The XXIXth Annual Occupational Ergonomics and Safety Conference
Seattle, Washington, USA
June 1-2, 2017

Ultraviolet Radiation Penetration Through Clothing and Hair

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Abstract: Occupation related exposure to solar ultraviolet radiation represents a significant public health challenge globally. Overexposure can lead to accelerated skin aging, sun burn, skin inflammation, excessive tanning, and skin cancer. Clothing and body hair can provide partial barriers against such exposure. However, the protection offered by clothing can vary depending on garment design, layering, fabric materials and garment moisture content. Also, the protection offered by hair can vary due to hair color, hair density and hair style. To assess the impact of layering on ultraviolet radiation penetration through clothing and through human hair, a series of laboratory tests was performed to determine the penetration through samples of cotton, polyester, Nylon, and silk fabric as well as human hair. The results showed that both the fabric samples and the human hair exhibited increasing ultraviolet radiation attenuation as layers were added. Referencing the fabric UV radiation penetration data to the UPF scale, it could be seen that cotton provided "good" protection even for a single-layer configuration while the polyester, Nylon, and silk samples offered similar protection only for multiple layers. The results of the study provide new insights into the relationship between fabric and hair layering and skin UV radiation exposure. This information can assist in providing better protection for persons who are exposed to intense outdoor solar radiation conditions during work and play.

Keywords: occupational health, protective clothing, ultraviolet radiation exposure

1. Introduction

Ultraviolet radiation constitutes about 5% of the total incident solar radiation reaching the earth's surface. Although UV radiation constitutes a relatively small proportion of the total solar irradiation spectrum, it constitutes the highest quantum energy compared to the visible and infrared radiation (Armstrong, 2001). Physiological effects of ultraviolet radiation depend on the radiation wavelength involved. The physiologically relevant UV spectra include the UV-A and UV-B radiation. The longer wavelength ultraviolet radiation (UV-A) is known to cause the transformation of melanin precursors in the skin that initiates the darkening of the skin and can lead to premature skin aging. The shorter wavelength ultraviolet radiation (UV-B) is known to cause acute reactions such as skin reddening (sunburn), basal cell carcinomas, squamous cell carcinomas, and malignant melanomas (Elwood, 1998, Hakansson, 2001).

Excessive exposure to solar ultraviolet radiation has important public health implications. The damaging health effects and injury to the skin resulting from UV radiation exposure has been documented in numerous epidemiological studies (World Health Organization, 2006, Findlay, 2008). Skin cancers are among the most severe of these health effects. Between 2 and 3 million non-melanoma skin cancers and 132,000 melanoma skin cancers occur globally each year (American Cancer Society, 2016). The worldwide incidence of malignant melanomas has continued to increase. The anatomical sites most common for skin cancer are the head and neck, and other areas which are exposed to the sun. Exposure to solar ultraviolet radiation can also increase the risk of other consequences such as early skin aging photo-dermatosis and actinic keratosis. Use of protective clothing, sun umbrellas, tents, hats and sunscreen lotions are recommended for reducing the potential adverse health effects of such UV radiation exposure (Menter, 2003, Rupp, 2001). However, it is often assumed that simple casual clothing will provide adequate protection to prevent such skin injuries. Although clothing can provide a barrier, the level of protection can vary depending on a variety of factors such as fabric type, stretch, thickness, porosity, wetness, color, layering and washing history (Hoffmann, 2001). In addition, when persons remove hair from their head to follow fashion trends, the risk of skin injury to the scalp may also increase. Additional approaches to the assessment of garment performance, garment design and garment use will be helpful. In pursuit of this objective, a series of laboratory experiments was conducted to assess the UV(A-B) protection offered by selected textile materials used in clothing and, additionally, the UV protection provided by hair on the scalp.

2. Methods

2.1 Fabric Material and Hair Samples

Tests were performed on fabric samples obtained from used clothing worn for casual purposes over an extended period of time. The samples included 100% cotton T-shirt, 100% polyester fabric obtained from a used man's dress shirt, 100% Nylon fabric sample obtained from a used blouse and a 100% silk fabric sample obtained from a head scarf. A total of four samples of each fabric material were evaluated. Hair samples were provided by a black-haired Asian female. Fabric samples and hair samples were tested for multiple layer configurations with samples being stacked in reverse order systematically. Fabric materials and hair samples were evaluated for the dry condition only with stacking combinations of 1, 2, 3, and 4 layers. All tests were performed three times and the data averaged.

