ThermoSense: Calibrating a Thermochromic Wearable for Accurate Fever Detection

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Abstract

Thermochromic materials change color in response to temperature and offer a low-cost visual method for temperature detection. This study investigated whether thermochromic bracelets could indicate temperature changes based on the magnitude of color change and whether a color–temperature scale could be developed to identify a critical temperature of 38 °C. Bracelets with one, two, and three layers of thermochromic pigment were analyzed at 35 °C and 40 °C. Color values were measured using the CIELAB (L*a*b*) color system, and total color difference (ΔE) was calculated. Independent samples t-tests and one-way ANOVA were used for statistical analysis. Results showed that temperature significantly affected color change in the second layer, while no significant differences were observed across layers at either temperature level. A ΔE threshold of approximately 30 was established as an indicator of a temperature near 38 °C. These findings support the use of thermochromic bracelets as threshold-based temperature indicators rather than precise thermometers.

Rationale

Monitoring body temperature is an important part of public health and safety, especially during disease outbreaks such as COVID-19, where fever is a common early symptom. During the pandemic, many communities relied on temperature screening to reduce the spread of illness. However, access to electronic thermometers and screening devices is not always consistent, particularly in areas with limited resources or during large public events.

In Yuma, Arizona, extreme heat is also a major environmental concern. High temperatures can increase the risk of heat-related illnesses, dehydration, and heat exhaustion. Because of this, there is a strong need for simple, low-cost tools that can provide quick visual warnings when a critical temperature is reached, whether for health monitoring or heat exposure awareness.

Thermochromic bracelets offer a practical solution because they change color in response to temperature without requiring batteries or electronics. However, visual color changes alone can be subjective. This study uses the CIELAB (L*a*b*) color system and total color difference (ΔE) to objectively measure color change and determine whether it can reliably indicate a critical temperature. A threshold of 38 °C was selected because it is commonly associated with fever and elevated body temperature.

By developing a color–temperature scale and analyzing the effects of temperature and bracelet layer thickness, this study evaluates whether thermochromic bracelets can function as reliable threshold-based temperature indicators for use in real-world health and environmental conditions.

Background Research

Scientific Context and Importance

Thermochromic materials are substances that change color in response to temperature changes. These materials are commonly used in consumer products such as mood rings, safety indicators, and temperature-sensitive labels because they provide immediate visual feedback without electronics. This makes thermochromic materials useful for health and safety applications where simple, low-cost temperature indicators are needed. Understanding how thermochromic materials respond to temperature is essential for evaluating their reliability and limitations as temperature indicators.

Thermochromic Mechanism

Most commercially available thermochromic pigments operate using **leuco dye systems**, which consist of a dye, a color developer, and a solvent. At lower temperatures, the solvent remains solid, allowing the dye and developer to interact and produce color. When temperature increases, the solvent melts, disrupting this interaction and causing the color to change. This process is reversible, allowing the material to return to its original color when cooled (Seeboth & Lötzsch, 2008). Because these pigments respond within specific temperature ranges, they are best suited for detecting temperature thresholds rather than exact temperatures.

Objective Color Measurement

Visual observation of color change can be subjective and influenced by lighting and human perception. To address this limitation, scientists use standardized color measurement systems. The **CIELAB (L*a*b*) color space**, developed by the International Commission on Illumination, quantitatively represents color using three values: **L*** (lightness), **a*** (red–green axis), and **b*** (blue–yellow axis) (CIE, 2004). This system is widely accepted because it closely matches human vision and allows precise comparison of color changes.

Total Color Difference (ΔE)

Overall color change is calculated using **total color difference (ΔE)**, which combines changes in L*, a*, and b* into a single numerical value. Higher ΔE values indicate greater and more visible color changes. In color science, ΔE values greater than 20 represent strong, easily noticeable differences (McLaren, 1980). ΔE is therefore an effective quantitative metric for evaluating thermochromic color responses.

Design Factors and Temperature Thresholds

The number of thermochromic layers may influence color intensity at lower temperatures because thicker layers contain more pigment. However, research suggests that thermochromic materials may reach saturation at higher temperatures, producing similar color changes regardless of thickness (Seeboth & Lötzsch, 2008). Since **38 °C** is commonly associated with fever and elevated body temperature, identifying a ΔE threshold near this temperature allows thermochromic

bracelets to function as **threshold-based warning devices**, which is often more practical than precise temperature measurement.

Problem Questions

1. How does temperature affect the magnitude of color change in thermochromic bracelets?
2. Does the number of thermochromic layers significantly influence color change at different temperatures?
3. Can a color–temperature scale be developed to identify a threshold temperature of 38 °C?

Hypotheses

- Increasing temperature will result in a greater total color difference (ΔE).
- Bracelets with more layers will exhibit greater color change at moderate temperatures.
- A ΔE threshold can be established to indicate when the bracelet reaches approximately 38 °C.

