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# *"MCB Hair: A Data-Driven Approach to Personalized Hair Color Recommendations Based on SkinTone"*

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## 1. Introduction

Hair color profoundly impacts facial perception and harmony, particularly in relation to skin tone—a universal challenge affecting women worldwide regardless of ethnicity. Both consumers and professional hairstylists face significant difficulties when selecting optimal hair colors. Consumers often minimize risk by choosing shades close to their natural color, fearing unflattering results. Meanwhile, hairstylists, feeling responsible for recommending appropriate shades but lacking confidence in color harmony principles, frequently default to familiar, safe options they've previously applied to clients with similar profiles.

Despite the extensive color ranges offered by most brands, fundamental questions remain: How can we ensure each woman finds her most flattering hair color? How can brands optimize limited shelf space to meet diverse consumer needs? And how can we empower hair professionals to provide truly personalized color recommendations that enhance their clients' appearance?

To address these challenges, we conducted a comprehensive study across six U.S. cities (Miami, Tampa, Freehold, Los Angeles, Chicago, and Atlanta) from June 2024 to April 2025. We tested 95 hair colors on six skin tone clusters—very light, light cool, light warm, medium, deep, and very deep—with approximately 120 women per cluster. These clusters were established based on measurements from approximately 3,000 women worldwide [1].

Traditional testing with oxidative hair colorants would have been impractical, requiring safety intervals between applications and potentially extending over six years per participant to test

80 different colors. Instead, we developed an innovative digital approach that ensures realistic color rendering on the person while enabling large-scale evaluation of numerous hair colors on over 1,000 women. This approach is new compared with the previous studies that have been done on avatar. [2, 3]

## 2. Materials and Methods

### a) Digital system

This section outlines the comprehensive methodology developed for digital hair color evaluation, including image acquisition, color measurement protocols, digital simulation, and consumer assessment procedures.

#### Hair Color Image Capture and Measurement

For digital hair color rendering, we employed a standardized in vitro measurement protocol on colored hair swatches. Oxidative hair coloration products were applied to standardized hair swatches following manufacturer specifications. Once processed, these colored swatches were measured using a spectral camera system to obtain both colorimetric data (L*ab** values) and high-resolution digital images. This dual acquisition approach ensured accurate color representation for subsequent digital simulations.

#### Hair Color Classification System

To facilitate the selection of representative shades for testing, we utilized L'Oréal's proprietary hair color classification system. This color science based framework categorizes the complete spectrum of achievable oxidative hair colors into consumer-relevant color families. The selection of the 95 test shades was strategically weighted across these families according to regional consumer preferences and market relevance, ensuring appropriate representation of colors for the US market.
Of these 95 shades, a core set of 65 were selected for evaluation by all participants. The remaining 30 shades were divided into three groups of 15, tailored to light, medium, and dark original hair colors, respectively

#### Colorimetric Measurement Protocol

Standardized colorimetric measurements were performed on both volunteer skin and original hair. Measurements were conducted using a calibrated spectrophotometer according to established protocols. Facial skin measurements were taken at multiple predetermined facial landmarks (forehead, cheekbone, jawline, and neck). Hair color was measured at specific zones determined by hair length, with a minimum of four measurements per volunteer to account for variation between the roots, the lengths and the tips.

#### Volunteer Image Acquisition System

A controlled imaging environment was established using a commercial lighting system. The setup consisted of five D55 diffuse light sources—three positioned to illuminate the subject's face and two directed at the background—providing consistent, standardized lighting conditions. High-definition images were captured using a professional-grade camera mounted on a fixed position. Illustration in Figure 1

Volunteers were positioned on a rotating platform, enabling the capture of five standardized angles (two right profile, one frontal, and two left profile views) without disturbing the subject's position. All camera and lighting parameters were optimized through iterative testing to achieve accurate skin and hair color reproduction, validated against spectrophotometric measurements and visual evaluation.

