EXPLORING THE EFFECTIVENESS OF APPLICATION METHODS FOR LIQUID FOUNDATION MAKEUP

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ABSTRACT

When applying foundation makeup, the method that is used can impact coverage, evenness, and product waste. To determine which application method maximizes coverage, minimizes waste, and gives even, uniform results, plastic slides were coated with liquid foundation makeup using a makeup brush, a cosmetic sponge, and a SiliSponge silicone pad. The mass of makeup used was measured with a precision scale before and after using the implement, and images were taken as light was transmitted through the slide. Opacity and homogeneity for each trial were found using computer-aided image processing. The data suggest that, with 95% confidence, the SiliSponge uses and wastes less product than the brush and sponge, while the brush and sponge result in more opaque, heavier coverage. A positive correlation between opacity and amount used suggests that heavier coverage could be obtained by increasing the amount of product used.

1. INTRODUCTION

Cosmetics is a multi-billion dollar industry, and it is estimated that over half of women wear makeup on a regular basis. Particularly prevalent is the use of foundation makeup to hide skin imperfections and create a smooth, even tone across the face. In order to do this, it is advantageous for the foundation makeup to have both high opacity and facilitate the even, uniform reflection of light. Naturally, these qualities can be affected by how the makeup is applied, and consequently the internet is full of articles and tutorials on how to choose and apply foundation makeup [1]. Recently, many trends have emerged regarding the best implement to use, including various foundation brushes, the popularization of the beauty blender sponge and, later, the SiliSponge.

However, these makeup trends, tutorials, and recommendations tend to be very subjective. Each application method is promoted or denounced for different reasons—for example, some say that sponges provide more even coverage, or that brushes are cleaner and waste less product. These arguments have led to developments such as the SiliSponge (a non-absorbent, easy-to-clean silicone pad), as well as absurd and potentially dangerous trends like putting a condom over a makeup sponge. Since claims about the "best" method are heavily based on anecdotal evidence, this study intends to provide a scientific basis for which application method provides the most opaque and homogeneous coverage, while also taking into account the amount of product used and the amount left over on the implement.

To that end, this study explored the effects of three application methods on the measured opacity (a quantitative metric for coverage) and homogeneity (a quantitative metric for uniformity or evenness) of a layer of makeup. Liquid foundation was applied to a clear plastic slide using either a foundation brush, a beauty blender sponge, or a SiliSponge applicator. To measure opacity and homogeneity, light was directed through the slide from LEDs on one side, while a camera on the other side captured images of the result. The images were then analyzed using MATLAB to determine homogeneity and average opacity for each trial. In addition, the mass of the slide was recorded before and after application, in order to calculate the amount used as well as the amount of product wasted for each method. A student t-test compared results for each application method to determine whether there were statistically significant differences between them.

2. BACKGROUND

2.1 HISTORICAL STUDIES ON MAKEUP APPLICATION

A study published in the Skin Research and Technology Journal in 2013 evaluated the spreadability, coverage, and adhesion effects after the application of base makeup using two methods; by hand or using an oscillation applicator (a motorized, vibrating puff) [2]. The study found that participants using the oscillation applicator had results twice as high as those who applied by hand.

Therefore, hand application has not been tested in this study.

Additionally, a study published in the Journal of the Optical Society of Korea in 2012 analyzed the opacity and haze effects of four different types of polymethylmethacrylate (PMMA) powders used in powder foundation. The goal was to determine which powder was the best at mimicking the light behavior of bare skin [3]. The results showed that the hemispherical PMMA powder produced the highest intensity of reflected light, which is desirable as it is similar to the reflection patterns seen in artificial skin. This quality is very important for cosmetics, since the goal of many cosmetics—like concealer and foundation—is to mimic healthy, smooth skin. The effects of reflected light are related to those of opacity, since a higher amount of reflected light will help conceal blemishes and other imperfections; as discussed below.

