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Examining the Effects of UV on Latex and Nitrile Glove Degradation

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By

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Abstract

Medical gloves, both nitrile and latex, are used as a protective barrier to limit the spread of disease. Gloves are a single use product and their demand is set to increase by 9 to10 percent each year. In 2008, it was estimated that 100 billion gloves were used globally each year (Scott, 2008). This study is exploratory in nature, to determine if Ultra Violet light (UV) exposure can cause an acceleration in the breakdown of latex and nitrile gloves. It was hypothesized that the tensile strength and length to breakage for both glove types, latex and nitrile, would decrease after exposure to UV. The experiment was set up as a 4x4 latin square, where 1: latex was exposed to UV for 24 hours, 2: nitrile was exposed to UV for 24 hours, 3: a nitrile control where no UV was used and 4: a latex control with no UV exposure. The data show a 40 percent reduction in tensile strength and a 40 percent reduction in length to breakage after a 24-hour UV exposure. The decrease in tensile strength and length to breakage was statistically significant with UV application ($p<0.0001$), regardless of glove type used ($p<0.0001$). We can therefore accept our hypothesis that UV light exposure can cause an acceleration in the breakdown of medical gloves. To expand upon this study, the application of UV could be commercialized to accelerate degradation of medical gloves. In this way, the hope is that medical gloves could become more sustainable.

Introduction

Nitrile and Latex Gloves as Medical Waste

As a standard precaution to limit the spread of disease from patient to patient, hospitals and clinics use single-use gloves as a protective barrier. Gloves also protect healthcare workers from infections from their patients. In 2008, approximately 100 billion gloves were estimated to be used around the world annually. If each of these gloves would be lined up, it would span the distance of the moon and back to earth 30 times (Scott, 2008). Most of these gloves are not a biomedical hazard, and the majority ultimately end up in a landfill. Interestingly, there is a knowledge gap about the pathways of latex and nitrile glove degradation and the impacts of the innumerable quantities that end up in landfills each year.

Gloves are a single-use product and their demand is predicted to increase by 9 to10 percent each year. Additionally, approximately 24% of medical waste comes from gloves. Of the gloves used worldwide, 57 to 80 percent are disposed of in a landfill. It is estimated that latex gloves take over 2 years to degrade in a landfill (Misman & Azura, 2013). The magnitude of single-use gloves that end up in a landfill is both unfathomable and unrestricted. The lack of research on how gloves break down could prove to be an environmental harm in the future due to the massive glove-quantities with unknown fates. To combat this, programs like RightCycle exist to repurpose glove waste. The gloves can be processed into pellets and then turned into shelving, tote bags, and outdoor furniture. While recycling programs exist, they are currently costly to medical facilities and therefore is currently underused (Kardis, 2017). Additionally, there is research ongoing to create biodegradable gloves. These gloves have been slow to reach the market and could potentially face opposition based on cost and efficacy. Current models of biodegradable gloves cost approximately $13 per box and a box of latex or nitrile gloves costs between $6 and $9. Ultimately, this study seeks to understand how glove breakdown can be accelerated. With this information, more sustainable solutions could be sought for medical glove disposal.

Latex Gloves

Gloves used in a medical setting are typically latex or nitrile. Natural rubber latex (NRL) is produced by more than 20,000 flowering plant species, which accounts for 10% of angiosperms. Latex is a sticky compound that exudes from the plant in response to tissue damage. Due to the plant's internal pressure, latex discharges from the damaged point and coagulates upon exposure to air. It has no known function in primary plant metabolism, but is most likely released to reduce herbivory and heal mechanical wounds of the plant. (Agrawal & Konno, 2009). Natural rubber consists of units of C_5H_8, containing a double bond in the cis configuration (Rose & Steinbuchel, 2005). NRL is formed by long and flexible polymer chains. NRL's flexibility is attributed to the rotation along the C-C bonds that can rotate into many conformations. Although 2,000 plants synthesize poly(cis-1,4-isoprene), only two varieties are produced commercially: *Hevea brasiliensis* (99%), and *Parthenuim argentatum* (1%) (Agostini et. al, 2008).