Methodology:

Procedure

1. Prepare a 1.5g thermochromic powder by mixing it to 25g of water and 25g of the binder (white glue) using a magnetic stirrer.
2. Three sets of bracelets were prepared using one, two, and three layers of thermochromic pigment paint in different colors.
3. Each bracelet was allowed to stabilize at room temperature before testing.
4. A hot water bath was prepared and adjusted to 35 °C, verified using a digital thermometer.
5. Bracelets were put in a zip lock bag then submerged it to a 35 °C water for 5 seconds to ensure uniform heating.
6. Each bracelet was photographed under consistent lighting and background conditions then measure using a colorimeter instrument.
7. Steps 3–5 were repeated at 40 °C.
8. Three trials were conducted for each layer at each temperature.
9. Calculate the overall color change of the system using CIELAB (L*a*b*) color space then record.

Graphs and Tables

Colorimeter Results

ONE LAYER (Violet to Purple)			
TEMPERATURE	25	35	40
L	79.53	50.31	86.29
A	37.55	44.05	59.73
B	-26.17	-2.18	10.41

ONE LAYER (Blue-Purple)			
TEMPERATURE	25	35	40
L	67.28	67.08	32.41
A	5.04	8.3	16.02
B	-0.96	-4.23	10.56

ONE LAYER P-B			
TEMPERATURE	25	35	40
L	77.27	93.1	35.09
A	10.87	12.1	11.67
B	-19.51	-20.86	13.85

TWO LAYERS (Violet to Purple)			
TEMPERATURE	25	35	40
L	66.92	72.94	19.25
A	44.79	59.14	40.97
B	-27.8	-19.45	3.29

TWO LAYERS (Blue-Purple)			
TEMPERATURE	25	35	40
L	51.67	53.72	17.46
A	4.64	6.38	15.17
B	-1.73	-0.61	-8.78

TWO LAYERS P-B			
TEMPERATURE	25	35	40
L	67.04	76.41	28.46
A	6.04	-0.36	8.68
B	-8.01	-23.1	17.76

THREE LAYERS (Violet to Purple)			
TEMPERATURE	25	35	40
L	67.14	77.37	8.56
A	44.54	69.46	21.17
B	-29.28	-16.92	0.8

THREE LAYERS (Blue-Purple)			
TEMPERATURE	25	35	40
L	50.31	69.86	23.33
A	4.05	27.79	22.77
B	-2.18	-16.75	12.56

THREE LAYERS P-B			
TEMPERATURE	25	35	40
L	50.77	68.74	30.92
A	6.03	-9.52	1.03
B	-9.8	-37.89	12.43

CIELAB Color Space Calculations

VIOLET TO PURPLE				
1st Layer (35)				
LAB SUBTRACT	LAB SQUARED		L+a+b	sqrtLab
29.22	853.8084		1471.579	38.36116
-6.5	42.25			
-23.99	575.5201			
2nd Layer (35)				
LAB SUBTRACT	LAB SQUARED		L+a+b	sqrtLab
-6.02	36.2404		311.8854	17.66028
-14.35	205.9225			
-8.35	69.7225			
3rd Layer (35)				
LAB SUBTRACT	LAB SQUARED		L+a+b	sqrtLab
-10.23	104.6529		878.4289	29.6383
-24.92	621.0064			
-12.36	152.7696			

VIOLET TO PURPLE				
1st Layer (40)				
LAB SUBTRACT	LAB SQUARED		L+a+b	sqrtLab
-6.76	45.6976		1875.746	43.30989
-22.18	491.9524			
-36.58	1338.0964			
2nd Layer (40)				
LAB SUBTRACT	LAB SQUARED		L+a+b	sqrtLab
47.67	2272.4289		3253.609	57.04042
3.82	14.5924			
-31.09	966.5881			
3rd Layer (40)				
LAB SUBTRACT	LAB SQUARED		L+a+b	sqrtLab
58.58	3431.6164		4882.58	69.87546
23.37	546.1569			
-30.08	904.8064			

