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Color accuracy and durability for printed, branded textiles

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Abstract

Branded athletic apparel is a multi-billion dollar business and it continues to expand year over year. Sports teams and their fans expect brand accuracy and durability across all types of textile-based products from clothing to home decor. Color is a vital part of a brand's identity and printing consistent, durable, and accurate brand colors across different materials can be challenging for manufacturers. This study examines the accuracy and durability of two brand colors, specified by the brand as Pantone and CMYK values and measured as LAB values using a spectrophotometer, and printed on three textiles commonly used for clothing. The study examined the three most common printing processes for manufacturing apparel–dye sublimation, direct-to-garment (DTG), and screen printing. Study results show that the screen printing process is able to provide the most accurate color replication on any of the three textiles when compared to the target brand color. The DTG process in combination with a polyester or poly-blend material provides the best durability of the color after the first cycle of laundering has been completed. However, dye sublimation on blend or polyester textiles provides the most color stability after the full five treatment cycles.

Introduction

Although not always defined clearly by the brand itself [1], colors are a recognizable element of a brand identity for a product, company, or sports franchise [2–4] and brand-based creators and manufacturers try to attain a high standard when producing them. Previous research demonstrates that fans of a sports team notice when the brand colors are represented inaccurately on screen [5] and researchers have worked towards solutions to address visual inaccuracies in a consistent and repeatable way [6–8]. However, brand colors are also represented on diverse media using many different printing processes and fans expect accurate representation across all types of branded products.

The market for officially branded, athletics merchandise was $280.3 billion in 2018 globally, up 3.2 percent from the previous year [9] with projections for continued growth across all sports. For example, the international football apparel market is expected to grow by $2.62 billion from 2020 to 2025, increasing 4.97% annually [10].

There are 130 Football Bowl Subdivision (FBS) Division 1 teams in the United States connected to higher education institutions. Branded apparel for both athletes and fans include a broad range of products such as shirts, hats, shoes, sweatshirts, etc. and home goods like flags, pillows, wall decor, etc. These products are a very large part of the clothing and textile market and the licensing fees contribute a significant amount to the athletic budgets for these educational institutions. Currently, there are five major manufacturers with contracts for branded NCAA (National Collegiate Athletic Association) merchandise. Nike, Adidas, and Under Armour have the majority of these apparel contracts, with the size, value, and production numbers matching that order. For example when this paper was published, Nike's website had almost 2000 NCAA branded shirts available for purchase [11].

Three processes commonly used in textile manufacturing are dye sublimation, DTG, and screen printing. Dye sublimation, also referred to as heat transfer printing, is frequently used to transfer designs onto plastics, polymers, and textiles containing polyester [12]. Items that are not plastic-based can be coated with a polymer spray prior to printing. Dye sublimation involves drafting the design, printing it onto transfer paper using special sublimation inks, preparing the substrate for printing, and applying the heat press to the substrate with the affixed transfer paper. Once the sublimation occurs (solid ink becomes gas with the addition of heat and pressure), the image adheres to the substrate as the material becomes permeated with the gas [13]. Some advantages of dye sublimation are high resolution prints, print durability, and the full color graphics are applied with a single pass, unlike traditional screen printing, flexography, and lithography [14].

DTG, is a printing process that sprays ink directly onto the textile using a modified inkjet technology [15]. The advantages of this relatively new technology include exceptional image detail and the ability to produce full color graphics in a single pass through the printer. DTG is higher in energy efficiency, resulting in a more environmentally friendly production process [15]. The samples printed in this study were not pretreated prior to printing with any of the processes although studies have found more accurate color results when pretreating before inkjet on textiles when trying to accurately represent a full color target [16].

Screen printing is an older print production process that involves transferring a stenciled design to a surface using a mesh screen and applying ink with a squeegee (rubber blade). The process can be done by hand or be automated by a machine. Advantages of screen printing include versatility, durability, vibrant color reproduction, speed and efficiency, and the process itself is relatively simple to execute [15].