2.2 OPTICS AND OPACITY IN COSMETICS

Skin is translucent, so when light hits it, some of the light is immediately reflected back to the viewer and some penetrates the skin's deeper layers. This results in a luminous effect—infants' skin is smooth and undamaged, so light that reflects off it does so uniformly, and light that is transmitted spreads through the skin to produce "a soft even luminosity and translucency" or "soft-focus" [3]. However, this uniform reflection decreases over time due to photodamage and aging, and contrast increases due to lines and wrinkles [3]. Optically, this results in skin looking less healthy and smooth, so some people apply cosmetics to counter this effect.

Cosmetics like foundation or concealer are intended to cover undesirable skin characteristics, so it is beneficial for them to have high opacity and facilitate the reflection of light. When foundation makeup is more opaque, less light reaches the skin beneath it. This means that the light is reflected off of the makeup and not the skin imperfections underneath, so the imperfections are not as visible. If the cosmetic also reflects light, the skin appears more luminous and healthy, as well as smooth (if the light reflects evenly). Figure 1 shows how light might behave when it meets a completely opaque layer of makeup on top of skin.

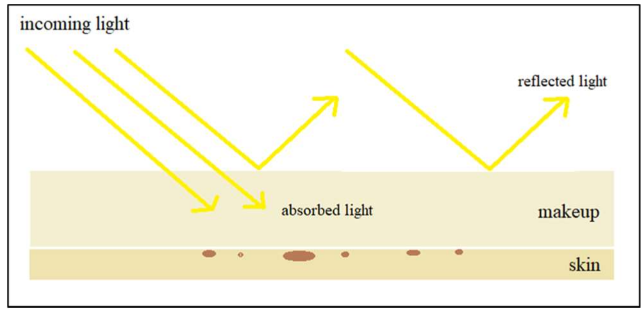

Figure 1: A diagram showing a layer of opaque makeup on top of skin with blemishes. The incoming light is absorbed by and reflected off of the makeup. Because no light is transmitted through the layer of makeup, no light reaches the blemishes, so they are not visible.

2.3 A DISCUSSION OF MEASURABLE PARAMETERS

Opacity, the parameter of interest, is defined differently for various scientific fields. As it pertains to visible optics and light intensity, opacity is the complement of transmittance, which is given by the Beer-Lambert Law [4]. Subtracting transmittance from 1 gives opacity: this is defined in Equation (1) where opacity is a value between 0 and 1, corresponding to 0% light blocked to 100% light blocked. Here, I_0 is the intensity of light at a distance x=0 and $I(x)$ is the intensity of light at a distance x.

$$Opacity = 1 - \frac{I(x)}{I_0} \tag{1}$$

In this way, opacity can be experimentally determined by shining a known amount of light through a medium and measuring how much of the light was able to pass through to the other side. Since application of cosmetics is never truly uniform, at least when done by hand, there may be multiple values for intensity (and therefore opacity) depending on the exact point where the intensity was measured. Because of this, average opacity should be calculated over the area in question.

However, cosmetics are colored, and simply using a light sensor does not account for color. In order to equate color and opacity, additional analysis must be done. Instead of using a light sensor, a photograph can be taken of light shining through the cosmetic. The image file (.jpg) contains RGB (red, green, blue) color information, which can be converted to HSL (hue, saturation, lightness). HSL is an additive color model where each pixel in a photograph has associated hue, saturation, and lightness values which combine to give one color. Figure 2 shows a graphical representation of the HSL color model as a cylinder. As shown, the values range from 0 to 360 degrees for hue, and 0 to 1 for saturation and lightness, where a lightness value of 0 corresponds to completely black and a value of 1 corresponds to completely white. In this model, hue is separate from lightness, so opacity can be calculated regardless of the color (hue) of the pixel.

