Original article

Changes in color usage in children's drawings between ages 2 and 8: a statistical analysis

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Abstract

Color usage in children's drawings provides insight into cognitive and perceptual development. This study investigated the changes in color usage in children's drawings between the ages of 2 and 8, focusing on the number of colors used, color diversity, and color distance in a perceptual color space. Although it was initially expected that color variety would increase steadily with age, a two-phase trajectory was found. During early childhood (ages 2-4), the number of colors, color diversity (measured using Simpson's diversity index), and average perceptual color distance increased significantly. However, in later childhood (ages 4-8), the number of colors and perceptual color distance declined, while color diversity stabilized. This shift suggests a developmental transition from early exploratory color use toward a more structured and realistic artistic expression. These findings align with neurodevelopmental patterns, where rapid early brain growth precedes a phase of refinement and specialization. The results provide insight into the cognitive and perceptual development of children and highlight how artistic expression may reflect underlying neurological changes. By establishing a quantitative framework for assessing color diversity in children's artwork, this study provides a foundation for future research into developmental psychology, art education, and neurocognitive growth.

Keywords

Children's artwork, Color diversity, Developmental psychology, Art education, Neurocognitive growth, Perceptual color distance, Artistic expression, Early childhood, Late childhood, Visual processing, Simpson's diversity index

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Introduction

Children's drawings offer a unique window into their cognitive and perceptual development. As children grow, the way they engage with colors in their artwork evolves, reflecting underlying changes in visual processing, motor control, and cognitive function (1). The ability to perceive and use colors is governed by specialized photoreceptor cells in the retina called cones, which are responsible for detecting the red, green, and blue wavelengths of light. These signals are integrated and processed by the visual cortex, forming the basis of color perception and artistic expression (2).

A growing body of research has examined how artistic representations can serve as a proxy for understanding brain development and neurological function. Previous studies have explored the use of spatial organization in paintings (3), differences in visual representation in neurotypical versus neurodivergent artists (4), and historical shifts in color usage in art over time (5). The latter study found that medieval paintings exhibited less color diversity than those from later artistic periods, suggesting a potential link between cultural and cognitive evolution. Building on this idea, the present study investigated how color usage in children's drawings changes with age, highlighting parallels between individual developmental changes and broader societal trends in artistic complexity.

Naively, it may be expected that as children grow older, the number of colors they use in their artwork will increase, accompanied by greater complexity in color selection and diversity. This expectation is based on two key considerations. First, the development of an individual child may mirror historical trends in artistic complexity: if later artistic movements demonstrate increased color variety, a similar progression may be expected as an individual child's cognitive abilities advance. Second, neurobiological studies suggest that brain structures involved in visual processing and cognitive control, such as the frontal and parietal lobes, continue developing through childhood and adolescence (6). Given the role of these brain regions in visual creativity and decision-making, it is reasonable to expect that increasing neurological maturity may correspond with more sophisticated color usage in drawings.

To test this presumption, we created a database of color drawings of children between ages 2 and 8, and analyzed their color content using statistical methods. We used several metrics to quantify color diversity, distribution, and complexity. In particular, we adopted Simpson's diversity index (7,8) to measure color diversity. The Simpson's diversity Index is a widely used metric in ecology that quantifies biodiversity by considering both species richness (the number of species present), and species evenness (the relative abundance of each species). The index, introduced by Edward Hugh Simpson in 1949 (9), measures the probability that two individuals randomly selected from a sample will belong to different species. A higher Simpson's diversity index value indicates greater diversity, while a lower value suggests dominance by a few species. In this study, we created an analogue of the Simpson's diversity index to investigate the richness of color usage by children of different ages.

By applying measures such as Simpson's diversity index, as well as the distance between colors used, we aimed to objectively assess how color selection changes over time. Our study provides insights into the interplay between cognitive development and artistic expression, offering a simple yet effective tool for understanding early childhood neurodevelopment.

Materials and methods

Institutional Review Board approval for this study was waived by the Orange County Science and Engineering Fair (OCSEF) Scientific Review. Informed consent was provided by the research subjects' parents.

Color drawings

To analyze color usage in children's drawings at different ages, artwork from 4 different children of ages 2-8 was collected. The study design was longitudinal, in that artwork by the same children was analyzed over a period of 7 years. Only female subjects were analyzed because comparison of genders was beyond the scope of this study. For each child, three different drawings from each age were used. Drawings at ages 2,3,4,5,6,7, and 8 years old were used, making this 84 drawings in total.

An iPhone 11 (the Camera app) was used to digitalize the images, creating 84 graphic files. All the photographs were taken in identical light conditions.

Quantification of the color content

In order to quantify the color contents of an image, the RGB space was used, where each color is represented by three coordinates that describe the contributions of the red, green, and blue colors. It has been argued that this space, while convenient for technical applications, does not correctly reflect how colors are perceived. In a more neurobiologically relevant description, colors that appear very different are represented by points far away from each other, and colors that appear similar are represented by points that are near each other. Such a color space is called the *Lab* space (10). In this space, each color has three coordinates, which are closely related to the perceived notions of lightness (through the achromatic coordinate L), and the perceived hue (chromatic coordinates a and b).