Latex gloves are waning in prevalence due to increasing latex allergies, but is currently still used in approximately 400 medical products (Binkley et al., 2003). Latex allergies range from skin redness and itching to full anaphylaxis and hypotension. Latex allergies occur in about 10% of healthcare workers and can appear in up to 67% of children with spina bifida (improper forming of the spine and spinal cord). Latex allergies are a sensitization allergy, meaning the reaction worsens with repeated exposure to latex (Sussman & Beezhold, 1995). Symptoms of allergy to latex occur after direct contact. Latex enters the body through the skin, mucous membrane, open wounds, and through inhalation. Since 1940, latex gloves have used cornstarch within the gloves as a drying agent. Relatively, cornstarch is lightweight and easily airborne, which binds with the latex molecules and makes the chance of ingesting airborne latex more likely. There is no cure for an individual's latex allergy, and the only way to mitigate the effects is to avoid contact altogether. Alternatives to latex include nitrile, vinyl, neoprene, and styrene butadiene (Binkley, et. al, 2003).

Nitrile Gloves

Largely due to the aforementioned increasing allergies to latex, nitrile gloves are becoming more prevalent in the health care industry. Nitrile butadiene rubber (NBR) is a synthetic macromolecule elastic compound, resistant to fatigue and wear. NBR is resistant to friction, making it a good material for rubber moving components of machines. However, NBR is not a good material for dissipating heat, and high temperatures cause the material to deteriorate and decrease its mechanical properties (Dong et. al, 2015). Additionally, NBR is not resilient to environmental factors. Extreme temperature, strong light, and great mechanical load can drastically reduce the durability of NBR. This is likely due to the unsaturated bonds of butadiene. It is less elastic than latex but is regarded as a stronger material (Liu et. al, 2016).

It is important to note that different brands of nitrile gloves reportedly have entirely different properties. Currently, there are no uniform standards for nitrile glove manufacturers, causing the formulation from glove to glove to be drastically different. These differences are due to a discrepancy in the amount of acrylonitrile compared to fillers, plasticizers, and the base polymer, which accounts for up to 85% of discrepancies. These discrepancies affect the functionality of the gloves. For example, non-polar plasticizers repel water, but decreases the ability to resist non-polar solvents. Additionally, the lack of plasticizers can decrease the elasticity. Plasticizers and fillers are not regulated, while the water-tight properties, thickness, dimension, and tensile properties are (Phalen & Wong, 2011).

<u>Glove Degradation: Previous Studies</u>

In a study of latex degradation by Lambert et. al (2013), latex film degradation was determined in simulated water ecosystems. The study simulated both freshwater and saltwater ecosystems across seasons – altering the sunlight cycle, intensity, and temperatures. In their study, it was reported that as a consequence of degradation, CO_2 and H_2O were released into the atmosphere. They determined these losses by placing filter paper over the containers. To determine the true breakdown in the environment, they added the atmospheric loss trapped by the filter paper to the remaining mass of latex and compared that to the starting weight. The greatest amount of mass loss occurred during the “summer” phase, when the latex was exposed to more solar radiation and higher temperatures. They concluded that photo-oxidation was the strongest contributor to latex breakdown within their study.

A similar study in Malaysia examined how NBR gloves breakdown under natural weathering conditions. Natural weathering was characterized by exposure to sunlight, heat, oxygen, and moisture in variable quantities over 3 and 6 months. The study found that increased exposure to natural weathering elements directly correlated to a decrease in the tensile properties of the NBR gloves. Noriman and his team attributed this decline in tensile strength to polymer oxidation, occurring from chain scissions due to the exposure to UV (Noriman & Ismail, 2010).

Objective

The objective of this study is to examine whether or not UV light will accelerate the degradation of medical gloves.

Hypothesis (1): Latex gloves will respond to UV light by having decreased tensile strength and decreased length to breakage after exposure.

Hypothesis (2): Nitrile gloves will respond to UV light by having decreased tensile strength and decreased length to breakage after exposure.

Materials and Methods

This experiment seeks to understand and identify methods that accelerate latex and nitrile glove decomposition. Namely, the experimental design focuses on exposing gloves to UV light for a set period of time and examining the effects on the length to breakage and tensile strength.