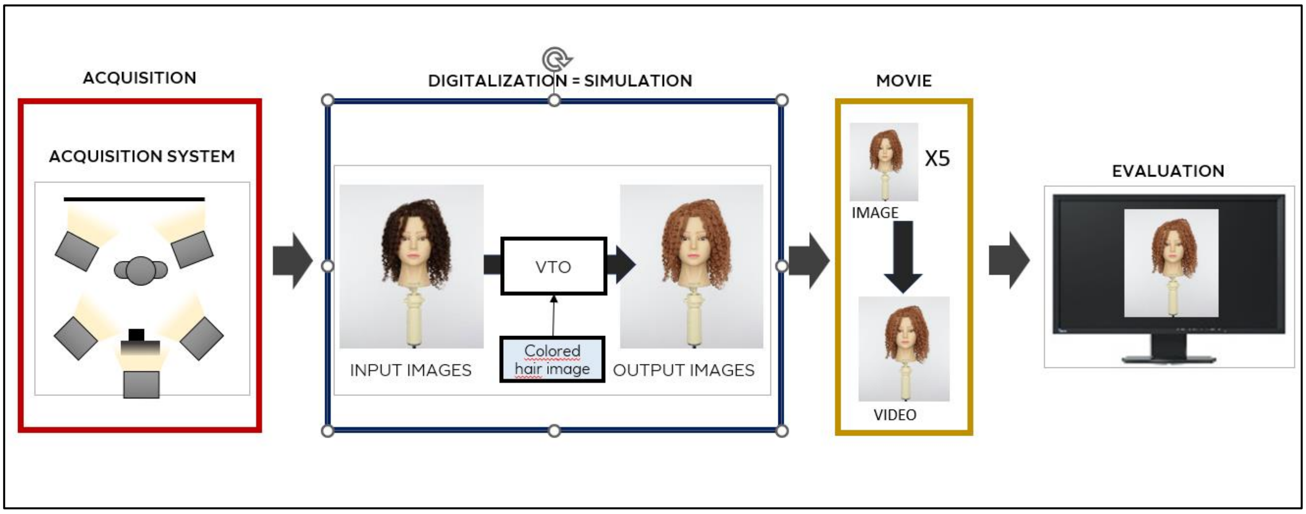
*[FIGURE 1: Acquisition system]*

**Digital Hair Color Simulation**

The acquired volunteer images were processed through a Virtual-Try-On system. For each simulation, the system was provided with the digital image of the target hair color. The algorithm then generated five modified images (corresponding to the five captured angles) with the simulated hair color applied to the volunteer's hair.

Based on the measured hair lightness of each volunteer, 80 shades are simulated : 65 common shades + 1 group of 15 shades depending of the lighteness of the current hair. These individualized selections ensured that each volunteer evaluated colors that represented both appropriate and challenging options for their specific hair characteristics. The five angle-specific images were then compiled into a short video sequence to provide a comprehensive view of the simulated color result.

The complete digitalization workflow is illustrated in Figure 2.
Example of haircolor simulation on a volunteer is illustrated in Figure 3.




*[FIGURE 2: Workflow diagram of hair color digitalization process]*

*[FIGURE 3: example of simulations on a volunteer]*

The full digital workflow has been patented under the reference FR24/14325

### b) Evaluation Protocol

Following the digital simulation process, each volunteer participated in a structured evaluation session. Volunteers were seated 60 cm from a color-calibrated display in a dark environment to eliminate ambient light interference.

The assessment followed a two-stage protocol:

1. Initial suitability screening: For each of the 80 simulated hair colors, volunteers responded to the question "Does this hair color suit you?" using a 5-point Likert scale.

The order of the 80 shade was randomely selected by an algorithm to make sure that there is no bias of this order on the preference.