In order to analyze the color contents of a drawing, a method to objectively describe the colors used was needed. The number of colors used can be obtained by simply counting those colors. This measure distinguished a color drawing that used just one or two colors from a drawing that contained many different colors. This counting method could not however distinguish a two-color drawing that used (for example) red and blue about equally, from a color drawing that was largely red with a small amount of blue. Therefore, a more precise measure of color richness of a drawing was needed.

A similar problem exists in ecology, when characterizing different habitats. It is not enough to simply count the number of species that occupy the habitat, but it is also important to know how common or how rare each species is. To capture both the number of species and their abundance, ecologists introduced a measure called Simpson's diversity index, Q (7-8). It is calculated as

$$Q = \sum_{i=1}^{n} p_i (1 - p_i) = p_1 (1 - p_1) + p_2 (1 - p_2) + \ldots \quad \text{(eq 1)}$$

where n is the number of species in a habitat, and p_1, p_2, p_3 … are proportions of the different species. The interpretation of the Simpson diversity index is the probability that two animals that are randomly picked will be of different species. This index is larger for ecosystems with a profusion of species (large n), and if the species are evenly distributed, as opposed to a single species dominating the population.

In this project, the Simpson's diversity index was used to characterize the diversity of colors in a drawing. Here, n represents the number of colors used in a picture, and p_1, p_2, p_3 … denote the proportions of the different colors used. This index could distinguish two drawings that -for the purposes of an example - only used red and blue. Suppose in drawing 1, both colors were used equally, at 50%, such that $p_1=p_2=0.5$. Suppose also that in drawing 2, red was used in 90% of the space and blue only 10% of the space, making $p_1=0.9$ and $p_2=0.1$. In both paintings, $n=2$ (two colors used), but the Simpson's diversity is different. For drawing 1, $Q=(0.5x0.5)+(0.5x0.5)=0.5$, and for drawing 2, $Q=(0.9x0.1)+(0.1x0.9)=0.18$, a smaller number. If red were to be used 99% of the time and blue only 1% of the time, the Simpson's diversity index of that painting can be calculated as $Q=(0.99x0.01)+(0.01x0.99)=0.0198$, which is even smaller. Therefore, the Simpson's diversity index accounted for the evenness of spatial color usage in a painting.

However, the Simpson's diversity index; in and of itself; still does not measure variety. Imagine that two drawings each use two colors, each at 50% of the space, but drawing 1 uses blue and orange, and drawing 2 uses two different shades of blue. The Simpson's diversity index for the two paintings will be the same, but clearly, drawing 1 has more variety. To capture how different the colors were from each other, the *Lab* space, that describes the distance between the colors was used. In the *Lab* space, each color is a point, and the distance between two points with coordinates (L_1,a_1,b_1) and (L_2,a_2,b_2) can be calculated as

$$dist_{12} = \sqrt{(L_1 - L_2)^2 + (a_1 - a_2)^2 + (b_1 - b_2)^2} \quad \text{(eq2)}$$

If there are several colors used, the color distance for each pair of colors can be calculated, as can the average. For example, for 4 colors, the average distance is calculated as

$$Avdist = \frac{1}{6}\left(dist_{12} + dist_{13} + dist_{14} + dist_{23} + dist_{24} + dist_{34}\right)$$

Color extraction
A color extraction website, TinEye (11), was used in order to extract the color content from all the drawings collected. TinEye's color extraction tool analyzes an image by scanning its pixels and identifying the most dominant colors present. It groups similar shades together using color quantization techniques and converts the detected colors from RGB values into hexadecimal (hex) codes. The tool then calculates the percentage of the image occupied by each color and presents the extracted shades as a structured color palette.

Each digitalized image was uploaded to the website, which extracted the colors used in the image, and displayed the percent of each color used, as well as each color's hex index (Figure 1). The hex index was converted to the Lab coordinate system, using a free online color converter; Nix Color Sensor (12).

Figure 1. An example of a TinEye analysis for a particular image. On the left is an actual image used, and on the right is a list of colors extracted, together with their percent of usage and a hex index.

Three measures of color usage
Three quantities that reflect the color usage by children were analyzed.

(1) The number of colors
The number of colors from each drawing was directly available from the TinEye output. The average number of colors used was calculated for each age-group, and plotted as a function of the age. For the 12 drawings in a single age-group, the average number of colors as well as standard deviation and relative standard deviation (RSD) were calculated.

(2) Simpson's diversity index
The percentages of usage for each color (which define the frequencies p_i) were used as input in equation 1 to calculate the Simpson's diversity

index for each drawing. The average Simpson's diversity index was calculated for each age-group, and plotted as a function of the age. The standard deviation for each age-group was also calculated, in a similar way.

(3) The distance between colors

For each pair of colors, in each drawing, the distance between the colors was calculated by using equation 2. Then, the average distance between colors was calculated for each drawing and then averaged over the age group. This was also plotted as a function of age, together with the standard deviations.