Based upon preliminary studies of tensile strength performed in Higley Lab, it was confirmed that gloves have extremely variable tensile strength throughout each individual glove. Sections of each glove cut from the finger and different portions of the palm were tested for tensile strength. With one end held stationary and the other attached to a crane scale, gloves were pulled to their breaking point. The palm-sections yielded extremely variable tensile strength, while the fingers typically remained within the same range. Therefore, the ring finger, middle finger, and pointer finger of each glove was cut at the base. Then, the tip of the finger was cut off, leaving a tube. The tube was then cut lengthwise, leaving one layer of glove. Then, a 3 by 4cm piece was cut from each finger portion.

Each prepared (3cm by 4cm) piece of glove was tested for tensile strength. Tensile strength is broadly defined as the resistance of a material until it reaches a breaking point under tension. Decomposition can be indicated by decreased tensile strength. The long-side of the glove pieces (4cm) were clamped. Within each clamp was 1cm of glove material. Between the clamps was 2cm of glove material. A 50cm ruler was secured to the table to ensure uniformity between tests, so that precisely 2cm were stretched in each trial. One clamp was held stationary, and a crane-scale was attached to the other clamp. The crane scale was pulled along the plane of the table slowly, digitally measuring tensile strength in kilograms (kg). Additionally, the ruler fixed beneath the clamps served to show the elongation at the breaking point in cm for each glove.

Using the slow-motion feature on an iPhone, each trial was recorded and the exact moment each glove reached their breaking point was captured. This gave a reading of the tensile strength of the gloves in kilograms. From the video, an estimation of elongation before breakage was estimated in cm, significant to 0.5cm.

The gloves were placed onto a sheet of parchment paper, divided as a 4 part latin-square with a factorial arrangement. The factors were glove type, latex or nitrile, with the treatment being either 24 hours of UV light or no UV light exposure. A latin square describes a controlled treatment arrangement in which each treatment occurs once in each column and row. Each square of parchment paper was labelled 1-4, where 1: latex exposed to UV, 2: nitrile exposed to UV, 3: nitrile control (no UV exposure) and 4: latex control. The experimental unit was each individual latin square.

To set up the experiment, a piece of parchment paper was folded into 16 squares, four in each row and column. The 16 squares were then labeled 1-4, with each individual value occurring only once in each column and row, signifying different treatments. Then, 16 4x3cm strips of each glove type were placed in the corresponding squares. A representation of the experimental method can be seen in figure 1 of the result section. The latex gloves were of the brand “Nice!”, powdered, and size large, while the nitrile gloves were of the brand “UpandUp”, powderless, and size large. One of each type of glove was placed on each of the 16 squares, designated by the aforementioned numbered arrangement. Then, the parchment paper-unit was placed under a fume hood. The squares indicated by 1 and 2 were treated with exposure to UV light. An 8 watt UV bar light was placed directly on top of the gloves. Then, a paper tent-like structure was placed above the UV bar light to ensure that the UV light did not interact with the untreated control glove-parts.

The gloves in squares 1 and 2 (UV light) were removed after 24 hours of exposure. At this point, they were tested for tensile strength and length to breakage. Additionally, the same measurements were taken after 24 hours for the control glove-parts in squares 3 and 4.

The experiments ran from March 27^{th} to March 30^{th}, in a succession of three 24 hour periods. Each unit of parchment paper had 4 nitrile glove-parts under UV light and 4 latex glove parts under UV light, with two experiments running at once. This lead to 8 treated nitrile experimental units and 8 latex experimental units per day, multiplied by three for a total of 24 treated latex units, 24 treated nitrile units, and 24 of each glove untreated as a control.

Results

Significant differences are shown in all factors, differences in glove type ($p<0.0001$), exposure to UV ($p<0.0001$), and the combination of the factors ($p<0.0017$). Visually, the gloves that were treated with UV light (squares 1 and 2) became discolored (figure 1). The untreated latex is ivory colored, and after UV exposure was a golden brown. The untreated nitrile gloves transitioned to a darker blue after UV exposure.

Table 1 shows that the average tensile strength for our untreated latex gloves is 1.781kg, while the average tensile strength for nitrile is 1.601kg. When UV is applied to these gloves, the tensile strength is reduced to 1.255kg in latex gloves, and 1.075 in nitrile gloves.

Table 2 shows the effects of UV, averaged across both glove types. The average tensile strength without UV exposure, 1.78 kg, decreased to 1.075 kg after UV exposure. In regards to elongation, the average decreased from 14.78 cm to 8.74 cm after UV exposure.