2. Detailed evaluation: For colors receiving high or neutral suitability ratings, volunteers viewed the simulation again and responded to three additional questions:
   - "How often would you wear this color?" (frequency scale)
   - "Which emotions do you feel when seeing yourself with this color?" (multiple-choice emotional response)
   - "Do you feel younger with this color?" (5-point agreement scale)

All responses were captured using standardized evaluation software to ensure consistent data collection across all test locations.

### c) ***Factor Analysis***

Consumer preference for hair color was assessed utilizing the Top2Box (T2B) metric. T2B analysis provides a concise summary of positive responses from scaled survey data by combining the top two ratings (e.g., 4 and 5 on a 5-scale rating). A hair color achieving an 80% T2B score, for instance, indicates that 80% of respondents provided a rating of 4 or 5, suggesting a high level of consumer satisfaction. For subsequent analysis, T2B scores for each hair color shade were computed within each predefined skin tone cluster, as described earlier.

To evaluate the potential impact of skin tone on hair color preference, a cross table (contingency table) and Pearson's chi-squared test were performed [5-7]. The null hypothesis ($H_0$) posited no association between skin tone and hair color ratings, while the alternative hypothesis ($H_1$) suggested the presence of such an association. The factor analysis, calculated using the T2B scores of all 65 common shades across six skin clusters, produced a chi-squared statistic and an associated p-value. If the p-value fell below the predetermined significance threshold (e.g., 0.01), the null hypothesis was rejected, signifying a statistically significant relationship between skin tone and hair color preferences.

## 3. Results

### *3.1.* ***Impact of Skin Tone***

Chi-Squared test results (Table 1) confirmed that skin tone significantly influences hair color selection. While no notable differences were detected between adjacent skin tone clusters (e.g., C1 vs. C2), statistically significant differences were observed between light and medium skin clusters (e.g., $p < 0.0001$** for C2 vs. C4), as well as between medium and deep clusters (e.g., $p < 0.0001$** for C3 vs. C6). To further validate these findings, adjacent clusters were merged into broader skin tone categories: light (C1-C2), medium (C3-C4), and deep (C5-C6). Same Chi-squared test was performed across these three consolidated skin tone groups, confirming highly significant differences ($p <= 0.001$**) in all inter-group comparisons (Table 2).

**Table 1.** P-value of Chi-Squared test between skin clusters and rating T2B

| | C1 | C2 | C3 | C4 | C5 | C6 |
|---|---|---|---|---|---|---|
| **C1** | / | | | | | |
| **C2** | 0.99 | / | | | | |
| **C3** | 0.99 | 0.67 | / | | | |
| **C4** | 0.13 | < 0.0001** | 0.65 | / | | |
| **C5** | < 0.0001** | < 0.0001** | < 0.0001** | 0.0003** | / | |
| **C6** | < 0.0001** | < 0.0001** | < 0.0001** | 0.30 | 0.99 | / |