Statistical analysis

To assess trends in various measures of color usage, linear regression analysis was performed using the online statistical tool GraphPad by Dotmatics (13) as well as Google sheets. Linear regression identifies the optimal linear fit for a given dataset, providing insights into the direction and strength of the relationship between variables. Positive and negative regression slopes indicate increasing and decreasing trends respectively. To evaluate the robustness of these findings, statistical significance was determined using the p-value, which represents the probability that the observed trend occurred by chance. Conventionally, a p-value threshold of $p < 0.05$ is used to indicate statistical significance, suggesting that there is a 5% probability that the detected trend is likely to be due to chance alone.

Results

An example of the color drawings that were collected is shown in figure 2. A total of 84 drawings were analyzed.

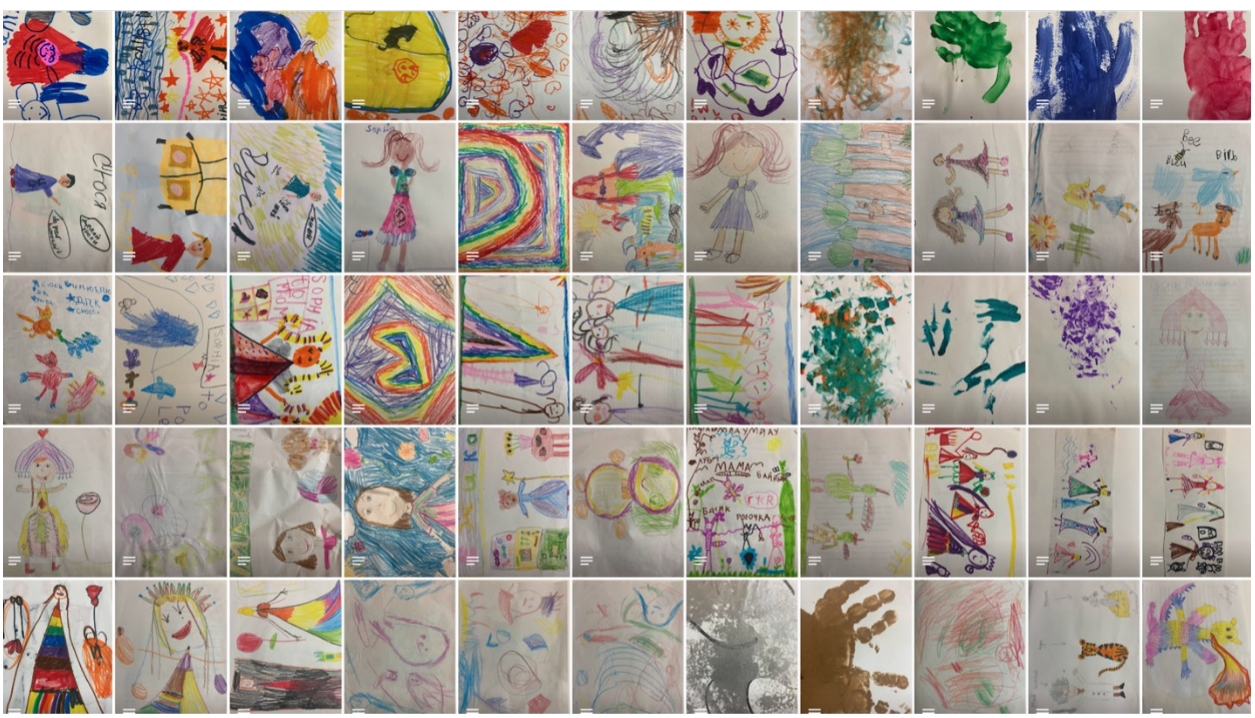

Figure 2. Examples of color drawings from different ages that were collected and analyzed (not presented in order).

Figure 3. A sample age-progression of drawings, with the output of the TinEye extractor shown on the left of each image.

Figure 3 shows an example of an age-progression of color drawings. Three sample drawings, from age 2, age 5, and age 8 are shown, together with the output of the color extractor on the left of each drawing. Each color used is listed with its percentage and its hex index.

The number of colors

Table 1 shows the mean and standard deviation of the number of colors used in the drawings for each age group, as well as the Relative Standard Deviation (RSD).

Table 1. The number of colors used in each of the drawings sorted by age, with the average and standard deviation calculated. Drawing numbers (1, 2, 3), (4, 5, 6), (7, 8, 9) and (10, 11, 12) are drawn by Child 1, 2, 3 and 4 respectively.