2.2 Ultraviolet Radiation

Ultraviolet radiation was generated using a 120V-100W self-ballasted mercury vapor lamp. The lamp was maintained at a constant operating temperature. The laboratory temperature was maintained at 22^0 C (± 2 ^{0}C) with a humidity of 15% (± 5%). The UV (AB) sensor was shielded from all external UV radiation sources. Radiation penetration values were obtained using a General Inc., UV 513A UV-AB radiation monitor calibrated for the 290-400 nm spectrum. Samples were exposed to a UV irradiance of 1150 μW/m^2 for a duration of 15 seconds.

3. Results

3.1 Fabric

UV radiation penetration was measured for 1, 2, 3, and 4 layers of cotton, Nylon, polyester and silk fabric samples. Each of the fabric samples exhibited unique UV(A-B) radiation penetration characteristics. Penetration for a single layer of cotton was 3.3%, 5.6% for polyester, 8.4% for silk, 8.6% for Nylon. Adding layers of fabric increased the attenuation substantially as summarized in Table 1.

Table 1. Summary of UV Radiation Penetration through Multiple Layers of Fabric

	Cotton	Nylon	Polyester	Silk
Layers	UVR(AB) Penetration (%)	UVR(AB) Penetration (%)	UVR(AB) Penetration (%)	UVR(AB) Penetration (%)
0	100	100	100	100
1	3.3	8.6	5.6	8.4
2	1.1	2.9	2.5	2.5
3	0.6	1.4	1.6	1.4
4	0.5	0.8	1.1	0.9

ISBN: 97819384965-5-4

3.2 Hair

UV radiation penetration values for 1, 2, 3 and 4 layers of human hair are summarized in Table 2. The human hair samples also exhibited specific UV(A-B) radiation penetration characteristics. The UV radiation attenuation was increased as the samples were stacked on top of each other. The penetration for a single layer of hair was 16.3% and deceased to 0.6% in the four-layer configuration.

Table 2. Summary of UV Radiation Penetration through Multiple Layers of Hair

Layers	Hair UVR(AB) Penetration (%)
0	100
1	16.3
2	5.1
3	1.7
4	0.6

4. Analysis

The data show that the fabric samples exhibited distinct UVR(A-B) attenuation characteristics as multiple layers were added. While the penetration was 3.3% for a single layer of cotton, 5.6% for polyester, 8.4% for silk, 8.6% for nylon, adding additional layers increased the attenuation. Figures 1 and 2 illustrate graphically the data summarized in Tables 1 and 2. It can be seen that the 100% cotton samples provided the most UV radiation attenuation overall while the Nylon and silk fabrics provided the least attenuation. UVR(A-B) attenuation for the human hair samples was also seen to be proportional to the total density of the hair. The penetration for a single layer of hair was 16.3% but deceased to 0.6% in the four-layer configuration.

Clothing UVR attenuation is rated on the basis of the "Ultraviolet Protection Factor" UPF (American Cancer Society, 2016, Das, 2010, Jevtic, 1990). This rating indicates how much a material shields the skin from ultraviolet radiation. The higher the UPF number, the greater the degree of UV protection a garment can offer. For example, a fabric with a rating of 50 will allow only 1/50th, or 2% of the UV radiation to pass through the material. It is generally believed that a UPF of 20 defines good protection, 30 very good protection, 45 excellent protection, and 50+ as ultimate protection.

To make the information obtained in this study relevant to the UPF rating scale which will allow health professionals to establish recommendations and guidelines for the use of appropriate clothing during exposure to solar radiation, a conversion chart was developed as illustrated in Figure 3. In this chart, the relationship between percent (%) penetration and the UPF scale is shown for the four fabric types tested, i.e., cotton, polyester, Nylon, and silk. It can be seen that only the cotton sample exhibited "good" UV radiation attenuation for a single-layer configuration. The other three materials tested did not. However, all of the fabrics assessed in this study achieved good to excellent UV protection when multiple layers were applied.

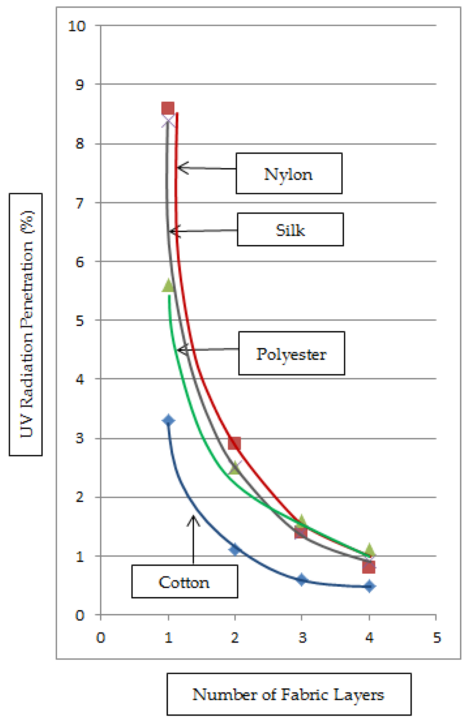

Figure 1. UV Radiation Penetration through Multiple Layers of Nylon, Silk, Polyester and Cotton Fabric Samples