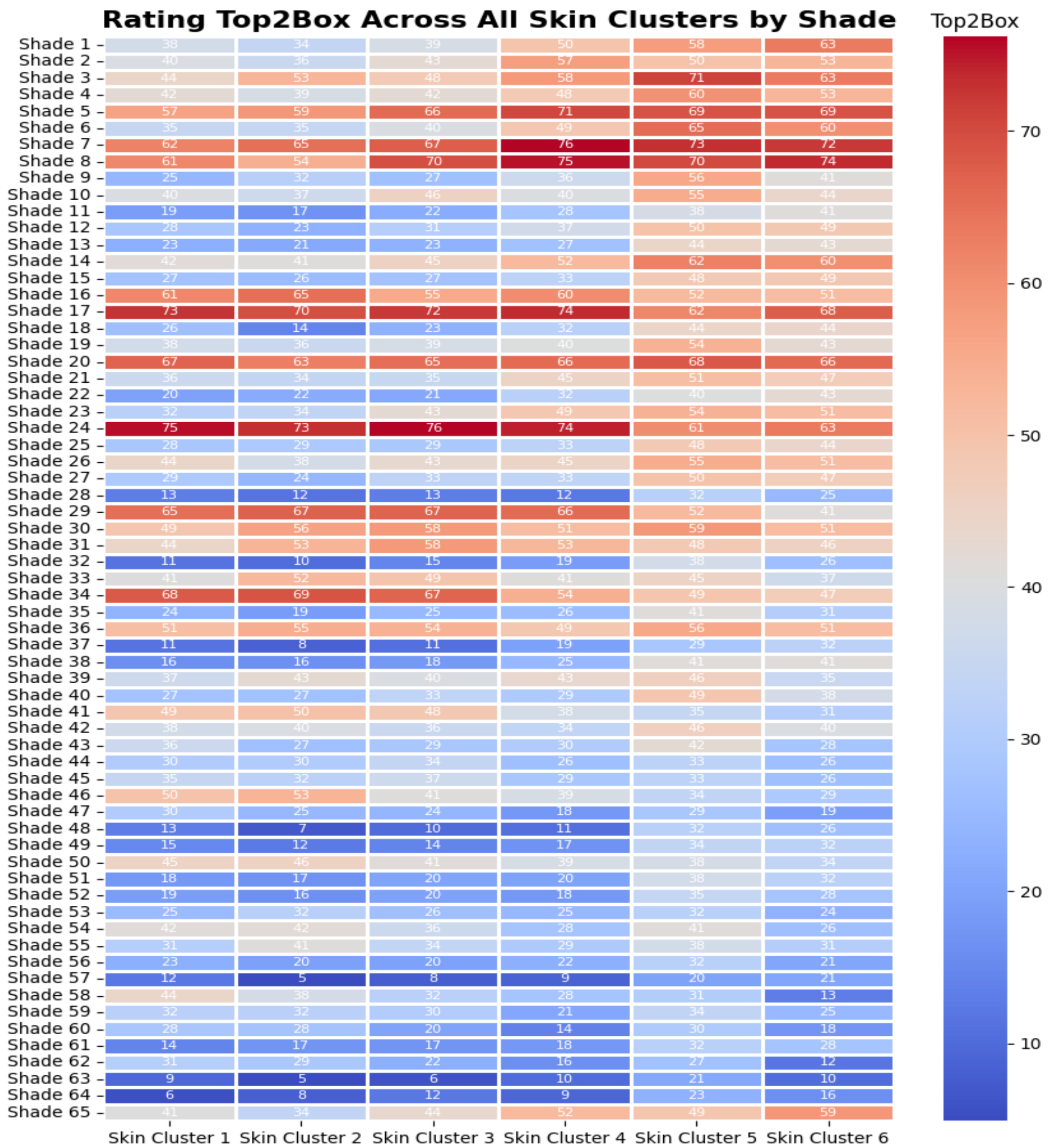
*Note: *p-value < 0.05 indicates a significant difference; **p-value < 0.01 indicates a highly significant difference*

**Table 2.** P-value of Chi-Squared test between skin tone groups and rating T2B

| | Light Skin Group (C1 - C2) | Medium Skin Group (C3 - C4) | Deep Skin Group (C5 - C6) |
|---|---|---|---|
| **Light Skin Group (C1 - C2)** | / | | |
| **Medium Skin Group (C3 - C4)** | 0.001** | / | |
| **Deep Skin Group (C5 - C6)** | < 0.0001** | < 0.0001** | / |

*Note: *p-value < 0.05 indicates a significant difference; **p-value < 0.01 indicates a highly significant difference*