# drawing	2 years	3 years	4 years	5 years	6 years	7 years	8 years
1	2	3	10	8	10	7	8
2	4	3	6	10	6	9	10
3	6	0	6	10	8	10	5
4	8	2	10	10	10	10	3
5	2	10	10	6	10	10	6
6	4	10	10	8	10	6	2
7	2	10	10	10	6	6	10
8	4	10	6	6	10	10	3
9	6	10	10	10	6	10	5
10	8	10	10	10	10	10	6
11	2	10	10	10	6	6	10
12	4	10	10	10	10	10	3
Average	4.1	7.3	9.2	8.7	8.7	7.3	5.3
St. dev.	2.0	3.7	2.7	1.8	3.1	2.1	2.7
RSD	0.5	0.5	0.3	0.2	0.4	0.3	0.5

The average and St.dev. for the 7 groups in Table 1 were used to perform a one-way ANOVA test, as well as the post-hoc Tukey HSD tests, using https://statpages.info/anova1sm.html . Prior to performing the ANOVA, a Levine's test for equality of variances was conducted using https://statskingdom.com/230var_levenes.html , which returned a p-value of > 0.38, indicative of homoscedasticity. The subsequently conducted ANOVA test found that there was significant difference between the groups with $p < 10^{-4}$, indicative of a significant difference in the cognition abilities of the children between the studied development years. Even though the physical populations (children) are the same over the years, their cognition abilities are different; making it appear as though they originate from 'different populations'. The post-hoc Tukey HSD p-values are presented in Table 2.

Table 2. Post-hoc Tukey HSD p-values for childhood years. Childhood year 1 represents biological age 2, etc.

Childhood year	1	2	3	4	5	6	7
1		0.07	0.0002	0.0012	0.0012	0.06	0.92
2			0.59	0.85	0.85	NA	0.52
3				0.99	0.99	0.59	0.01
4					NA	0.85	0.04
5						0.85	0.04
6							0.52
7							

The data of Table 1 were also used to perform an analysis of between-child consistency, see Table 3. For each child, *i,* in each age group, *a*, the average (μ_i^a) and the standard deviation (σ_i^a) of the number of colors were calculated, and then the percent relative standard deviation was determined as RSD_i^a=100% $\times \frac{\sigma_i^a}{\mu_i^a}$. Then, the inter-child standard deviation of their RSD's was determined, see the last row of Table 3. These ranged from 4.5 to 44.2.

Next, the age-dependency of the numbers of colors was studied. Figure 4 presents the plot of the average number of colors used in the drawings, as a function of age. To determine if there were any trends, first linear regression was performed over the whole age-range (panel (a)). No statistically significant trend was found. Subsequently, the data were split into early age (2-4) and later age (4-8), and linear regression was performed separately for the two time-periods (panel (b)). Both parts of the data showed statistically significant trends: the number of colors first increased, and then decreased with age. Note that the regression was performed over the whole dataset, not just the average values. For example, the left part of the regression was drawn through 36 data-points, 12 per age-group. The right part of the regression was drawn through 60 data-points.

We concluded that; interestingly, the number of colors first increases and the decreases as a child becomes older. Also note that the term 'statistically significant', when derived from regression, is to be understood as p values becoming lesser when the data was split using different developmental time block periods, when compared to the entire range.

Table 3. Between-child analysis of variation, for the number of colors used, for that childhood year.

	2 years	**3 years**	**4 years**	**5 years**	**6 years**	**7 years**	**8 years**
Child 1 avg	4.00	2.00	7.33	9.33	8.00	8.67	7.67
Child 1 std	2.00	1.73	2.31	1.15	2.00	1.53	2.52
Percent RSD	50.00	86.60	31.49	12.37	25.00	17.63	32.83
Child 2 avg	4.67	7.33	10.00	8.00	10.00	8.67	3.67
Child 2 std	3.06	4.62	0.00	2.00	0.00	2.31	2.08
Percent RSD	65.47	62.98	0.00	25.00	0.00	26.65	56.77
Child 3 avg	4.00	10.00	8.67	8.67	7.33	8.67	6.00
Child 3 std	2.00	0.00	2.31	2.31	2.31	2.31	3.61
Percent RSD	50.00	0.00	26.65	26.65	31.49	26.65	60.09
Child 4 avg	4.67	10.00	10.00	10.00	8.67	8.67	6.33
Child 4 std	3.06	0.00	0.00	0.00	2.31	2.31	3.51
Percent RSD	65.47	0.00	0.00	0.00	26.65	26.65	55.45
Inter-child std. of RSD	8.9	44.2	16.9	12.4	14.4	4.5	12.5