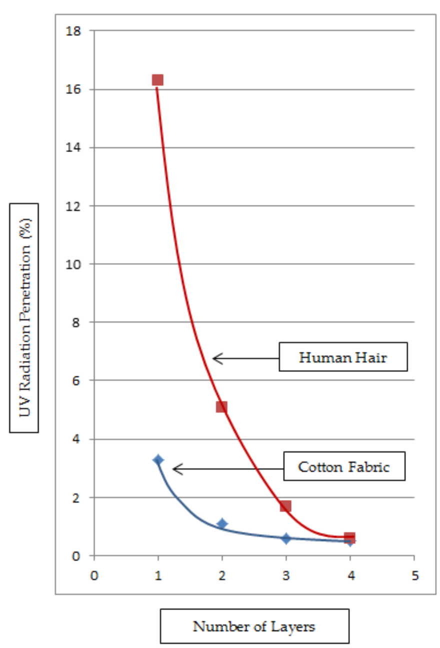

Figure 2. Comparison of UV Radiation Penetration through Multiple Layers of Cotton Fabric and Multiple Layers of Human Hair

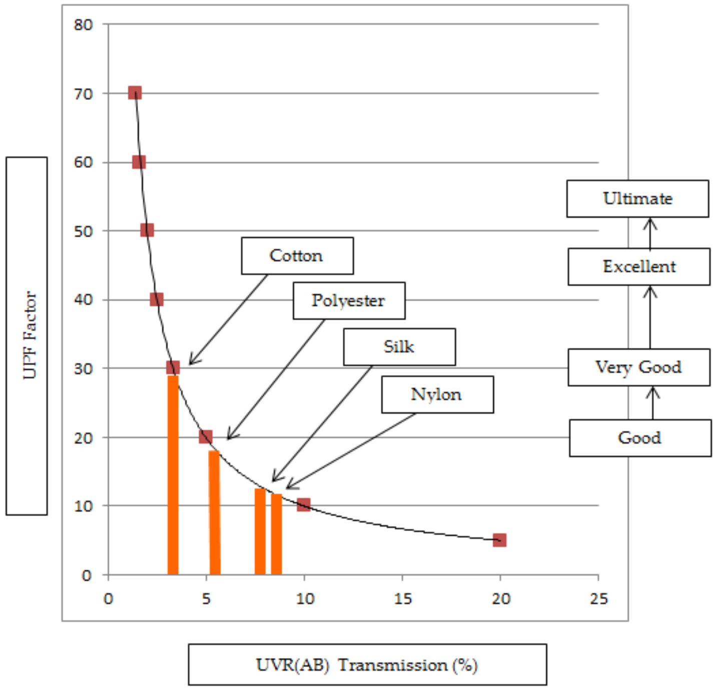

Figure 3. Relationship between UV Radiation Penetration and the UPF Scale. The Vertical Bars Represent the Radiation Penetration Values obtained for the Fabric Samples

A field study investigating the UV protection offered by wigs worn by a manikin exposed to outdoor solar radiation showed that, regardless of hair style, hair length, and hair color, the human hair did not provide good UV radiation protection (Parisi, 2009). The relative poor performance was attributed to the open spaces created when the hair was parted since these spaces exposed the scalp to direct sunlight. The results of our study confirm this issue. However, the fundamental principal involved is hair is "density". The density, or number of hair strands per area, will determine the UV overall protection level. This is demonstrated in Figure 2 in the reduction of UV radiation penetration as the number of layers of hair is increased, i.e., four layers.

5. Conclusions

This study provided insight into the effectiveness of multiple layers of clothing in reducing ultraviolet radiation exposure for persons working or recreating in an outdoor sunlight environment. Such information can be used to assist in skin cancer awareness programs. Also, clothing manufacturers may consider including multiple fabric layers in their design recommendations. With regards to head protection, dense hair on the head can provide good protection against ultraviolet radiation exposure while sparse hair provides only limited protection. In such cases, hats or cotton scarfs can be used effectively to protect the scalp from overexposure.

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