Table 3 indicates the effects of UV on each glove type. For latex, the mean tensile strength without UV exposure was 1.73 kg. After UV exposure, tensile strength decreased to 0.78 kg. Length-to-breakage was 17.29 cm without UV exposure. After UV exposure, length-to breakage decreased to 9.49 cm. For nitrile, the mean tensile strength without UV exposure was 1.83 kg. After UV exposure, tensile strength decreased to 1.37 kg. Length-to-breakage was 12.27 cm without UV exposure. After UV exposure, length-to breakage decreased to 7.99 cm.

Table 4 shows the overall significance of tensile strength by ANOVA. There were significant mean differences in the length-to-breakage of the gloves, where $F(3,92)=40.98$, $Mse = 5.43$, $p < 0.0001$ The decrease in tensile strength was statistically significant, occurring less than 1/10,000 times by chance.

Table 5 shows the overall significance of each of the factors: glove type, exposure to UV, and the combination of the factors. The results are highly significant, with glove type ($p < 0.0001$), UV ($p < 0.0001$), and the combination of the factors, Type*UV, ($p < 0.0013$).

Table 6 examines the overall significance of length-to-breakage by ANOVA. There were significant mean differences in the length-to-breakage of the gloves, where $F(3,92)=56.58$, $Mse = 401.65$, $p < 0.0001$. The decrease in length to breakage was statistically significant, occurring less than 1/10,000 times by chance.

Table 7 shows the overall significance of each of the factors: glove type, exposure to UV, and the combination of the factors. The results are highly significant, with glove type ($p < 0.0001$), UV ($p < 0.0001$), and the combination of the factors, Type*UV, ($p < 0.0017$).

Table 8 compiles the data. Latex gloves, L, are shown for their response to 24 hours of UV light (1) or no UV light (0). Nitrile gloves, N, are also shown for their response to 24 hours of UV light (1) or no UV light (0). The tensile strength of latex decreased from an average of 1.731kg without UV exposure to 0.779kg after UV exposure. The length to breakage decreased from an average of 17.292cm to 9.492cm. The tensile strength of nitrile decreased from an average of 1.831 kg without UV exposure to 1.371kg after UV exposure. The length to breakage decreased from an average of 12.271cm to 7.992cm after UV exposure.

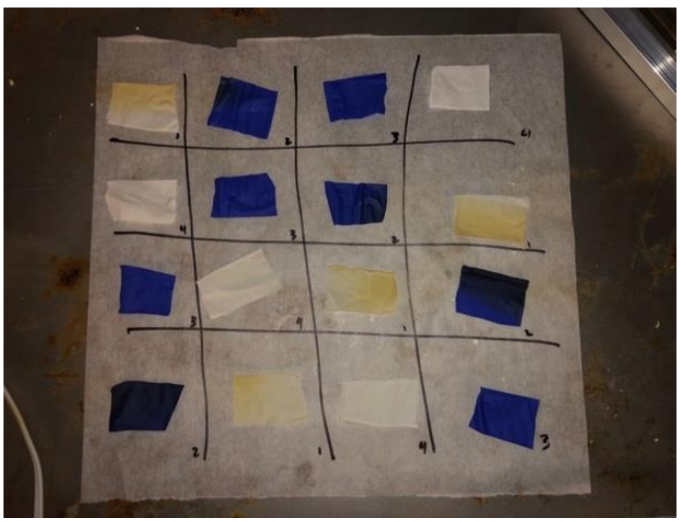

Figure 1: The image shows the latin square arrangements, with squares 1 and 4 with latex gloves, 2 and 3 with nitrile gloves. Squares 1 and 2 were treated with 24 hours of UV light, and are visibly discolored.

Data Tables

Table 1: The overall means across both glove types, including gloves with and without UV exposure in terms of tensile strength (kg) and length (cm).

		Tensile	Length
Type			
L	**Mean**	1.255208	13.39167
	StdErr	0.081354	0.66829
N	**Mean**	1.601042	10.13125
	StdErr	0.068812	0.513714

Table 2: Shows the effects of UV across both glove types.

		Tensile	Length
UV			
0	**Mean**	1.78125	14.78125
	StdErr	0.053586	0.504832
1	**Mean**	1.075	8.741667
	StdErr	0.066694	0.425087

Table 3: The means and standard errors for the combination of the two factors: glove type and treatment.