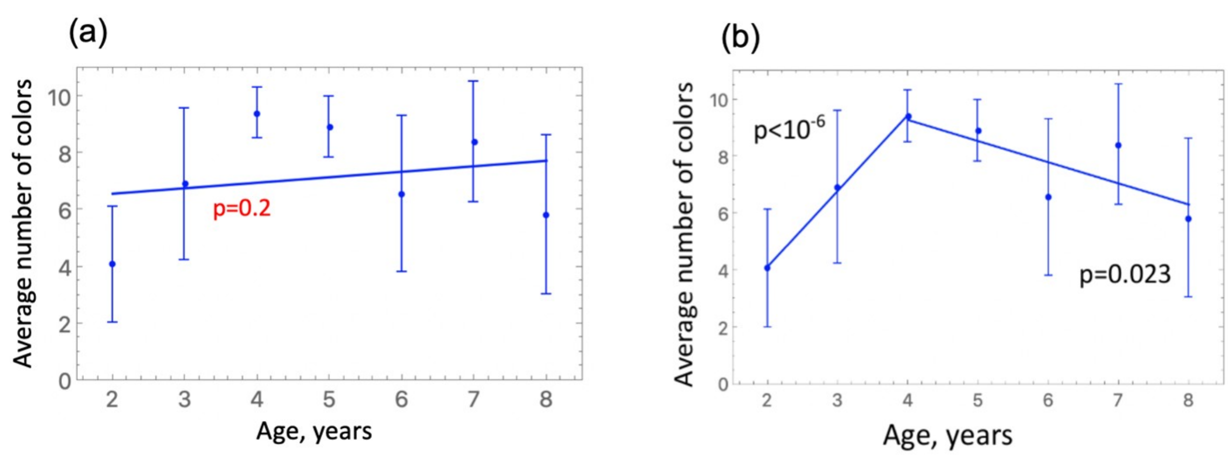

Figure 4. The average number of colors plotted for each age with vertical bars representing the standard deviation. (a) Linear regression over the full range of data is not statistically significant, with p=0.2. (b) Linear regression through the points between ages 2-4 and between ages 4-8 gives statistically significant trends.

Simpson's diversity index

Simpson's diversity index is the probability that two points randomly picked from a drawing will be of the same color. Figure 5 illustrates this concept by showing three cases of color usage, where the number of colors is the same, but the colors are used most evenly in the first case, corresponding to the largest Simpson's diversity index, and the least evenly in the third case, giving the smallest Simpson's diversity index.

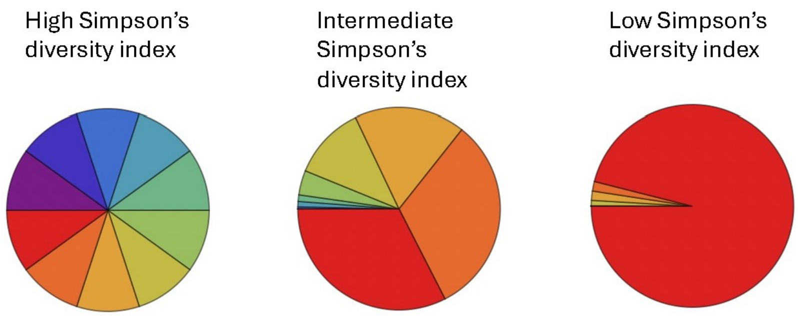

Figure 5. Three examples illustrating Simpson's diversity index applied to colors.

Figure 6 shows the graph of the average Simpson's diversity index of the children's drawings in our sample, plotted as a function of the children's age. As with the average number of colors, there was no statistically significant trend for a regression drawn over the entire age-range. When the age-range was split into early and later ages, a statistically significant increase of the Simpson's diversity index was observed during the early ages. Later on, color diversity seemed to stabilize, because no significant trend was observed between ages 5-8. We concluded that the Simpson's diversity index of colors first increased with age, and then remained constant as a child became older.

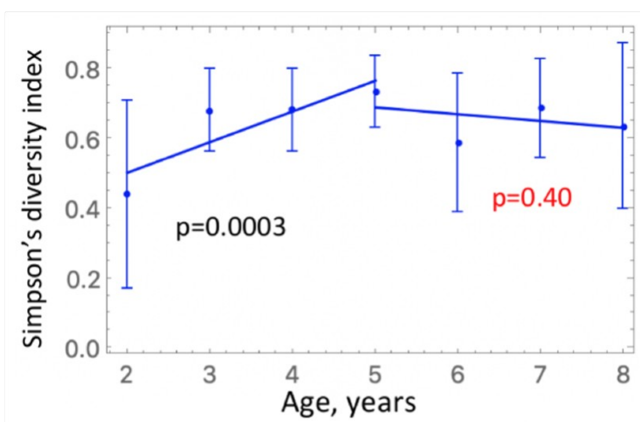

Figure 6. Average Simpson's diversity index plotted as a function of age, with vertical bars representing the standard deviation. Linear regression through the early age and later age are shown, together with the corresponding p-values.

The average distance between colors

The distance between colors was calculated by representing each color in a 3-dimensiona *Lab* space and calculating the distance between the corresponding points. Large distances in the *Lab* space reflect colors that are perceptually different, and small distances correspond to colors that appear similar. Figure 7 shows three colors represented as points in a 3D space.

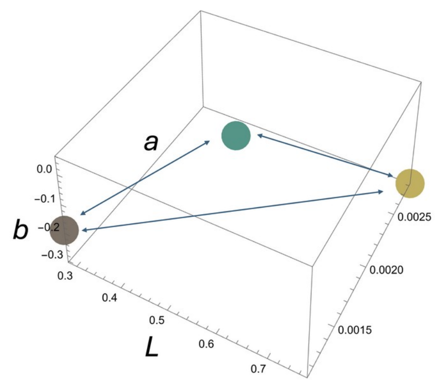

Figure 7. An illustration of the concept of color distance in the Lab space, see equation 2.

Figure 8 shows the average distance between colors in the drawings from our sample, as a function of a child's age. Similarly to the number of colors and the Simpson's diversity index, the average distance between colors does not show a significant trend if we consider all the ages between 2 years and 8 years. If, however, the data is split into two age-groups, then it can be observed that the average distance between colors increases for ages 2-4 and decreases for ages 4-8.