The most commonly used textiles in fan apparel production include 100% cotton, cotton/polyester blends (referred to as blend going forward), and 100% polyester. This study sought to test color accuracy across three production processes using these commonly used fabrics. The various characteristics of these fabrics impact the initial appearance and the long term durability of the colors. Cotton and blend fabrics, frequently used in screen printing, are known to absorb ink well, especially water-based inks. The consistency of the fabric affects the overall print and durability. For example, thicker material will absorb more ink than thinner materials. This can result in long-lasting, more vivid color [16]. Dye sublimation commonly utilizes polyester because of the ability to repel water-based inks. This characteristic causes polyester to not be as suitable for DTG printing which uses water-based inks, unless the textile is pretreated prior to production [17].

Several previous research studies in textile printing examine color accuracy and fastness across the full color spectrum or focus strictly on process color reproduction (cyan, magenta, yellow, and black) [18]. Many of these studies also emphasize the testing of specific inks and fabrics using a variety of production processes.

Previous research analyzed the color accuracy and durability of textiles in print production by testing according to the standards set by the International Organization for Standardization (ISO 105 C06). Alternatively, the American Association of Textile Chemists

and colorists (AATCC 61) provides standards for testing color fastness in textiles [19].

This research sought to examine color accuracy (defined as the recreation of the specified color onto the textile) and durability (defined as color fastness after treatment) using three different manufacturing processes (dye sublimation, DTG printing, and screen printing) across three types of material (cotton, blend, and polyester). This study is unique in that it analyzed a pair of brand-specific colors. It also included DTG printing, which is considered a newer technology documented in few previous studies. For this study, samples were tested according to the domestic laundering equivalency recommended by ISO 105 C06, the standard for testing color fastness which included five total launderings with the temperature not exceeding 70 degrees Celsius [20]. This type of laundering mimics the wear and tear common in household use which aligns with how fan apparel is likely to be treated and maintained. Therefore, this study will demonstrate brand color durability across three common print processes and three textile compositions as a consumer would experience it with fan apparel. The findings will provide recommendations for brand owners, manufacturers, and fans who want to ensure brand color accuracy and long term durability on their products.

Background

This study began with a survey of top manufacturers and an in-person visit to a smaller manufacturer. All of these manufacturers hold licensee rights for many athletic brands, including the brand used in this study. The survey built on previous research into color reproduction and process, but focused on the experience of large-scale manufacturers. Survey responses guided the researchers in designing this study investigating the accuracy and durability of the primary processes and textiles used when producing branded apparel for both fans and athletes.

Survey

Five vendors completed the survey. All of them identified as large vendors who own or engage with multiple manufacturing facilities. All respondents produce officially licensed apparel for many different brands. When asked about what printing processes they use, all but one of the companies use multiple types of printing processes. Screen printing made up a significant portion of the manufacturing process for the majority of the vendors with the exception of one company who focused solely on the production of dye sublimated products. Survey respondents stated that the primary driver for choosing which process to use for a product was the type of material requested by the client and the detail and quality needed on the final product.

Two of the vendors use primarily or exclusively 100% polyester fabrics for their products. Two other vendors use a mix of 100% cotton and blends, using very little 100% polyester fabrics. The fifth vendor used an equal mix of all three types of fabrics in their manufacturing. According to the respondents, the color accuracy depends on the process but one vendor said that in general blends can result in more subdued final colors, creating challenges when trying to reproduce highly saturated color palettes.

All vendors admitted challenges with color accuracy on some fabrics, depending on the process. There was some agreement that the screen printing process consistently produced more accurate color reproduction due to having a single bucket of ink for each brand color versus dye sublimation and DTG which both use color builds from cyan, magenta, yellow, and black (CMYK) or expanded gamut ink sets. For screen printing, this was true for vendors whether custom mixing brand ink or purchasing the ink as a pre-mixed spot color.

