch and the knee (defined as a horizontal contour drawn through the uppermost point of the patella where it meets the femur) corresponding with the lowest depicted yellow line shown on the right leg (Figure 1). For a lower body garment to qualify for a GPF, it will protect less BSA than required by the European EN 13758-2:2003+A1[20] standard, which requires coverage to below the patella, but does ensure compatibility of the GPF with minimum international standards (AS/NZS 4399:2017)[18] as currently proposed.

To account for potential differences between the anterior and posterior distribution of a garment placed upon a mannequin body model each counted anterior and posterior contour is weighted by 0.5. Thus, a garment placed on a mannequin model covering the whole of a posterior contour but not its corresponding anterior contour would be counted as 0.5 horizontal contours covered by clothing. For a contour (either anterior or posterior) to be counted as 'visible', the entire line segment must be discernable and not obscured either partially or fully by the garment. By counting the number (and proportion) of horizontal contours fully visible on a clothed mannequin and comparing this to the same mannequin unclothed, we have developed a reproducible method for determining the protected BSA of a garment. For instance, a long-sleeved shirt covers a greater number of total contour segments than an elbow-length shirt.

RESULTS

The GPF is designed to be consistent with the current Australian/New Zealand, European and US standards for the evaluation and classification of sun-protective clothing[18,20,22,23]. According to the revised Australian/New Zealand standard, provision is already made for the categorization of upper-body, lower-body and all-in-one garments to either 'meet' the Standard (minimum UPF 15); provide 'good' protection (minimum UPF 30); or 'excellent' fabric protection (UPF 50 or 50+)[18]. We present a new method that combines BSA and UPF in a single equation for incorporation into future revisions of this and other standards, so that manufacturers of garments striving to incorporate higher UPF rated textiles and designing garments covering more than the minimum specified BSA can achieve a higher categorical score. We adopt the use of three categorical scores to be consistent with AS/NZS 4399:2017[18], these are 'minimum standard' ($0 \leq GPF < 3$), 'good protection' ($3 \leq GPF < 6$)

and ‘excellent protection’ (GPF $\geq$ 6) for garments that just meet the minimum BSA requirement but have progressively higher UPF ratings. The categories we introduce also reward sun-protective garment designers by application of Equation 1, whereby the gradient of GPF verses UPF increases as the protected BSA increases. GPF versus UPF is shown in Figure 2 for garments that protect from 0% to 100% of the available excess skin surface.

The proposed GPF plotted in Figure 2 as a function of UPF shows the range of values able to be obtained for garments with UPF ratings of 15 or above. Here, garments will still either meet the standard for BSA contour coverage or exceed them up to the maximum number of contours visible on the mannequin within the specific upper-body, lower-body or all-in-one range limits. Thus, while a UPF 15 garment that protects the minimum surface area ‘meets’ the standard, it may achieve a ‘good protection’ rating if the UPF is increased toward (but not reaching) UPF 30 and the BSA covered exceeds the minimum limit by more than 0%. A garment with a UPF between 25 and 30 may similarly reach an ‘excellent protection’ standard provided the BSA cover improves (as shown by the dotted lines in Figure 2).

Example protection categories derived from the calculated GPF are listed in Table 1 for an upper-body, lower-body and full-body garment of a 3-year-old child (Figure 3). All sampled clothing items exceed the minimum BSA requirements, with the number of protected contours (P) visible in Figure 1 exceeding the minimum BSA limit (μ). The degree to which the BSA exceeds the minimum limits in addition to the UPF of the clothing item is reflected

in the GPF, with garments that provide better protection receiving higher categorical ratings.

DISCUSSION

Currently, UPF informs wearers of sun-protective clothing of the quality of protection offered by garment textiles. The UPF has subsequently been implemented in several international standards for sun-protective clothing (AATCC TM183:2014[22], EN 13758-2:2003+A1[20], AS/NZS 4399:1996[16]). As a further public health measure, aimed at reducing potentially harmful exposure to solar UVR, the GPF introduced here has the potential to encourage the design of better sun-protective clothing that can be assessed (quantitatively) by taking into account both the UPF and the total protected BSA. The GPF provides an easy to understand protection rating for clothing designed to minimise the potentially damaging effects of sun exposure. The GPF rating encourages garment design that covers a greater surface area than the minimum specified up to defined limits for both the upper- and lower-body. In this way, the GPF should encourage designers and clothing manufacturers to not only meet the minimum UPF and BSA requirements, but also to cover a greater proportion of the available BSA to improve a garment's sun-protective capabilities and its rated category.