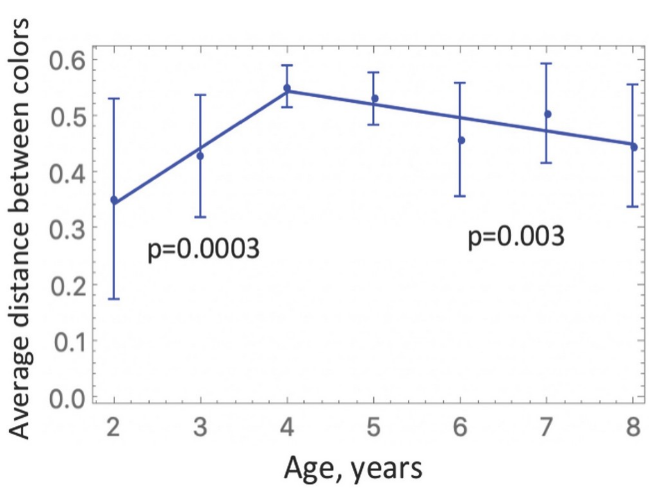

Figure 8. Average distance between colors shown as a function of age, with vertical bars representing the standard deviation. Linear regression through the early age and later age are shown, together with the corresponding p-values.

Tables 4 and 5 show the Simpson's diversity index and the color distance for the drawings.

Table 4. The Simpson's diversity index for each of the drawings sorted by age, with the average and standard deviation calculated. Drawing numbers (1, 2, 3), (4, 5, 6), (7, 8, 9) and (10, 11, 12) are drawn by Child 1, 2, 3 and 4 respectively.

# drawing	**2 years**	**3 years**	**4 years**	**5 years**	**6 years**	**7 years**	**8 years**
1	0.66	0.83	0.84	0.79	0.66	0.61	0.71
2	0.38	0.81	0.70	0.72	0.62	0.87	0.74
3	0.57	0.47	0.65	0.79	0.36	0.76	0.60
4	0.44	0.62	0.62	0.82	0.36	0.81	0.75
5	0.00	0.67	0.82	0.84	0.59	0.54	0.73
6	0.50	0.56	0.81	0.82	0.80	0.58	0.00
7	0.82	0.76	0.64	0.84	0.80	0.84	0.74
8	0.56	0.56	0.53	0.55	0.36	0.80	0.85
9	0.76	0.78	0.51	0.69	0.56	0.81	0.83
10	0.00	0.71	0.66	0.59	0.78	0.54	0.42
11	0.46	0.83	0.58	0.78	0.31	0.46	0.49
12	0.15	0.60	0.83	0.59	0.85	0.64	0.77
Average	0.44	0.68	0.68	0.73	0.59	0.69	0.64
St. dev.	0.27	0.12	0.12	0.10	0.20	0.14	0.24
RSD	0.61	0.18	0.17	0.14	0.34	0.20	0.37

Table 5. The average (per drawing) distance between the colors for each of the drawings sorted by age, with the average and standard deviation calculated. Drawing numbers (1, 2, 3), (4, 5, 6), (7, 8, 9) and (10, 11, 12) are drawn by Child 1, 2, 3 and 4 respectively.

# drawing	**2 years**	**3 years**	**4 years**	**5 years**	**6 years**	**7 years**	**8 years**
1	0.36	0.53	0.55	0.51	0.35	0.51	0.47
2	0.42	0.52	0.58	0.48	0.37	0.56	0.53
3	0.55	0.54	0.48	0.45	0.40	0.55	0.38
4	0.52	0.43	0.57	0.54	0.45	0.51	0.31
5	0.00	0.31	0.51	0.52	0.57	0.55	0.35
6	0.43	0.30	0.60	0.58	0.46	0.52	0.38
7	0.49	0.32	0.54	0.46	0.49	0.49	0.53
8	0.34	0.34	0.55	0.56	0.29	0.47	0.49
9	0.32	0.50	0.60	0.54	0.39	0.52	0.49
10	0.00	0.30	0.51	0.60	0.50	0.26	0.26
11	0.36	0.59	0.55	0.58	0.59	0.47	0.53
12	0.44	0.48	0.57	0.54	0.62	0.64	0.63
Average	0.35	0.43	0.55	0.53	0.46	0.50	0.45
St. dev.	0.18	0.11	0.04	0.05	0.10	0.09	0.11
RSD	0.51	0.25	0.07	0.09	0.22	0.18	0.24

Discussion

The initial premise of this research was partially supported by the findings. It was proposed that as a child's brain develops in size and complexity, this progression would be reflected in an increase in both the number and complexity of colors used in their drawings. The result of the ANOVA provided justification that there existed a statistical difference in the average number of colors used throughout the various developmental childhood ages.