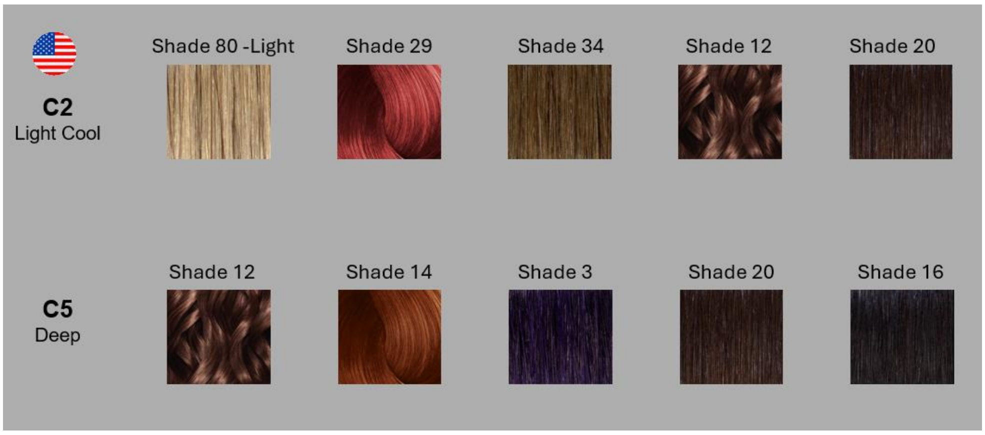
These results suggest a gradient effect, where hair color preference diverge markedly across broader skin tone ranges but remain relatively consistent within closely related clusters. This observation was further supported by the T2B rating heatmap across six skin clusters (Figure 4), where red represents high T2B scores (preferred shades) and blue signifies low T2B scores (dissatisfaction). For example, Shade 34 showed strong preference among light skin clusters (C1–C2), whereas Shade 3 was predominantly favored by deep skin clusters (C5–C6). This visual stratification aligns with the statistical results, reinforcing that shade suitability vary sharply across distinct skin tone groups.




*[Figure 4. Heatmap of T2B ratings for 65 common shades across different skin clusters]*

### *3.2.* ***Most Suitable Shades***

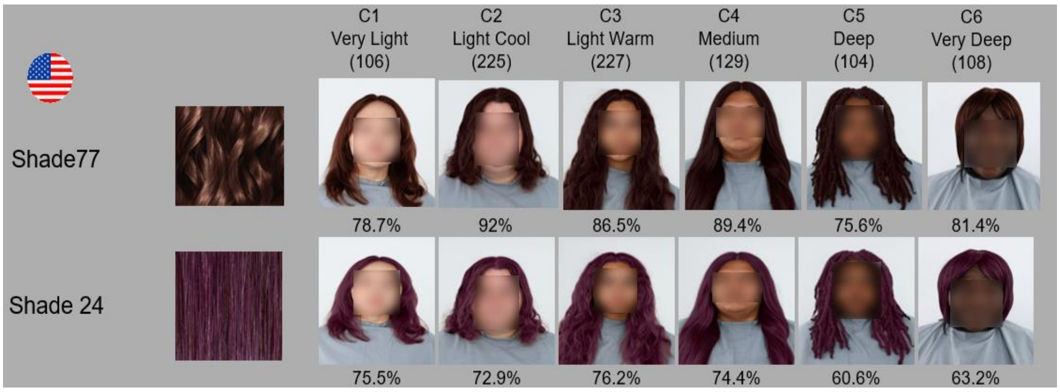
As previously stated, the performance of test shades was quantified using T2B metric based on participant ratings. Hair shades meeting the qualification criteria (T2B >60%) were defined as suitable hair colors. Figure 5 illustrates examples of suitable shades for C2 and C5 skin clusters. Participants from Light Cool (C2) and Deep (C5) clusters displayed overlapping preferences for certain hair colors, such as Shade 12 and Shade 20, indicating the potential existence of universal shades that appeal across various skin undertones. However, clear distinctions were observed: C2 participants showed a stronger preference for light, vibrant shades (e.g., Shade 80, Shade 34), whereas C5 participants favored deeper, more muted tones (e.g., Shade 3, Shade 16).




