Implementing Infant Vision: Color Perception

Computational Visual Perception Project Part 1
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1 Introduction

Infant vision undergoes rapid development during the first 12 months of life. At birth, infants have limited vision with poor visual acuity (below 20/600), primarily perceiving black-and-white contrasts [1]. Over the first two months, light sensitivity, focus, and basic color perception improve [5]. By 2 to 3 months, recognition of red and green, and familiar faces emerge [4]. Depth perception and binocular vision develop around 4 to 6 months [7], while maturing color vision allows infants to distinguish subtle hues [9]. By 7 to 12 months, as crawling and walking begin, visual-motor coordination supports better distance judgment and object manipulation [2][3].
Infant vision can be characterized along key dimensions of development: with acuity, focus, and contrast sensitivity improving early, followed by color vision, tracking, and depth perception. The development is pragmatically synchronized: with low light sensitivity, a narrow visual field, and reddish color perception, infants are particularly attuned to faces above them, which stand out due to brightness, proximity, and contrast (see section 5). Interaction between these dimensions appears crucial in computational models of development; if one element is impaired or restored later with an abnormally precise onset, it may disrupt the overall progression of visual processing [8].

2 Infant Vision: Color Perception

This implementation focuses on the color perception dimension of infant vision following the developmental stages outlined by Skelton et al. [6].
Infant color perception begins with a grayscale view at birth and a slight ability to perceive red within the first few weeks. During the first 2–3 months the red-green color mechanism emerges. Around 3 months, infants become trichromatic, with blue perception lagging significantly. By 4–5 months, sensitivity to red, green, and yellow allows gradual recognition of color shades. By 6–7 months, the full-color spectrum becomes visible, though less vivid than adult vision, with color recognition continuing to refine. By 10–12 months, infants achieve near-adult color perception.

3 Implementation: Methods

The implementation models the progression of infant visual perception through an image transformation pipeline, designed within a PyTorch data loader class. The pipeline supports custom images for detailed visualizations and the CIFAR-10 32x32 image dataset, for large-scale, but storage-efficient testing.

Infant color perception is simulated by scaling RGB channels to reflect asynchronous sensitivity development. Unlike masking, which applies a global tint, it adjusts colors locally, reflecting color as a phenomenon of localized light refraction.

For months 0–1, the transformation emphasizes grayscale perception with a slight enhancement of the red channel e.g., scaling factors of 0.15 for red, green, and blue at birth and 0.255 for red at month 1. At months 2-3, green is gradually introduced, while red remains prominent, with a difference of 0.1 in their scaling factors. While blue remains suppressed, yellow emerges in months 4-5, reflected by a slow matching of the red and green channels. Over the following months, the red-green and blue-yellow mechanisms increase in sensitivity, with blue progressively catching up to the scaling of the red and green channels, reaching saturation levels of 80-90% of adult vision across channels. At the one-year mark, color perception reaches near adult level with 95% saturation.

To accurately capture the interplay of developmental dimensions in visual perception, the implementation optionally applies an acuity transformation that simulates its development by linearly scaling image granularity based on age.

The acuity scale factor is a linear interpolation between a minimum visual acuity (20) and a maximum (600), tied to the infant's age in months following Vogelsang et al. [8]. As age increases, the scale adjusts to reflect improving acuity, with granularity linearly decreasing over the first 12 months.

4 Implementation: Performance

The performance of the Infant Vision data loader class was tested on the CIFAR-10 dataset. Four transformation types were tested: None, All (color and acuity transformations), Color only and Acuity only. Each configuration was run five times with a batch size of 10, using 100 images.

- **None (No transformation)**: Average load time of 0.0097 seconds.
- **All (Color + Acuity transformations)**: Average load time of 0.0234 seconds, representing a 141.17% increase in loading time compared to None.
- **Color transformation only**: Average load time of 0.0210 seconds, a 116.36% increase.

- **Acuity transformation only**: Average load time of 0.0166 seconds, a 70.65% increase.

These results confirm the expectation that applying transformations within the infant vision DataLoader introduces additional overhead, whereby the channel-wise transformations representing infant color perception introduce more load than the linear scaling of acuity. Conversely, applying both transformations sequentially—first reducing granularity, then applying the channel-wise color transformation—results in a sub-additive computational load, as the reduced resolution decreases the workload for the color transformation by operating on fewer pixels.