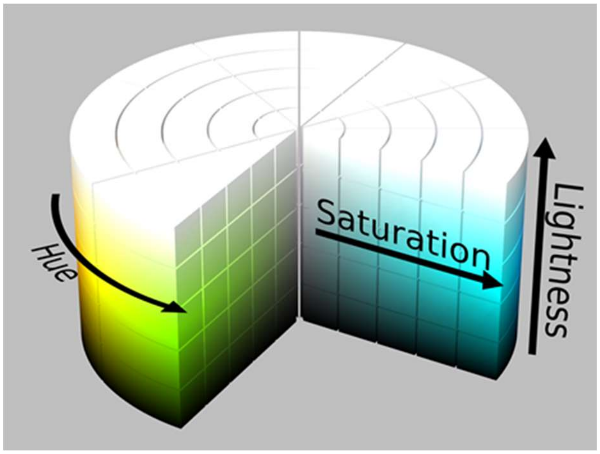

Figure 2: A graphical representation of the HSL (hue, saturation, lightness) color model. Hue corresponds to the angular position around the cylinder, saturation is distance from the origin, and lightness is height. [5]

In order to determine opacity, lightness values for each pixel in the area of interest are identified and averaged using image processing software. The same is done for a control photograph, in which there is no cosmetic applied between the light source and camera. Then, the average lightness is subtracted from the average control lightness to find an opacity value for each image. Since lightness is a value from 0 to 1, opacity can be understood in units of percent. This relationship is shown in Equation (2), where L_c is the average lightness of the control image, and L_t is the average lightness of the trial image in question.

$$Opacity = L_c - L_t \tag{2}$$

The formula calculates the opacity of the image by comparing color lightness to the control. This comparison is necessary because, depending on the experimental setup, pure white may not be the resultant color in a photograph of the light source. Here, the parameter of opacity serves as an analog for coverage—a higher opacity value corresponds to better makeup coverage.

Image homogeneity is a way to determine the uniformity of pixels in an image, and thus homogeneity of a photo of makeup application can be used to quantitatively measure evenness of the application. Homogeneity is a property of the gray-level co-occurrence matrix created from a grayscale image. Each (i,j) value in this matrix is calculated by finding how often a pixel with grayscale intensity value i occurs next to a pixel with the value j. Homogeneity is then the closeness of the distribution of matrix elements to the diagonal [6]. Since homogeneity is based on grayscale intensities, it is not affected by differences in pixel hue.

3. EXPERIMENTAL DESIGN

In order to measure opacity of the liquid foundation for different application methods, an experiment was conducted using a custom-built test apparatus, a phone camera, and a precision scale. First, plastic slides were weighed on the scale before and after being coated in makeup with one of three application methods. Then, images of light transmitted through the slide were taken and analyzed to obtain values for opacity and homogeneity.

3.1 TEST APPARATUS

To conduct the experiment, a test apparatus was constructed to allow for repeated sampling. The apparatus is designed to direct a constant amount of light through the sample of makeup and facilitate the acquisition of photographs at a constant position relative to the sample. To this end, the apparatus consists of a box-like structure made of black acrylic, with an LED light source in the bottom. The LEDs direct light up through a diffuser sheet to the sample, which rests on a circular cutout above the LEDs. The cover of the structure contains a circular hole which fits the lens of a Motorola Moto Z Play phone camera, so that photographs may be taken at the same position for each trial. The seams of the structure are sealed against ambient light with black felt and electrical tape. Figure 3 depicts a digital rendering of a section view created from the CAD model of the test apparatus.

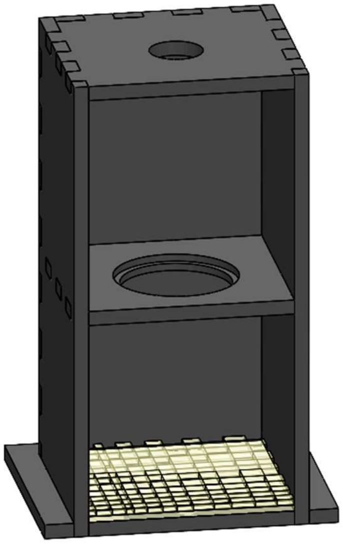

Figure 3: A section view of the Computer Aided Design (CAD) model of the sealed test apparatus. The structure, made of black acrylic, is laser-cut with notches so that the parts fit together at right angles. The apparatus contains a shelf with a cutout to rest the sample slide, while LEDs direct light up through the slide. (Not shown: sheet of diffusing paper affixed to the bottom of the shelf, to distribute light from the LEDs more evenly.)