			Tensile	Length
Type	UV			
L	0	Mean	1.73125	17.29167
		StdErr	0.042007	0.24803
	1	Mean	0.779167	9.491667
		StdErr	0.074692	0.664196
N	0	Mean	1.83125	12.27083
		StdErr	0.098761	0.657302
	1	Mean	1.370833	7.991667
		StdErr	0.070641	0.498437

ANOVA procedure, Dependent Variable – Tensile Strength

Table 4: By ANOVA, this shows the overall significance of treatments for tensile strength.

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	16.29177083	5.43059028	40.98	<.0001
Error	92	12.19229167	0.13252491		
Corrected Total	95	28.48406250			

Table 5: By ANOVA, this shows the overall significance of the main effects of glove type, UV treatments, and their interaction.

Source	DF	Anova SS	Mean Square	F Value	Pr > F
Type	1	2.87041667	2.87041667	21.66	<.0001
UV	1	11.97093750	11.97093750	90.33	<.0001
Type*UV	1	1.45041667	1.45041667	10.94	0.0013

ANOVA procedure, Dependent variable – Length

Table 6: By ANOVA, this shows the overall significance of treatments for length.

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	1204.942813	401.647604	56.58	<.0001
Error	92	653.104583	7.098963		
Corrected Total	95	1858.047396			

Table 7: Each variable is shown for significance: glove type, exposure to UV, and the combination of the two factors.

Source	DF	Anova SS	Mean Square	F Value	Pr > F
Type	1	255.1276042	255.1276042	35.94	<.0001
UV	1	875.4376042	875.4376042	123.32	<.0001
Type*UV	1	74.3776042	74.3776042	10.48	0.0017

Table 8: Where n=24 and N=96. Latex gloves, L, are shown for their response to 24 hours of UV light (1) or no UV light (0). Nitrile gloves, N, are also shown for their response to 24 hours of UV light (1) or no UV light (0).

Level of Type	Level of UV	N	Tensile		Length	
			Mean	Std Dev	Mean	Std Dev
L	**0**	24	1.73125000	0.20579248	17.2916667	1.21509229
L	**1**	24	0.77916667	0.36591656	9.4916667	3.25388285
N	**0**	24	1.83125000	0.48382815	12.2708333	3.22011061
N	**1**	24	1.37083333	0.34607007	7.9916667	2.44183051

Discussion

Due to the fact that this experiment has not been largely studied, the findings are exploratory in nature. The goal of this study was to understand if UV exposure can cause an acceleration in the breakdown of both latex and nitrile medical gloves. Ultimately, we aim for the application of these findings to a larger scale to make glove waste more sustainable.

In a previous study, Lambert et. al (2013) examined the degradation of latex films in different environments. The degradation rate was most strongly linked to treatments with the most solar radiation, causing the fastest rate of breakdown. Photo-oxidation was the primary pathway for this degradation. This occurred in response to UV light from the sun.

Additionally, Noriman and Ismail tested nitrile butadiene rubber for its response to natural weathering conditions. Here, they factorially tested for humidity, temperature, rainfall, and UV exposure. The declination of tensile strength in this study was attributed to oxidation of the polymer in response to UV.

The findings of this study corroborate what previous studies have found. For both glove types studied, latex and nitrile, the impact of UV light exposure on breakdown was significant ($p<0.001$). After exposure to UV light, the tensile strength required decreased for both glove types. We expected a drastic decrease in tensile strength after UV light exposure, but the ultimate effect on the elasticity of the glove was surprising.

Table 1 indicates the means and standard errors across the glove types, regardless of treatment exposure. Latex required an average of 1.255 kg to break at 13.392 cm while nitrile required 1.601 kg to break at 10.131 cm. Overall, nitrile gloves have more tensile strength. Table 3 shows the average length to breakage of nitrile without UV exposure was 12.271cm, while the average length to breakage of latex without UV exposure was 17.292, 5cm greater than nitrile. The data shows that the latex gloves were more elastic than nitrile gloves, despite nitrile having more tensile strength. The study by Liu et. al (2016) corroborates these findings regarding the elasticity and strength of nitrile.