Vendor Facility Tour

The researchers also visited a mid-sized vendor to see first-hand the manufacturing process. During the tour several of the survey questions were answered but this smaller-sized licensed vendor was not included in the survey results above. However, the researchers decided to include their verbal responses because they may be representative of dozens of licensee holders of a similar size and scope that produce licensed apparel. For example, the NCAA program that was used in this study has almost 550 manufacturers of all sizes and product types holding rights to produce branded products [21].

This mid-sized apparel vendor produces primarily screen printed shirts. They also offer small-run DTG textile printing. They have a color technician and an ink mixing room where they mix screen printing inks to brand specifications in-house. Using this method of producing batches of ink for screen printing, they can provide very consistent color across even large batches of printed shirts. They offer apparel in 100% cotton, several blends, and 100% polyester and did not identify any of their materials as being more challenging for color reproduction. This aligns with our survey results where color accuracy was easier to maintain across all textile types when using the screen printing process.

Methods

Based on previous research combined with the responses from manufacturers, this study looked at the accuracy and durability of two brand colors across three common textile printing processes and three types of textiles used for fan apparel. Color was measured on a standard tint scale with patches measuring from 0% to 100% opacity using i1Basic Pro 3 Plus spectrophotometer set to D50/2°. This particular unit has a wider aperture of 8 millimeters allowing for more accurate color measurements for textiles. The device was calibrated using the manufacturer provided white patch prior to each set of readings. Initial measurements were recorded after printing but before any treatment cycles to determine the accuracy of brand representation on each textile type based on the 100% tint patch within the scale. Measurements were taken with a white backing under the t-shirt material. Patches were designed to be an appropriate size to measure with this device and did not reveal noticeable differences within the patch itself, therefore, each patch was read one time and the reading recorded.

Treatment included five total washings in hot water (not exceeding 70 degrees Celsius) using original Tide-brand detergent. This was performed using a standard home washing machine and dryer to mimic how fan apparel would be laundered and cared for by the average user and followed ISO 105 C06 recommendations for domestic testing of color fastness. Samples were then dried in a standard home dryer set to “standard,” the most often used home dryer setting because it is quick and normally the hottest setting available on the machine. Measurements were taken after completing each treatment cycle to identify durability of the brand colors through repeated washing and drying cycles. The post measurements were then compared with the initial color readings

from before treatment using the Delta E 2000 formula to determine how different fabrics and printing processes fade over time and with recurring washes.

Materials & Processes

Three printing processes were used for this study–dye sublimation, DTG, and screen printing. For dye sublimation production, a 406.4 mm x 508 mm George Knight Digital Swing flatbed heat press was used for both the heat cure and the dye sublimation image transfer. An Epson Surecolor F570 roll fed printer loaded with Epson brand CMYK dye sublimation inks was used to print the artwork. The printer was set to "flexible material" and used the manufacturer provided profile for textile production. A thick polymer coating was applied to each textile sample utilizing an aerosol spray bottle. The coating was then cured using the manufacturer recommended time, temperature, and pressure. The image transfer also used time, temperature, and pressure recommendations from the manufacturer. For cotton and blended textiles the setting was 60 seconds, 375 degrees Fahrenheit/ 190 degrees Celsius, and medium pressure. For polyester, the setting was 45 seconds, 400 degrees Fahrenheit/ 204 degrees Celsius, and medium pressure. Parchment paper was placed between the textile and the heat press for both the cure and image transfer pressings.

The DTG printer for this project was the Epson Surecolor F2100. This unit has a large platen and additional substrate capabilities beyond traditional t-shirt production. This printer also provides the capability to print white ink although that was not used for the samples in this study since all the textiles were white. The decision was made not to pretreat the fabrics, as is customary in DTG printing, because previous research suggested that pretreatment does not impact the overall durability and accuracy of color on light-colored fabrics, especially when no white ink is being applied [22]. The same digital file was used for each process and the color management was handled by the printer based on the manufacturers recommendations for the DTG output. Each textile was printed on the Epson and then cured using a George Knight Swing flatbed heat press. The press was set at 335 degrees Fahrenheit/ 168 degrees Celsius and hovered over the sample for 30 seconds without direct contact or pressure. Then, light pressure was applied for one additional minute.