To evaluate this idea, the study examined changes in three key measures: (i) the number of colors used, (ii) the Simpson's diversity index, and (iii) the average distance between colors in the *Lab* space. The result was interesting. Instead of finding a single trend in ages 2-8, two separate trends were found for each of these three measures. During the early ages (from 2 to 4 years old), the number of colors, the diversity index and the average distance between colors used in the drawings showed a visual increase. This was partly supported by the post-hoc Tukey HSD test p-values for ages (1,2), (1,3), and (1,4) but not by p-values for ages (2,3), (2,4) and (3,4) (Table 2). Then, for the later part of the age-span studied, the pattern changed: while the diversity of colors remained steady (no significant change), the number of colors used and the Simpson's diversity index decreased between the ages 4 and 8. Although, here again, the post-hoc Tukey HSD test p-values for the number of colors were not entirely consistent with this pattern; being significant between years (4,7) and (5,7), but not significant between years (4,6), (5,6) or (6,7) (Table 2). This may not be entirely unexpected, since consecutive years would not differ as much in the various metrics as those at the ends of that age subset spectrum. Furthermore, the post-hoc p-values from the Tukey HSD for the age of 3 years may not be valid since the inter-child standard deviation of RSDs' in that year was ≥ 3X those from other years (Table 3).

The number and diversity of colors used by a given child in a given drawing do not only depend on the child's cognitive stage, but also on other factors. One such factor is the subject matter of the drawing. The RSD values in Table 3 were analyzed to determine if this factor could be largely discounted, for the purposes of interpreting cognitive development. Ignoring the high value of 44.2 for the 3rd year of childhood (Table 3), the values ranged from 4.5 to 16.9. This can be taken to imply that, except for the 3rd childhood year, the subject matter, or the content of the painting did not contribute overtly dis-similarly to the cognitive capability of those children in other childhood years. Hence, even though the content or subject matter of a painting obviously influences resultant metric scores (see the Limitations section), those scores are not influenced overtly dis-similarly (except in the 3rd year of childhood). Therefore, excluding the 3rd childhood year, the content or subject of the painting as a confounding factor influencing childhood cognitive development could be largely discounted. The high value in the 3rd year of development presented a conundrum, which we cannot explain.

From the point of view of development, these changes can be explained as follows.

According to the data, the number and diversity of colors steadily increase in the early childhood, but after the age of about 4, the number of colors used began to decrease, and diversity stopped increasing. This is most likely due to the fact that after some time, a child begins to mature and their drawings begin to look more realistic. Unlike their previously abstract and colorful drawings, their artwork starts to look more reasonable, therefore using less colors. Concurrently, it was also found that the distance between colors in the *Lab* color space first increased and then decreased. It is proposed that the reason for this is connected with the drawings becoming more realistic. At first, the young child uses random rainbow colors. Later on, as the art becomes more realistic when the child grows older, the distance between the colors grows smaller as a result of the colors in the drawings becoming less random and more thought out. Instead of bright rainbow colors, children start using shades of the same color, making the artistic expression subtler.

These findings can also be explained from the point of view of the physiology of the developing brain. Figure 9 presents two neurological studies from the literature. In panel (a), a graph from paper (14) is replotted that shows the cerebral area versus the age. The authors note that the period of cerebral enlargement is limited to the first decade of life, and the increase is especially steep in the first half of the first decade of life. In other words, the cerebral area first increases rapidly, and then the increase slows down after the age of 4, see the graph in Fig. 9(a).

Figure 9(b) replots a graph from Dekaban et al. (15) that shows the brain weight divided by the individual's body mass, as a function of age. Again, a change of behavior between these two time-intervals can be observed. These findings show that some qualitative physiological /neurological change takes place during the first years of life. This may help explain the observed change in the patterns of color usage in children.

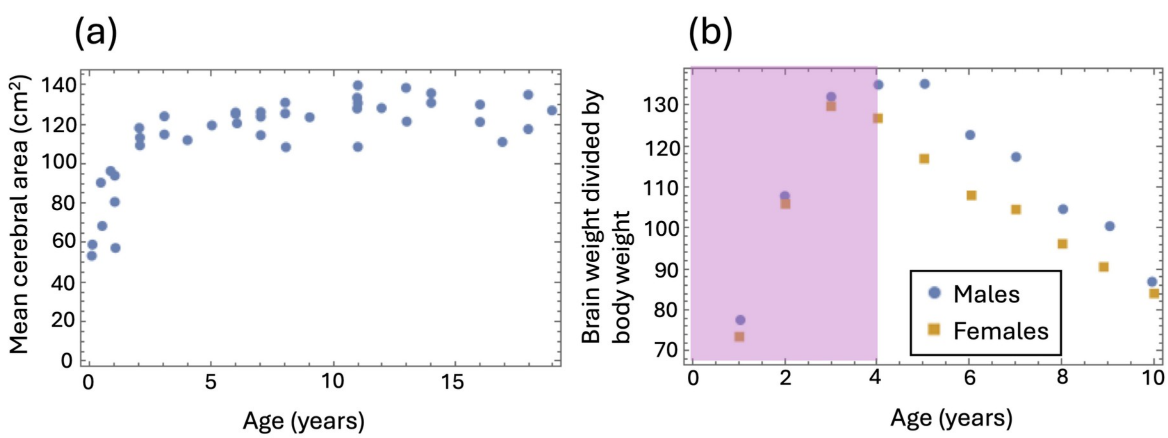

Figure 9. Measurements of the developing brain (14,15). (a) A scatter-gram of age versus mean cerebral area in normal subjects, from (14). (b) Brain weight in kilograms divided by body weight in kilograms by age groups in 2,603 males and 1,848 females, from (15). The period before age 4 is shaded.