Table 2 shows the effects of UV across both glove types. Without UV exposure, the average tensile strength was 1.781 kg and the length to breakage was 14.781 cm. When UV was applied, the means decreased to 1.075kg and 8.741 cm**.** There was a 40% reduction in tensile strength when UV was applied. Additionally, there was a 40% reduction in length to breakage with UV application, applicable to both glove types. Therefore, the data show that UV influences the accelerated breakdown of both latex and nitrile glove types.

Table 5 indicates that the decrease in tensile strength was statistically significant with UV application, $p<0.0001$. It also indicates that the type of glove is significant, $p<0.0001$. Table 7 indicates that the decrease in length to breakage was statistically significant with UV exposure, $p<0.0001$. It also indicates that length to breakage was dependent on the glove type, $p<0.0001$. This decrease in tensile strength would only occur by chance 1/10,000 times.

Table 8 provides a summary of the data findings. For latex, tensile strength of glove-parts with UV application decreased by 55% and length to breakage decreased by 46%. For nitrile, tensile strength of glove-parts with UV application decreased by 26% and length to breakage decreased by 35%.

Conclusion

Significant differences were shown in all factors; glove type, exposure to UV light, and the combination of the two. This study corroborates what others have found in terms of the quality of materials. Latex is more elastic than nitrile, but is more susceptible to breakage, requiring less tensile strength to break. Ultimately, UV exposure accelerated the breakdown of both glove types, as previous studies have noted.

Latex was more greatly affected by the exposure of UV light than nitrile. The effect was decreased tensile strength, and decreased elongation. The tensile strength of latex decreased by 55% and the length to breakage decreased by 46%. For nitrile, the tensile strength decreased by 26% with UV application and the length to breakage decreased by 35% with UV application.

It was hypothesized that exposure to UV would cause decreased tensile strength across both glove types. Additionally, it was hypothesized that exposure to UV would cause decreased length to breakage. Based on the results, both hypotheses are supported.

Implications

Ultimately, the goal is to apply these findings to a larger-scale medical operation. Significant degradation was shown with an 8-watt UV bulb applied directly to the surface of the gloves. Intensity is dependent upon distance of the bulb from the target and the wattage of the bulb. To commercialize this, the experiment would need to be replicated on a larger scale with equal or greater UV light intensity. The distance of the light source from the gloves and therefore the wattage would have to increase to apply UV light to a greater quantity of gloves.

Ultimately, this study could provide the groundwork for a change in how medical glove waste is disposed of. It has shown that UV light has an effect on accelerating the glove’s degradation. Gloves could be treated with UV lights within a hospital or clinical setting before being sent to a landfill. The partially degraded gloves would therefore degrade faster once in the landfill. Current medical gloves take 2 years to degrade, so further research could examine the faster degradation time after UV treatment.

Recommendations

Future studies should examine if these results stand across different brands of gloves. There are minimal standards for NBR glove formulation. Therefore, differing formulations result in different chemical resistance and integrity between glove brands (Phalen & Wong, 2011). It is important to compare UV accelerated breakdown between different glove brands, to ensure a wide application. In hindsight, I would recommend weighing the gloves before and after treatment to see if the mass significantly differs after UV exposure. Previous studies had suggested that atmospheric losses occurred, so it would be interesting to examine the impact.

Also, an 8-watt, 1-foot long UV bulb was used in the study. To apply this on a larger-scale, a larger bulb with greater intensity would to be applied to multiple, entire gloves at once. Significant differences in tensile strength and elongation were shown in this study with an 8-watt bulb. Intensity is dependent upon distance from the material and the wattage. In a larger operation, the wattage would have to increase to increase the distance from the gloves for the same effect. Dependent upon distance, I would predict that increasing wattage would further accelerate the degradation.

To further this study, treated gloves should be put into landfill conditions to see if the exposure to UV aided in accelerated degradation.

Limitations

This study was limited in that it only examined two brands of gloves, “Nice!” latex gloves and “UpandUp” nitrile gloves. In order to apply these findings to a larger scale, the study would have to be repeated with more glove brands and with more trials.

Due to time constraints, the experiment was run over the course of three days, with 24 of each treatment tested. A larger sample size would be recommended, although the results were statistically significant within a smaller sample size. Only the fingers of each glove were examined, one layer thick. Further research could examine how the entire glove responds to UV.

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