In our derivation of the GPF, we have set fixed coefficients to weight the influence of the textile UPF and the excess BSA covered above the minimum national standard we could identify. Equation 1 is purposefully designed such that a garment which meets the AS/NZS 4399:2017[18] minimum BSA requirement (0% excess surface protection) may receive either a 'minimum', 'good' or 'excellent' protection rating under the proposed GPF category limits of $0 \leq GPF < 3$; $3 \leq GPF < 6$; and $GPF \geq 6$ respectively depending on the UPF of the garment textile (Figure 2). It should be noted a garment that just meets the BSA standard (0% excess surface protection) will receive a 'good' protection rating if the UPF of the textile used is 30. A garment meeting the minimum standard (0% excess surface protection) will also receive an 'excellent' protection category if the UPF of the textile used is 45 or more. Not only are our suggested protection categories compatible with the recommendation of the Australian/New Zealand standard, the proposed protection categories also reward clothing designers who increase the BSA protected beyond the minimum limits. The GPF has been designed such that garments which cover the maximum body surface (100% excess surface protection), as proposed by the contour limits set in Figure 1 will have a GPF of 9 when the UPF of the garment textile is 30 (Figure 2). This effectively elevates a garment just meeting the minimum BSA standard from a 'good' protection category to an 'excellent' protection category. Similarly, a garment covering the maximum possible surface area (100% excess surface protection) that is rated UPF 20 will receive a 'good' protection category compared with a garment with the same UPF that covers only the minimum BSA (0% excess surface protection). Garments that cover any BSA fraction between 0 and 100% of the available excess skin surface area are accounted for by application of Equation 1.

The minimum UPF 15 standard applied here is compatible with the ASTM D 6603 standard for labelling (United States) and AS/NZS 4399:2017 which list UPF 15 as the minimum rating able to be claimed for items sold as sun-protective[18,23]. These standards are not as prescriptive as others, such as the European Standard EN 13758-2:2003+A1[20] which restricts garments that can claim a sun-protective advantage to those items which achieve a minimum UPF of 40, and cover a greater proportion of the lower-body. The minimum BSA specified in the European Standard covers the trunk from the neck line to the hip, across the shoulders and three-quarters of the way down the upper-arm for upper-body garments, and from the hip to below the knee (patella) for lower body garments. As a linear scale, the GPF can be used to compare the sun-protective capacity of any clothing items, provided the minimum BSA and UPF ratings are met. The extra protection provided by the minimum UPF and BSA requirements of the European EN 13758-2:2003+A1[20] standard would equate for example, to a GPF of 5.0 and 8.2 for our 3 year-old mannequin for respective upper- and lower-body garments (rows 1 and 2 of Table 1). This would change our suggested sun protection category for respective upper- and lower-body garments meeting the European standard to 'good' ($3 \leq GPF < 6$) and 'excellent' ($GPF \geq 6$) ratings compared to the minimum standard, beginning at GPF 0.

A garment with a UPF of 40 will exceed a GPF of 9 when the amount of BSA covered exceeds 40% of the minimum limits defined in Equation 1 (Figure 2). Categorical ratings exceeding 9 could therefore be extended beyond the three we suggest for garments derived using the GPF. These types of garments may be considered as providing 'superior' sun-protection. Future work assessing the derived GPF for the large range of garments currently sold as

'sun-protective' will determine the suitability of the GPF ratings as currently proposed. The GPF presented in this work is the first quantifiable method to incorporate the two most important factors that influence the level of solar UVR protection provided by clothing. The proposed method also enables sun-protective garments to be compared objectively across different national standards.

The GPF is designed to be compatible with existing international standards for clothing labeled as sun-protective. The revised Australian/New Zealand AS/NZS 4399:2017[18] standard addresses the need to include provision for minimum BSA coverage. This standard, as currently proposed, is not as prescriptive as the European EN 13758-2:2003+A1[20] which requires minimum coverage of a greater surface area of the legs. Adoption of the European standard would therefore be an improvement on the currently proposed Australian/New Zealand standard, and perhaps a good starting place for an international minimum standard. However, regardless of the sun protective clothing standard adopted, there remains limited incentive for industry (clothing manufacturers) to strive for the design of garments sold as sun protective to improve BSA coverage that exceeds the minimum requirements. A GPF, compatible with existing international minimum BSA limits encourages industry to improve their design (and get a higher GPF rating) by incorporating garments that progressively cover a greater BSA and incorporate higher UPF rated textiles. The GPF as proposed is simple and can be derived readily for any standard size of clothing. The inclusion of GPF labeling with garments rated as sun protective (meeting current standards) will both inform consumers by providing a quantitative metric easily comparable between garments

of different designs and encourage greater competition by industry to develop clothing with improved sun protective qualities.

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TABLES

Table 1. Calculation of Garment Protection Factor (GPF) and suggested protection category for clothing items rated for a 3-year-old child. Sample Ultraviolet Protection Factors (UPF) are nominal (not measured values) and are included here as examples to demonstrate the calculation of GPF.

Item	**Nominal UPF**	**Number of Protected contours (*P*)**	**Maximum number of body contours (*U*)**	**Number of contours to meet minimum standard (μ)**	**GPF**	**Suggested Protection category**
Long-sleeved shirt	20	$P_U = 48$	$U_U = 63$	$\mu_U = 39$	1.8	Meets standard
Shorts	25	$P_L = 24.5$	$U_L = 45$	$\mu_L = 17$	3.1	Good protection
Full-body suit	40	$P_L + P_U = 86$	$U_L + U_U = 108$	$\mu_L + \mu_U = 56$	10.8	Excellent protection