The screen printing unit selected for this project was a 4-station manual screen printing press. Screens were a 200 mesh count for optimal print detail and shirts were cured using a standard commercial belt dryer. Screens were made using a SAATI laser engraving and exposure unit. Screen printing ink was mixed to the brand specifications at the vendor facility visited by the researchers prior to beginning this project.

The DTG and dye sublimation processes both used CMYK inks to produce specific colors whereas screen printing used premixed spot color ink. As previously mentioned, dye sublimation requires at least some polyester to be in the textile itself or a pre-coat on the fabric is necessary for the inks to properly adhere to the surface. DTG and screen printing both work well with most textile bases; however, to effectively print white ink using DTG, a pretreatment must first be applied but this was not necessary as white ink was not used for this study.

The brand provides color specifications for the brand orange in CMYK, RGB, Pantone numbers for uncoated, coated, and apparel, and a hex number for web reproduction [23]. Since this study looked at textile reproduction, the Pantone value for textile was considered the color reference for this color. For the secondary color, the brand provided CMYK, RGB, a single Pantone reference, and hex number values [23] so the Pantone color reference was again used even though it was not specified directly for textiles. The provided Pantone number was converted to LAB values using Pantone's Connect tool for comparison with the spectrophotometer readings [24]. According to the conversion tool, LAB reference values for the orange (Pantone 165C) are L 64.76, a 58.52, b 67.92 and the purple brand color (Pantone 268C) are L 28.22, a 34.22, b -41.18. Both brand colors are in gamut for CMYK on the devices used for this study.

The artwork contained three different sizes of the brand logo–small, medium, and large (approximately 50, 100, 150 mm respectively)–and thirteen tint patches ranging from 100% to 0% opacity. The logos were not measured with the spectrophotometer but provided a visual reference for small detail reproduction and a larger patch of ink to look for consistency and ink laydown. All processes used the same artwork which was prepared in Adobe Illustrator using the official brand logos and spot colors provided by the university.

Textiles commonly used to create fan apparel include 100% polyester, blends, and 100% cotton. In the blend category there are many variations, but for this study a 50% cotton/50% polyester blend was used based on a preliminary study showing it worked well with DTG inks. Although weight information was not available from the large online retailer the shirts were purchased from, approximate weights were 150-200 gsm (grams per square meter) for the cotton, 120-140 gsm for the blend, and 180-220 gsm for the polyester shirts. Six t-shirts were printed with each color–primary (orange) and secondary (purple) brand colors–resulting in four 100% cotton shirts, four blend shirts, and four 100% poly shirts for each process. One full set of the printed shirts were held back from the washing cycle and the other eighteen shirts entered the treatment cycles.

Results

After the initial printing of each shirt, all the tint patches were measured and recorded into a spreadsheet using an i1Basic Pro 3 Plus spectrophotometer. These pre-treatment measurements documented a quantifiable baseline for the replication of each printing process, textile makeup, and brand color and were used for the accuracy part of this study.

Accuracy

Accuracy was determined by using the spectrophotometer to measure the 100% patch on each sample prior to treatment and comparing it to the brand-specified color value using the Delta E 2000 formula. The Delta E 2000 calculation was selected based on consultation with industry experts who suggested that this formula is the current standard in textile color measurement and quality control.

Analysis showed that screen printing produced the most accurate and consistent color when compared against the brand specification. On all three fabrics, the DE was 2.5 or below, with the cotton shirt being the most accurate color with a DE of 1.35. The purple colored ink produced less accurate color reproduction than the orange, although screen printing was still the most accurate process even when printing purple. DE measurements ranged from 5.27 to 7.52 for the purple colored ink. Surprisingly, the cotton fabric was the least accurate color reproduction with the

purple ink with the blend material reproducing the purple brand color most closely, Figure 1.