*[Figure 2. Examples of suitable hair colors for skin clusters C2 and C5]*

### 3.3. ***Universal Hair Colors***

An analysis of overall color preferences revealed the existence of universally appealing shades—those favored across all skin tone clusters. To further identify shades with broad appeal across diverse skin tones, "universal shade" was defined as any shade achieving a T2B score exceeding 60% across all six skin tone clusters. This threshold represents a substantial level of acceptance among diverse consumer groups. This analysis revealed 14 shades meeting this criterion. Figure 6 highlights four exemplary shades, illustrating corresponding T2B scores and simulations on various skin tones.




*[Figure 6. Examples of universal hair colors and simulations on each skin cluster]*

Analysis of universally appealing shades highlighted shade 77, brown hues, distinguished by subtle warm undertones. The consistent presence of this shade among the top-ranked colors across all skin tone clusters underscores its broad appeal and suitability for a diverse range of skin tones.

Intriguingly, the study also revealed unexpected preferences, such as the positive reception of shade 24 across all skin tone clusters. Shade 24, a more chromatic pink violet hue with cool, bluish undertones, currently holds a relatively smaller market share.

## 4. Discussion

This study illuminates the significant relationship between preferred hair color and skin tone, suggesting that perceived color harmony between hair and skin plays a key role in consumer choices. Our findings demonstrate the feasibility of identifying both skin-tone specific shades, which enhance individual complexions, and universally flattering shades that appeal across a diverse range of skin tones. This latter observation reinforces the potential for developing hair colors with broad appeal, transcending individual variations.

The identification of universally appealing shades, such as shades 77 (Figure 6), aligns with existing market data, where analogous colors rank among top-selling products. This convergence validates the efficacy of our novel digital approach and confirms the real-world relevance of these shades for a diverse consumer base. It strengthens the argument for using digital methodologies to understand consumer preferences and predict market trends.

Intriguingly, our results also reveal unexpected preferences for shades with currently limited market presence. For instance, shade 24 (Figure 6), a chromatic pink with cool, bluish undertones, exhibited surprising popularity across all skin tone clusters. This finding suggests a potential disconnect between current market offerings and consumer desires, indicating untapped market potential and highlighting opportunities for future product development and targeted marketing strategies. It underscores the value of this research in uncovering latent consumer preferences and challenging existing market paradigms.

While this study provides valuable insights, further investigation is needed to fully elucidate the complex relationship between skin color characteristics and hair color preferences. Deeper analysis will enable us to decode these preferences and develop a robust knowledge base for creating more inclusive shade ranges. This knowledge will empower both consumers and hair professionals to navigate the vast landscape of hair color options and confidently select the most suitable shades, celebrating individual uniqueness and diversity.

It is important to acknowledge that data acquisition for this study is ongoing. The current dataset presents an imbalance in the number of respondents per skin tone cluster, which may affect the generalizability of our findings. Subsequent data collection efforts will prioritize achieving a more balanced representation across skin tones to ensure a more robust and representative analysis.

## 5. Conclusion

This study leveraged a novel digital methodology to investigate the complex interplay between skin tone and hair color preference, providing valuable insights for both consumers and the cosmetics industry. By enabling participants to visualize themselves with a wide range of hair colors through realistic simulations, we overcame the limitations of traditional, time-consuming, and potentially risky physical dye application methods.

Our findings confirm a significant correlation between skin tone and preferred hair color, highlighting the importance of personalized color selection. The identification of both unique, skin-tone specific shades and universally flattering shades underscores the potential for developing inclusive and broadly appealing hair color products. Moreover, the discovery of unexpected preferences for underrepresented shades challenges existing market trends and reveals opportunities for innovation. While the ongoing nature of data collection and current cluster imbalances represent limitations, this research establishes a crucial foundation for understanding the nuances of hair color selection. Future research will focus on refining these insights through continued data collection, more granular analysis of skin undertones and age-related factors, and exploration of cross-cultural influences on color perception and preference. This comprehensive approach promises to empower consumers and professionals alike with the knowledge to confidently navigate the world of hair color, ultimately fostering self-expression and celebrating individual diversity.

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