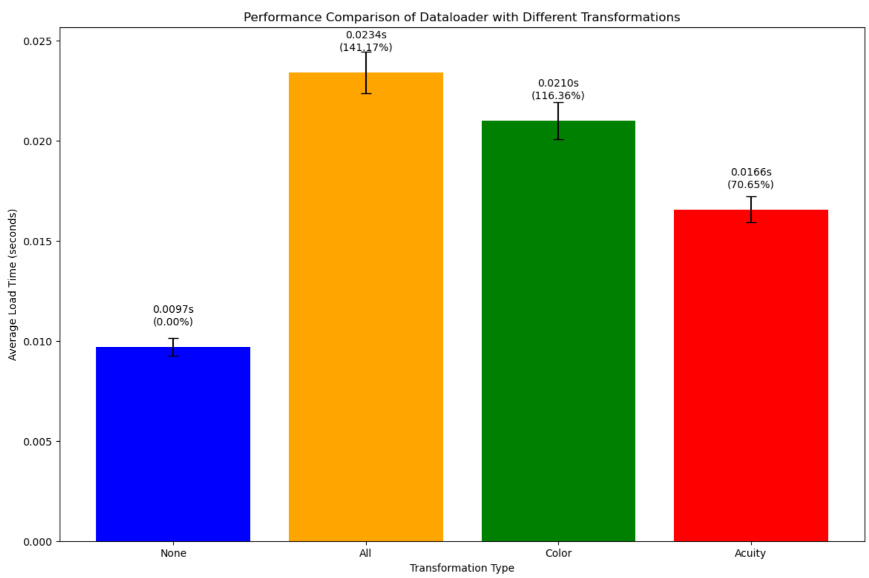


Figure 1: Performance Comparison of DataLoader with Different Transformations

5 Implementation: Results

The images below illustrate the progression of infant vision from 1 to 12 months using three different transformation approaches: Acuity Transformation Only, Color Transformation Only, and a combination of both transformations.

1. **Acuity Transformation Only**: This set shows improvement in visual acuity. Clarity increases each month, reaching near-adult sharpness by 12 months, but color remains constant.

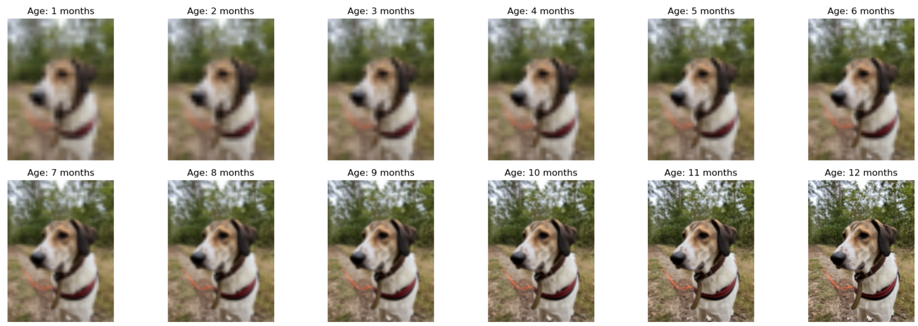
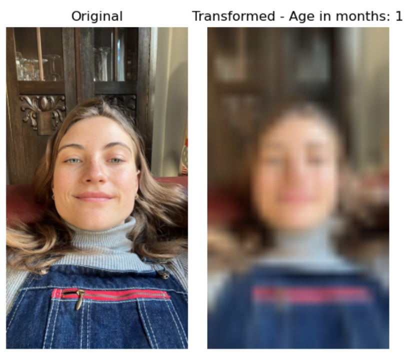
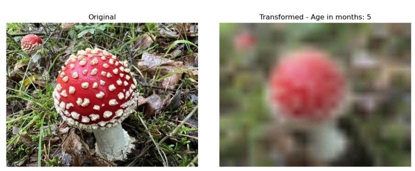


Figure 2: Acuity Transformation Only across 12 Months: Shows progressive improvement in sharpness without color change.

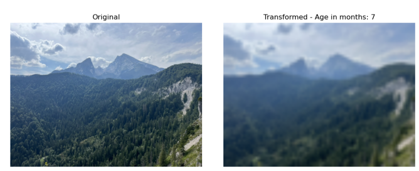


(a) Acuity Transformation Month 1

(b) Acuity Transformation Month 3



(c) Acuity Transformation Month 5

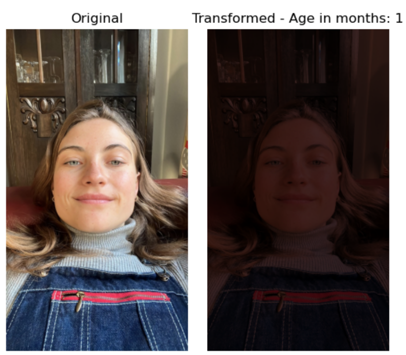


(d) Acuity Transformation Month 7

Figure 3: Acuity Transformation across Months for additional Samples

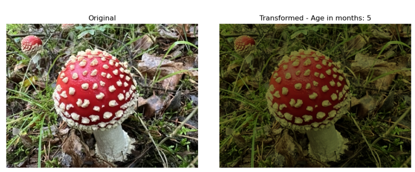
2. **Color Transformation Only**: This set highlights color development (section 2 and 3) without altering sharpness.