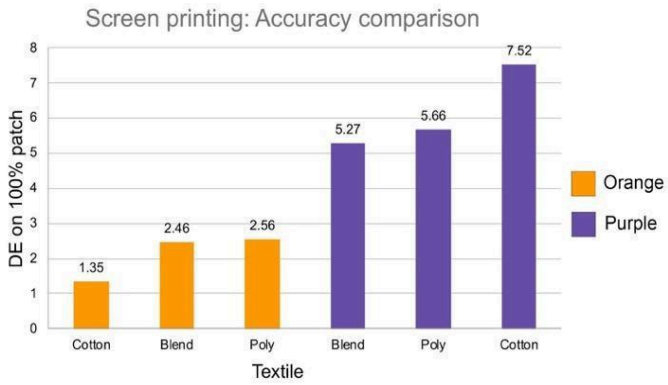

Figure 1. *Screen printing produces the most accurate color reproduction across all textile types, especially with the orange ink.*

Both the dye sublimation and the DTG processes produce much less accurate color reproduction compared to the screen printing process. DE values ranged from fourteen to twenty-eight. Between these two processes, dye sublimation produced the most accurate colors on polyester fabrics with DE readings of fourteen for both brand colors. DTG performed better on orange across all three textiles compared with purple.

Durability

Durability of the printed samples was evaluated based on DE readings following the treatment cycles. The ISO recommendations for domestic laundering, ISO 105 C06, include five wash and dry cycles with the temperature not exceeding 70 degrees Celsius and using laundry soap commonly available to the public consumer, in this case Tide-brand original formula. This treatment process was chosen to align with examining fan apparel which would likely be laundered with these common household methods.

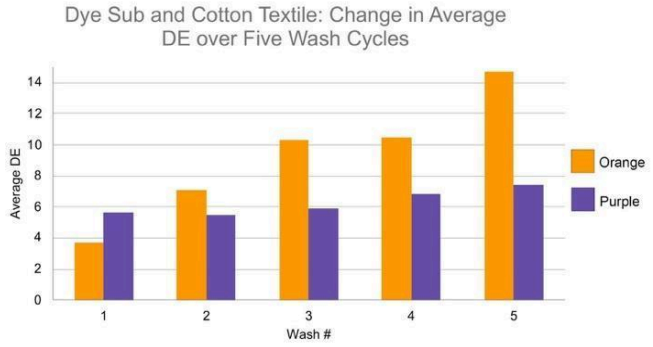

Figure 2. *Distribution of average DE values for all patches on the tint scale with cotton textile samples printed with dye sublimation across all five treatment cycles.*

When examining the impact of each treatment cycle, there were some notable trends in the different combinations of processes, colors, and textiles between cycles. For example, with dye sublimation on cotton durability of the orange ink decreased with each washing but held relatively stable with the purple ink, Figure 2. On polyester printed with the dye sublimation process, both colors held stable throughout the five treatments with orange consistently performing better (DE 2.79-2.97) than purple (DE 5.11-5.51). However, for DTG printing, blended textiles produced highly accurate color initially but colors began to degrade by the final wash cycle.

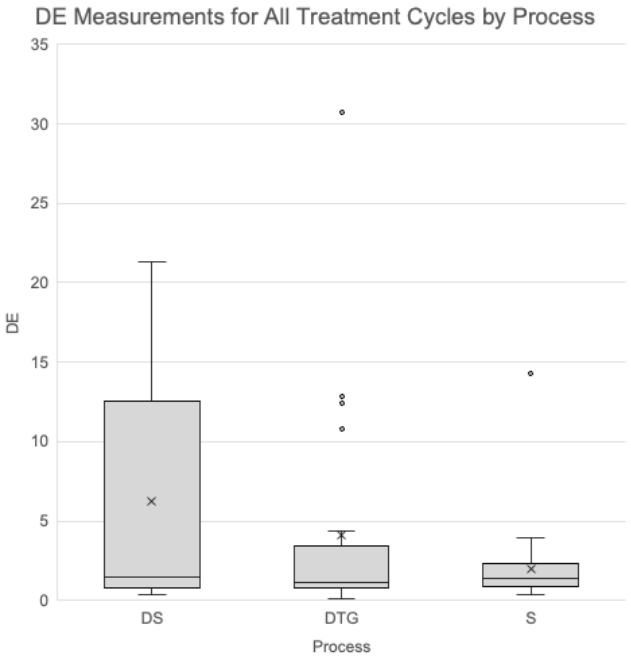

Figure 3. *Distribution of DE values on the 100% color patch on both colors and across all treatment cycles visualized by process. Process noted as: DS=Dye Sub, DTG=Direct-to-garment, and S=Screen printing.*