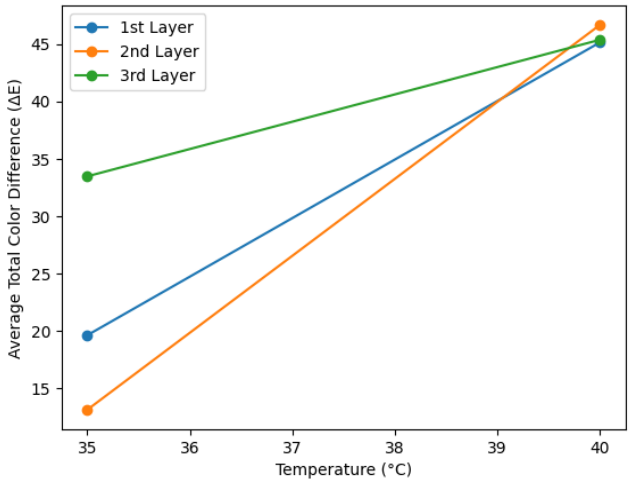
BLUE TO PURPLE				
1st Layer (35)				
LAB SUBTRACT	LAB SQUARED		L+a+b	sqrtLab
0.2	0.04		21.3605	4.621742
-3.26	10.6276			
3.27	10.6929			
2nd Layer (35)				
LAB SUBTRACT	LAB SQUARED		L+a+b	sqrtLab
-2.05	4.2025		8.4845	2.912817
-1.74	3.0276			
-1.12	1.2544			
3rd Layer (35)				
LAB SUBTRACT	LAB SQUARED		L+a+b	sqrtLab
-19.55	382.2025		1155.979	33.99968
-24.92	621.0064			
-12.36	152.7696			

BLUE TO PURPLE				
1st Layer (40)				
LAB SUBTRACT	LAB SQUARED		L+a+b	sqrtLab
34.87	1215.9169		1469.188	38.32998
-10.98	120.5604			
-11.52	132.7104			
2nd Layer (40)				
LAB SUBTRACT	LAB SQUARED		L+a+b	sqrtLab
34.21	1170.3241		1330.908	36.4816
-10.53	110.8809			
7.05	49.7025			
3rd Layer (40)				
LAB SUBTRACT	LAB SQUARED		L+a+b	sqrtLab
26.98	727.9204		1295.626	35.99481
-18.72	350.4384			
-14.74	217.2676			

PURPLE - BLACK				
1st Layer (35)				
LAB SUBTRACT	LAB SQUARED		L+a+b	sqrtLab
-15.83	250.5889		253.9243	15.935
-1.23	1.5129			
1.35	1.8225			
2nd Layer (35)				
LAB SUBTRACT	LAB SQUARED		L+a+b	sqrtLab
-9.37	87.7969		356.465	18.88028
6.4	40.96			
15.09	227.7081			
3rd Layer (35)				
LAB SUBTRACT	LAB SQUARED		L+a+b	sqrtLab
-17.97	322.9209		1353.772	36.79363
15.55	241.8025			
28.09	789.0481			

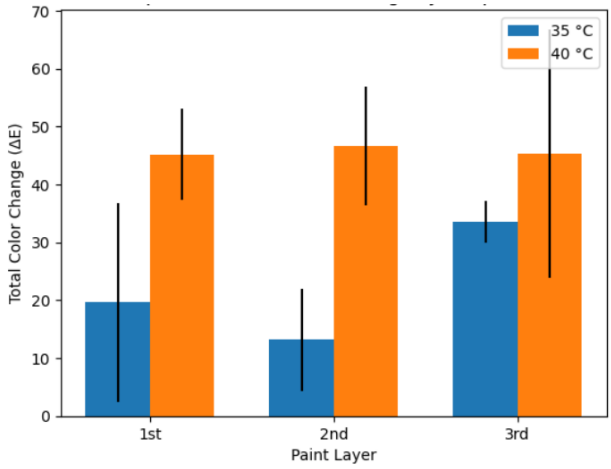
PURPLE - BLACK				
1st Layer (40)				
LAB SUBTRACT	LAB SQUARED		L+a+b	sqrtLab
42.18	1779.1524		2892.682	53.78366
-0.8	0.64			
-33.36	1112.8896			
2nd Layer (40)				
LAB SUBTRACT	LAB SQUARED		L+a+b	sqrtLab
38.58	1488.4164		2159.479	46.47019
-2.64	6.9696			
-25.77	664.0929			
3rd Layer (40)				
LAB SUBTRACT	LAB SQUARED		L+a+b	sqrtLab
19.85	394.0225		913.1954	30.21912
5	25			
-22.23	494.1729			

Graph no. 1 – Overall Color Change vs Temperature per layer



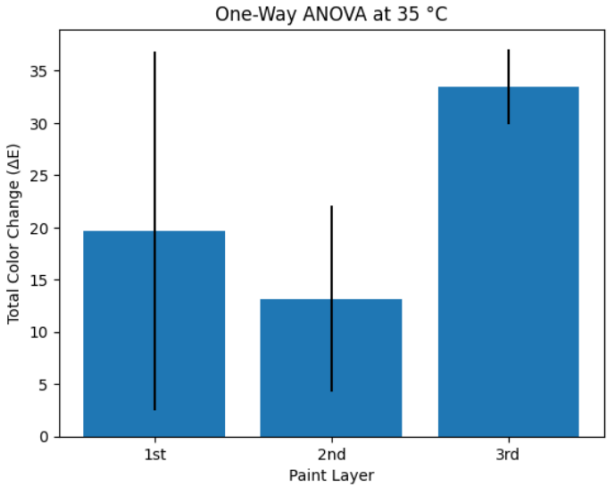
The graph shows that the average total color change (ΔE) increases as temperature rises from 35 °C to 40 °C for all bracelet layers. The 2nd layer exhibits the steepest increase, indicating a stronger sensitivity to temperature change, while the 3rd layer shows consistently high color change at both temperatures. Overall, the trend