Figure 4: Color Transformation Only across 12 Months: Highlights the gradual development of color perception without altering sharpness.

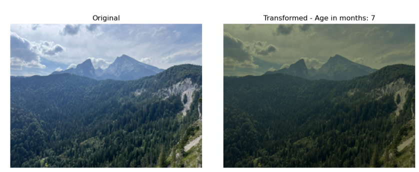


(a) Caption for Image 1

(b) Color Transformation Month 3



(c) Color Transformation Month 5



(d) Color Transformation Month 7

Figure 5: Color Transformations across Months for additional Samples

3. **Both Color and Acuity Transformations**: By combining just two developmental dimensions, we can observe a pragmatic alignment in infant visual development that enhances e.g. the maternal face above them at their most vulnerable stage. The enforced early focus on facial features can be observed by comparing Fig. 6 (1) and Fig. 7 (a), which both simulate the first month.

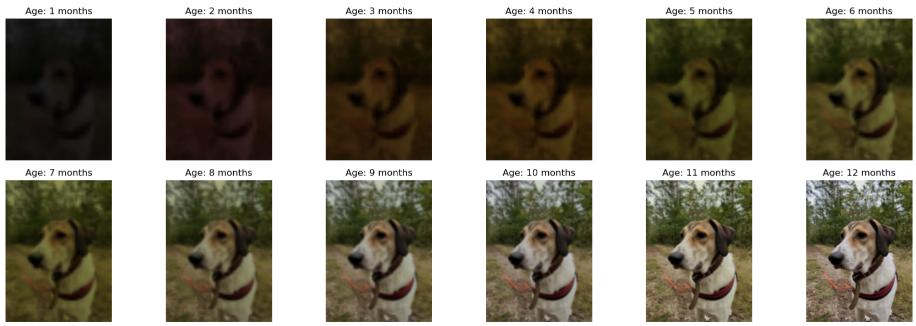
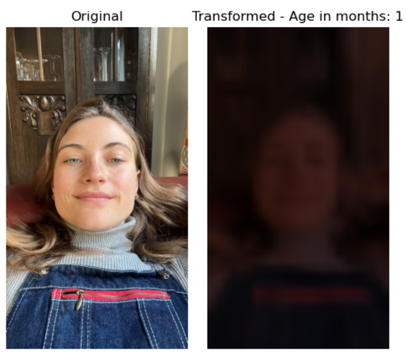
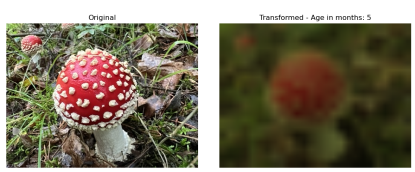


Figure 6: Both Color and Acuity Transformations across 12 Months: Simulates improvement in color perception and visual sharpness.

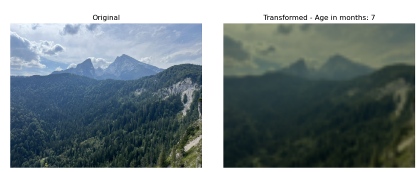


(a) Color and Acuity Transformation Month 1

(b) Color and Acuity Transformation Month 3



(c) Color and Acuity Transformation Month 5



(d) Color and Acuity Transformation Month 7

Figure 7: Both Color and Acuity Transformations across Months for additional samples

Overall, applying both transformations offers a significantly more accurate approximation of infant vision development than using color or acuity transformations alone. This supports the expectation that incorporating additional developmental dimensions would yield a more realistic representation.

References

[1] R. J. Adams. An evaluation of color preference in early infancy. *Infant Behavior & Development*, 10(2):143–150, 1987.

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[3] American Optometric Association. Infant vision: Birth to 24 months, n.d. Accessed: 2024-11-15.

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[9] I. Zemach, S. Chang, and D. Y. Teller. Infant color vision: Prediction of infants' spontaneous color preferences. *Vision Research*, 47(10):1368–1381, 2007.