After the completion of the full treatment process, the DE of the 100% tint patch was examined to look at the difference in process, Figure 3, and textile, Figure 4, and if there were trends in how the two colors reacted to the treatment. When considering all the processes and textile combinations, cotton experienced the most variance after treatment especially when printed with dye sublimation. Screen printing and DTG were much more stable than dye sublimation following treatment. Except for the cotton samples printed with dye sublimation and the purple DTG sample, the other samples remained close to the original colors after the full treatment, indicating durability in all but these three cases, Figure 5.

When drilling down to results based on process, screen printing held true to the original color with the DE range of 0.65 for the orange cotton sample and 1.58 for the orange polyester sample. All of the DE values for screen printing after treatment would indicate that any degradation in color would be unnoticeable to most consumers. The same is true for blend or polyester textiles printed on the DTG (DE=0.72-1.49). Cotton printed with DTG exhibited unacceptable color change, especially with the purple ink (DE=10.76). The samples printed with the dye sublimation press also performed well for the blend and polyester textiles with the exception of the blended textile and purple (DE=4.36). The cotton samples experienced a significant color shift with the dye sublimation printing process with DE readings of 19 and 21.35 for the orange and purple colors, respectively.

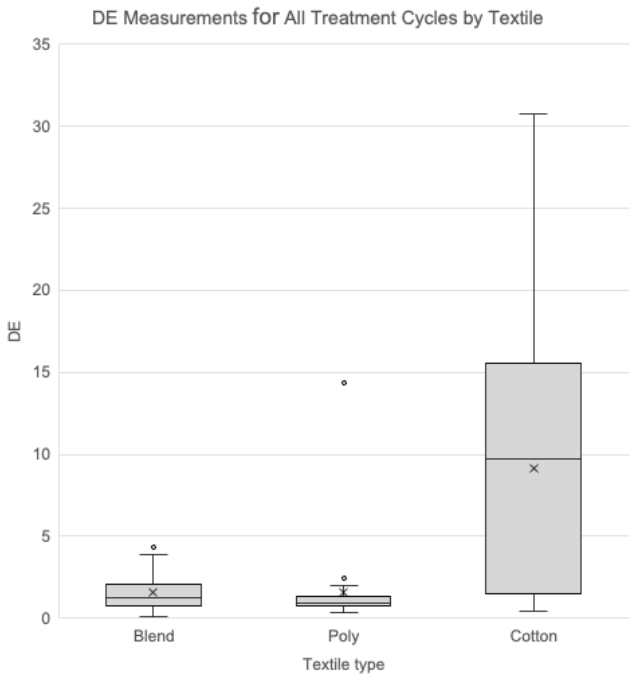

Figure 4. *Distribution of DE values on the 100% color patch on both colors and across all five treatment cycles by textile type.*

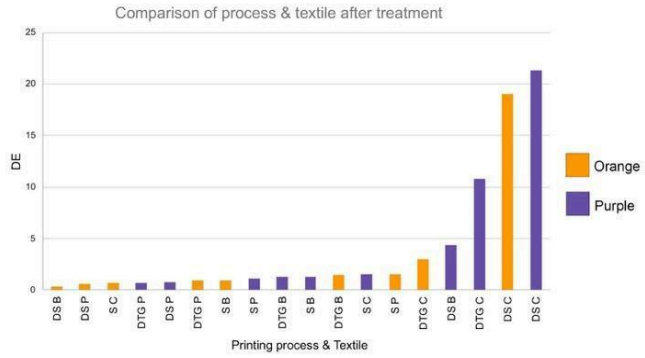

Figure 5. *Distribution of DE readings on the 100% patch for all textiles and process combinations after full treatment. Process and textile noted as: DS=Dye Sub, DTG=Direct-to-garment, S=Screen printing, and B=Blend, C=Cotton, P=Polyester.*