3.2 DATA COLLECTION

Each trial consists of a plastic slide being coated with a layer of Wet 'n Wild Coverall cream foundation (an affordable, widely-available liquid foundation) and photographed inside the test apparatus. Each slide was weighed with an American Weigh Scales GEMINI-20 precision milligram scale three times: first when the slide was bare, then after makeup was applied, and finally after spreading the makeup on the slide using the appropriate method. This was done to obtain measures of how much makeup was used (how much left the tube) and how much makeup was wasted (how much remained on the implement after application). Foundation makeup was applied using either an e.l.f. foundation brush, an Up-and-Up white cosmetic wedge sponge, or a SiliSponge silicone pad. Mass, application method, and corresponding image filename were recorded for each trial. There were 11 trials using the sponge, 10 trials using the SiliSponge, and 9 trials using the brush.

3.3 ANALYSIS METHODS

Once photographs were obtained for each application method, the photographs were analyzed using MATLAB to determine opacity. To do this, the image's RGB pixel values were derived and then converted to HSL using the rgb2hsl.m script [7]. Then, a circular region of the image inside the sample slide was auto-selected, and average opacity was calculated over all pixels in the region using Equation (2). Image homogeneity was determined from the properties of the gray-level co-occurrence matrix constructed from image lightness values. The final reported parameters were image filename along with average opacity and homogeneity for that image.

4. RESULTS AND DISCUSSION

Representative images for each application method are shown in Figure 4 below. Qualitatively, the sponge displays the most even and uniform results, while the other two are streaky and less uniform. It also appears that the sponge application is most opaque.

Figure 4 (a-d): Representative images taken during the experiment using a) no makeup, b) a brush, c) a sponge, and d) a SiliSponge. The "no makeup" image was used as a control to find comparative opacity for subsequent images. The black ring around the inside of the no-makeup image is the lip that the plastic slide rested on.

The data show that the SiliSponge application method both used and wasted far less product than the other two methods; however, it produced relatively low opacity and homogeneity. As seen in Figure 5, there is a positive correlation between opacity and amount used, so SiliSponge opacity could perhaps be increased to the same levels as the brush or sponge by simply using more product.

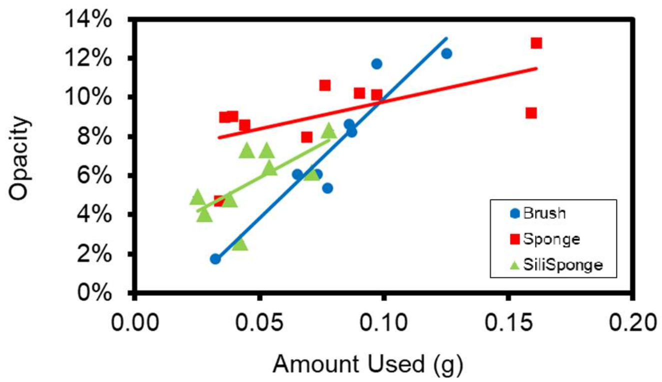

Figure 5: Graph of opacity vs. amount used, color-coded by application method. There is a statistically significant positive correlation between opacity and amount used for all three methods at the 95% confidence level. The slope is 1.22 ± 0.14, 0.28 ± 0.08, and 0.68 ± 0.21 %/g for the brush, sponge, and SiliSponge, respectively. Note that error bars are not included on the data points, since the large number of pixels in each image used to find opacity makes each uncertainty negligible.

The results for homogeneity are incredibly interesting because the data suggest that the sponge produced very uneven coverage. Student t-tests were used to analyze the differences between averages. As shown in Figure 6, the average homogeneity for the sponge was statistically significantly lower than that of the brush or SiliSponge. However, this homogeneity data is at odds with a qualitative analysis of the "evenness" shown in the images. For example, looking at Figure 5, the sponge appears to provide the most even coverage by far. Because the data do not reflect that, another metric should be investigated to measure evenness. Since homogeneity does not capture human perception, those results should be ignored.