There is strong evidence from neuroscience and developmental studies that a significant change occurs in brain development around the age of four. Both qualitative and quantitative changes take place during this period, affecting brain structure, function, and cognitive abilities. The biphasic behavior of the numbers of colors used, the color diversity, and the mean color distance is consistent with these patterns. In particular, executive functions, such as working memory, attention control, and decision-making, show noticeable advancements after age 4, coinciding with structural brain maturation (16,17). In addition, studies in language acquisition indicate that the most rapid period of vocabulary and grammar development occurs before age 4, after which language learning becomes more dependent on experience rather than innate neuroplasticity (18,19). Finally, it has been reported that visual processing and color perception also develop during this period, supporting the idea that color usage in children's drawings may reflect underlying neurodevelopmental changes (1,20).

Limitations

While the three metrics used here (the number of colors, Simpson's diversity index, and perceptual color distance) provide useful information about the color content of children's drawings, each of these metrics has limitations. The number of colors is the simplest metric, but it lacks information about color distribution. The Simpson's diversity index uses colors' frequencies of use, but it does not contain information on color differences: for example, it cannot distinguish between color contents of a drawing that contains 3 shades of pink at frequencies 10%, 20%, and 70%, and a drawing that uses 10% pink, 20% green, and 70% blue. Finally, the average perceptual color distance, while focusing on color differences, does not use color numbers or frequencies of usage.

More generally, a limitation of the analysis presented here is that the number and diversity of colors used by a given child in a given drawing do not only depend on the child's cognitive stage, but also on other factors. One such factor is the subject matter of the drawing. For example, if a child draws a desert, they may choose to use few colors and shades closer together compared to a drawing of a colorful spring flower bed. Another factor is the availability of colors at the moment of the drawing. Whether a child is presented with only 3 crayons or with 36 crayons may make a difference in the number of colors used in the drawing.

In the present study, an inter-child variation analysis showed that between-child consistency was sub-optimal, ranging from a Percent RSD of 4.5 to 16.9, discounting the 44.2% RSD in year 3 (Table 3). This was taken to imply that – with the exception of year 3 -the content of the painting did not contribute overtly dis-similarly to the cognitive capability of those children in other childhood years. In order to improve such consistency further and minimize the content-dependence and availability-dependence of the results, a larger-scale analysis should be performed, where the influence of factors such as drawing-content and color availability may become minimal.

Perspectives

The methodological framework used in this study could be extended to cross-cultural investigations of children's artwork to examine potential variations in color usage across different cultural and environmental contexts. Such an approach may provide insights into the influence of cultural factors on artistic development and cognitive processing, contributing to a broader understanding of developmental and neurobiological influences on artistic expression.

Another extension of this work lies in evaluating whether the color-based indices measured here, namely, the number of colors used, Simpson's diversity index, and perceptual color distance, could serve as early indicators or "photomarkers" of visual system abnormalities or neurodevelopmental disorders. For instance, significant deviations from typical trajectories in color usage, such as unusually low color diversity or small perceptual distances between colors, may reflect atypical development of the visual system, including cone cell function or cortical color processing. This raises the possibility that children at risk for color vision deficiency (e.g., congenital red-green defects) might exhibit restricted color palettes in their drawings well before standard Ishihara testing would detect them (21), or that early rod–cone dystrophies could manifest as altered perceptual color distances due to selective cone loss (22). Likewise, subtle changes in color discrimination have been documented in presymptomatic Leber hereditary optic neuropathy and dominant optic atrophy (23). Given the strong link between artistic output and neurovisual development (1,2,20), further research could investigate whether deviations in these color usage metrics correlate with clinical or subclinical markers of ocular diseases (24). If validated, such tools could become valuable, non-invasive screening methods to flag potential vulnerabilities early, enabling timely lifestyle interventions or medical follow-up. Future longitudinal studies linking color metrics in children's drawings with visual and neurological assessments may help establish a predictive framework for identifying such conditions.

Conclusion

This study analyzed the variation in color usage in children's drawings between the ages of 2 and 8 by a statistical evaluation of extracted color data. Three distinct measures of color diversity were employed: the total number of colors used, the Simpson's diversity index, and the average perceptual distance between colors in the *Lab* color space. The findings indicate a shift in color usage patterns between early childhood (ages 2–4) and later childhood (ages 4–8). During the earlier developmental phase, all three measures exhibited a statistically significant increase, suggesting greater exploratory behavior in color selection. However, in the later phase, while color diversity remained stable, both the total number of colors and the perceptual color distance decreased, indicating a transition from uninhibited experimentation toward a more structured and realistic artistic representation. These trends align with established neurodevelopmental patterns, including changes in brain mass relative to body size, which exhibit a similar trajectory during early childhood.

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