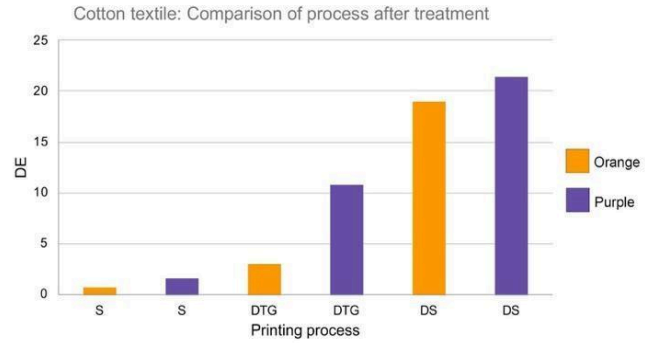

Figure 6. *Distribution of DE readings on the 100% patch for cotton textile across all processes and colors after all five treatment cycles..*

When analyzing results by the type of textile after treatment, polyester was overall the best choice across any process, both colors with the highest DE reading of 1.58 after treatment, still well below what most consumers would notice. Four of the six polyester samples were below a DE of one. The screen printed polyester read the highest after treatment, DE of 1.12 for purple and 1.58 for orange. Blended textile was stable for every sample except for the dye sublimated purple. Cotton on the other hand should be avoided when using dye sublimation or DTG, if color durability is a concern, Figures 6 and 7. However, the screen printing on cotton samples performed well after treatment with DE readings of 0.65 for orange and 1.55 for purple.

Figure 7. *Results for blended (top), cotton (middle), and polyester (bottom) printed with dye sublimation after treatment. The sample in the center shows the instability of this process when printing on 100% cotton textiles.*

Conclusions

Color accuracy on all the tested textiles aligned with the initial survey responses from manufacturers, revealing that screen printing produced the closest color match to the brand specifications. Out of the processes tested, screen printing uses custom spot colors for each color printed rather than a CMYK build which contributed to the resulting color accuracy. The purple brand color was more challenging than orange to attain color accuracy, with the highest DE readings prior to treatment found on all three textiles printed with the DTG printer.

The durability of the colors changed once the samples entered treatment. After completion of the first treatment cycle, results are mixed but in general, polyester and blend textiles maintain their initial color better than cotton across any of the processes with the exception of the orange screen printed cotton sample. DTG performed better than the other printing processes except for one cotton sample, purple. For blended textile, DTG showed fade that slowly progressed but still resulted in acceptable DE readings after the complete treatment. Dye sublimation on polyester stayed very stable from the first wash to the final treatment for both colors. If printing on cotton with either color, screen printing is the most accurate and durable option outperforming both other processes.

It should be noted that some of the DE readings in this study would be considered far out of specification in a production facility. The current conversation around color tolerances for print tends to lean into DE<2.0 as the acceptable deviance from a

prescribed color although not all researchers agree that this level of accuracy influences consumer behavior [25-26] or can even be reliably identified as being in or out of specification using current measuring devices [27]. Even with just a visual check, a few of the samples produced in this study indicate unacceptable color reproduction when using some textile types with certain processes, for example dye sublimation on cotton. This data and analysis were still useful because they indicate which textile choices can be most easily printed on each process when color accuracy and durability are the primary concern.

Future Studies

A future study plans to evaluate the impact of commercial laundering and chemicals commonly used for the care and maintenance of team uniforms. Other recommendations for future work could examine if additional brand colors maintain durability and accuracy better than the ones used in this study. Another study might investigate what impact the initial color of the fabric has on the results since this study tested only white textiles. Based on the survey results, manufacturers felt that screen printing was the most color accurate and consistent printing process for brand colors printed on white or black textiles. This could be investigated more thoroughly in a future study by using textiles with other base colors.

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