When considering product use and product waste, Figure 7 shows that the SiliSponge tended to both use less and waste less product. All trials for the SiliSponge show less than 0.1 g of used product (product taken from the bottle) and less than 0.02 g of wasted product (product that is left on the implement after application). This may be explained by the composition of the SiliSponge—since it is made of silicone, it does not absorb makeup like a porous material would. With 95% confidence, there is a statistically significant positive correlation between amount used and amount wasted for all three application methods. However, the incremental change is not as great for the SiliSponge. This suggests that the SiliSponge can use more product without increasing waste as much as the other methods.

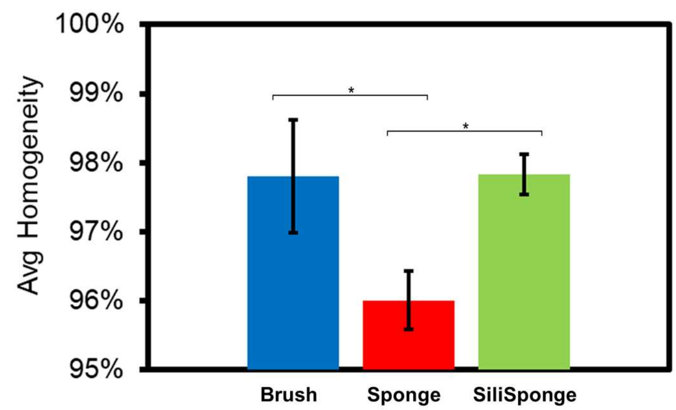

Figure 6: Average homogeneity for each application method. Statistical significance at the 95% confidence level is shown with brackets and an asterisk. There is a statistically significant difference between the sponge compared to the brush, and the sponge compared to the SiliSponge.

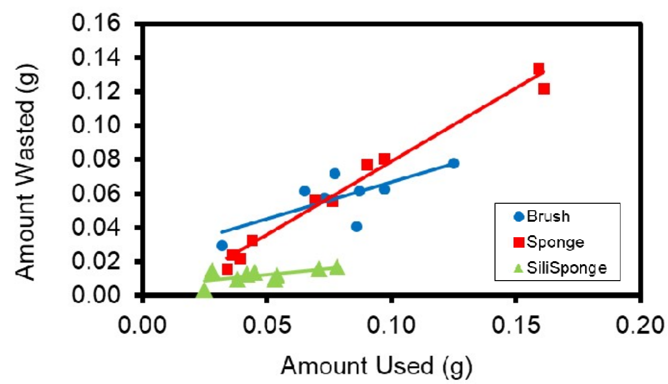

Figure 7: A plot showing amount wasted vs. amount used for each trial, along with linear fit lines for each application method. Trials with greater measured waste than measured amount used were removed from the dataset entirely due to measurement error. The data show that the SiliSponge consistently used and wasted less product. There is a statistically significant positive correlation for all three application methods. The slope is 0.43 ± 0.13, 0.863 ± 0.028, and 0.142 ± 0.049 g/g for the brush, sponge, and SiliSponge, respectively.

Looking at average values for the data, student t-tests at the 95% confidence level were performed to determine statistical significance for each noticeable difference. Differences between two values that are statistically significant are indicated using brackets with an asterisk.

The statistical differences shown in Figures 9 and 10 demonstrate that the SiliSponge both used less and wasted less makeup than the sponge and brush, which is desirable, but also had lower opacity compared to the sponge (as seen in Figure 8), which is not ideal. The brush and sponge had nearly identical average results with the exception of the homogeneity data, which is to be ignored.

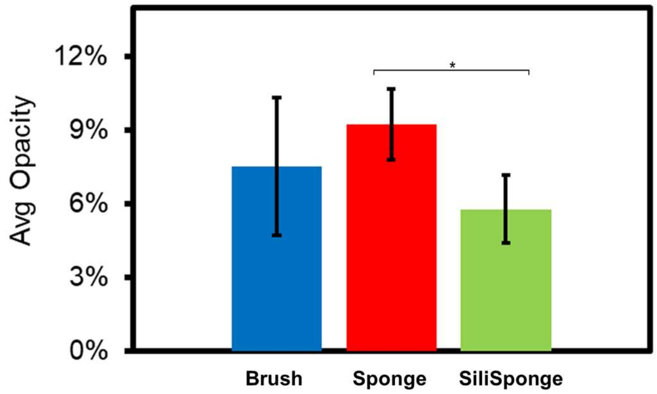

Figure 8: A bar graph showing the average opacity for each application method. The SiliSponge resulted in the lowest opacity compared to the sponge and brush. At the 95% confidence level, the sponge and brush are not statistically different enough to be significant.