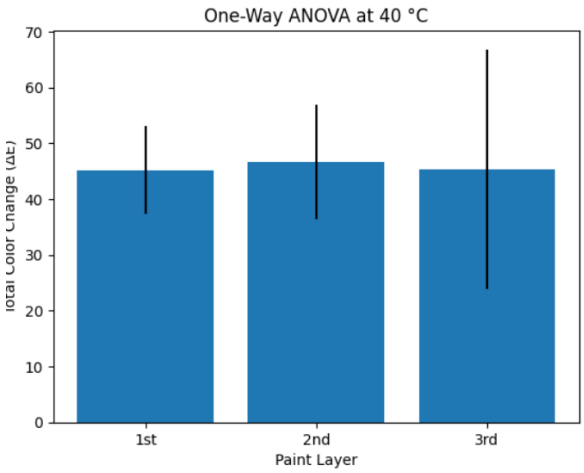
Graph 2 - Independent t-Test (35 °C vs 40 °C)



The graph shows that all layers have higher average color change at 40 °C than at 35 °C. The second layer shows the largest increase, which supports the t-test result showing a statistically significant temperature effect for this layer.

Graphs 3 and 4 – One-way ANOVA at 35 and 40 degrees Celsius





The one-way ANOVA graphs show the average total color change (ΔE) across the three paint layers at 35 °C and 40 °C. At 35 °C, the third layer exhibits a higher mean color change; however, the error bars overlap across all layers, indicating that the differences are not statistically significant. At 40 °C, all layers display very similar mean ΔE values with substantial overlap in variability, suggesting thermochromic saturation. Together, these results indicate that layer thickness does not significantly affect color change, and that temperature is the primary

Development of the Color–Temperature Scale

Final Color–Temperature Scale

ΔE Range	Temperature Interpretation
ΔE < 20	Normal temperature
ΔE 20–29	Warm / approaching threshold
ΔE ≥ 30	≥ 38 °C (Fever threshold)

A color–temperature scale was developed by interpolating between the measured ΔE values at 35 °C and 40 °C. A ΔE threshold of approximately 30 was identified as an indicator of 38 °C, which was selected as a critical temperature associated with fever. This scale was intended to function as a threshold-based indicator rather than a precise temperature measurement.

Conclusion

This study found that temperature significantly affects the magnitude of color change in thermochromic bracelets. As temperature increased from 35 °C to 40 °C, the total color difference (ΔE) increased across all bracelet layers, indicating that higher temperatures produce stronger and more visible color changes.

Statistical analysis showed that the second thermochromic layer exhibited a statistically significant increase in color change with temperature. Independent samples t-test results indicated that the mean ΔE of the second layer at 40 °C was significantly higher than at 35 °C ($p < 0.05$). In contrast, the first and third layers did not show statistically significant differences between temperatures. When comparing color change among layers using one-way ANOVA, no statistically significant differences were found at either temperature, indicating that layer thickness did not significantly influence overall color change.

Finally, this study demonstrated that a color–temperature scale can be developed to identify a threshold temperature of 38 °C. By interpolating between measured ΔE values at 35 °C and 40 °C, a ΔE threshold of approximately 30 was identified as an indicator of 38 °C. This scale allows thermochromic bracelets to function as threshold-based temperature indicators, providing a clear visual warning rather than an exact temperature measurement.

Recommendations

Based on the findings of this study, thermochromic bracelets are recommended for applications where **visual temperature alerts** are more important than exact temperature values. These bracelets may be useful for preliminary fever screening, heat exposure awareness, and educational demonstrations of thermochromic behavior. To improve reliability, users should ensure consistent lighting and viewing conditions when interpreting color change. For future studies or practical use, standardizing bracelet thickness and pigment application is recommended to reduce variability and improve consistency.

Future Plans

Future research should include testing at additional temperature points, particularly around the critical range of 37–39 °C, to improve calibration accuracy of the color–temperature scale. Increasing the number of trials would strengthen statistical power and reduce uncertainty. Further studies may also explore long-term durability, repeated heating and cooling cycles, and performance under different environmental lighting conditions. Expanding the design to include different pigment formulations or wearable formats could broaden potential applications. Ultimately, integrating thermochromic bracelets into low-cost health monitoring or heat-safety programs may enhance accessibility to non-electronic temperature indicators.

References

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