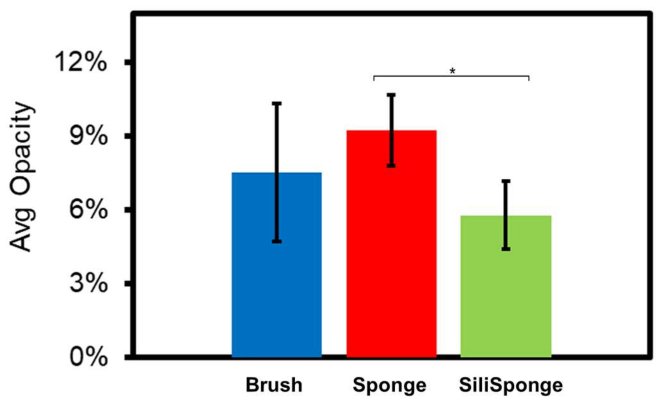

Figure 9: A bar graph showing the average amount of makeup wasted (in grams) for each application method. Although the error bars overlap, student t-tests showed statistically significant differences, meaning that SiliSponge used less product than the brush and sponge with 95% confidence.

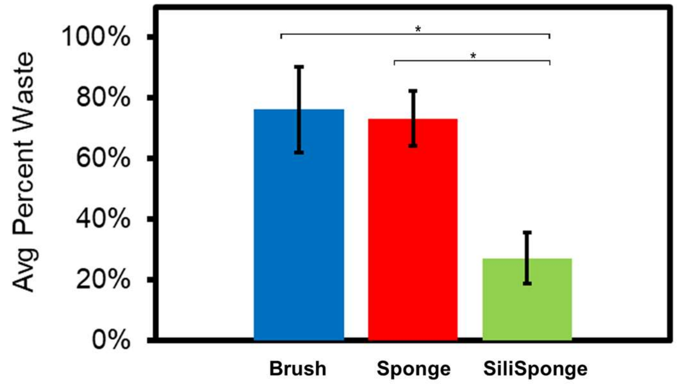

Figure 10: A bar graph showing the average percentage product waste for each application method. Percent waste is calculated as a percentage of the amount of product used, that is, the percentage that is not present on the slide after application. Here, the SiliSponge wasted a statistically significantly lesser amount than the sponge and brush.

Some mitigating factors in this experiment include the measurement and analysis methods for opacity, ensuring continuity in application for all trials within a group, and the relatively small sample sizes. In future versions of this experiment, perhaps a photometer or other light meter could be used to measure intensity of light instead of performing image analysis. Even with a control, finding opacity without measuring light on both sides of the medium is difficult to do accurately. In addition, a way to apply makeup to slides in a consistent manner could be valuable to prevent confounding variables, as would more trials, to reduce uncertainty and allow for stronger conclusions to be drawn.

5. CONCLUSIONS

The data show with 95% confidence that the SiliSponge wastes, on average, 46 percent less product than the brush or sponge. The SiliSponge also resulted in a lower average amount of product used, but an average opacity that was 3 percentage points below the opacity of the sponge. However, since a positive correlation exists between opacity and amount used, the SiliSponge might produce opacity similar to that of the sponge or brush if more product is used. Given these results, the SiliSponge is an ideal choice when the user prefers to be economical by using and wasting less makeup overall. The sponge is ideal when the user desires more opaque, complete coverage, at the cost of product use and waste. A qualitative analysis suggests that the brush provides the least even coverage (despite homogeneity data pointing to the contrary) and is therefore undesirable as an application method.

The results of this experiment point to either the sponge or SiliSponge as the most effective application method depending on the user's needs. Overall, this study provides scientific perspective into the application of liquid foundation makeup, so users can make informed choices that fit their needs and understand the aesthetic results they observe.

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