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REPORT

A new method for calibrating perceptual salience across dimensions in infants: the case of color vs. luminance

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Abstract

We report a new method for calibrating differences in perceptual salience across feature dimensions, in infants. The problem of inter-dimensional salience arises in many areas of infant studies, but a general method for addressing the problem has not previously been described. Our method is based on a preferential looking paradigm, adapted to determine the relative salience of two stimuli. We report here on the case of stimuli differing in color and luminance, though the method has wider potential. We were able to determine on a psychophysical curve the point at which a color contrast was equally salient to infants as a given luminance contrast. We then used these calibrated, 'iso-salient' stimuli in an object memory study. Results showed that 6.5-month-old infants noticed a color, but not a luminance, change while tracking an occluded object. Our method should have numerous applications in the study of bottom-up effects on infant attention and visual working memory.

We identify and remember objects based on features such as shape, color and size. In studying how these abilities develop, researchers often wish to compare how readily infants detect changes in appearance along one feature dimension versus another; such a comparison gives insight into infants' relative memory ability.

Previous studies of infants' visual working memory (VWM[1]) have found little evidence for memory for color in the first year of life. One of our own studies showed that 9-month-old infants apparently remembered the shape of an object, but not its color (Kaldy & Leslie, 2003). Other studies found memory for size and shape at 6 months, but no memory for color until the end of the first year (Wilcox, 1999; Kaldy & Leslie, 2005). However, all of these studies faced difficult choices: Since memory is evaluated by the likelihood that an infant will notice a change in a to-be-remembered stimulus, then, for instance, what kind of color change (a pale blue disk to deep blue? to bright red?) should be compared to what kind of size change (a 20% increase? 200%)? Here we argue that one should only compare changes that are equally 'noticeable' and 'interesting' to the infant, that is, that are equally *salient*.

Salience is understood to reflect an assessment of relative behavioral significance of visual information and, as such, largely determines what is prioritized for further processing. Behavioral studies of attention in adults and neurophysiological studies in monkeys have shown that bottom-up perceptual information and top-down volitional effects seem to be combined in a unified topographical map in the brain (see Itti & Koch, 2001; Treue, 2003). This map controls attention and eye movements, while attention, in turn, implements a bottleneck for the incoming sensory information and allows only a part of it to reach working memory. It is largely independent of the nature of the particular task and it is computed very rapidly (Itti & Koch, 2001). Recently, Dannemiller and his colleagues conducted pioneering research on the bottom-up factors affecting infant attention (Dannemiller, 1998, 2000; Ross & Dannemiller, 1999). They showed that as early as 7 weeks, sensitivity for a small moving stimulus can be significantly influenced by the simultaneous presence of competing targets of attention in the visual field (Dannemiller, 2000), and at 3 months of age, salience effects based on luminance and color contrast

[1] Visual working memory is defined as the transient, but non-iconic memory representations of relevant visual information at a given moment (see e.g. Gazzaniga, Ivry & Mangun, 2002).

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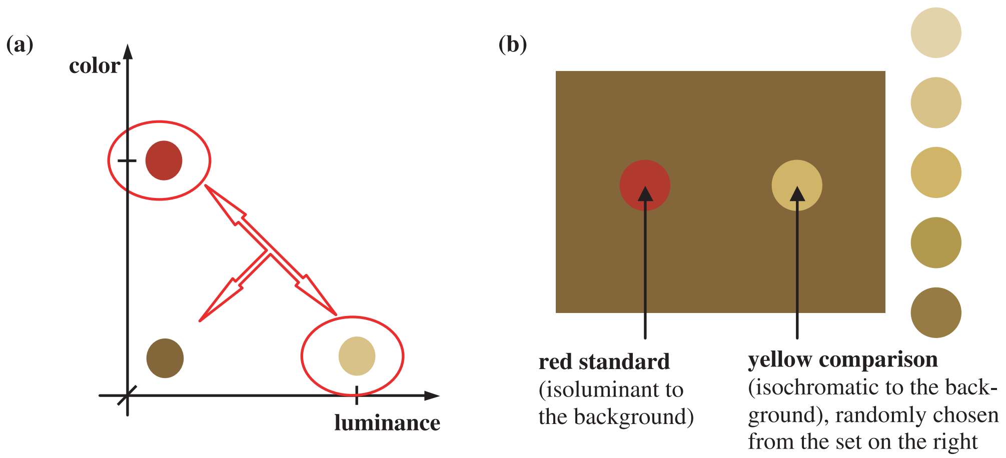

Figure 1 *Salience calibration. (a) The purpose of salience calibration is to find equally (or iso) salient differences along the color and the luminance dimensions. (b) A sample stimulus from Experiment 1.*

contribute to orienting (Ross & Dannemiller, 1999; see also Atkinson, Hood, Wattam-Bell & Braddick, 1992).

As part of a larger push toward the incorporation of the technical conventions of adult psychophysical studies to infant research (see Aslin & Fiser, 2005), here we describe how to extend a preferential looking paradigm so that one can psychophysically calibrate salience, across perceptual dimensions. Our particular goal here was to compare infants' ability to notice changes in color versus changes in luminance – and therefore gain insight into relative memory – where those changes have been calibrated to be equally salient.

1. Experiment 1: Calibrating salience

To develop a salience calibration paradigm, we adapted the classic forced-choice preferential looking (FPL) method that has proved exceptionally useful in perceptual threshold measurements (Teller, 1979; for a recent review, see Teller, 1997), in order to compare the relative salience of two stimuli.[2]

Our goal was to lay the groundwork for a comparison of visual working memory for color versus luminance. To accomplish this, we needed to generate a set of three stimuli (see Figure 1a): a 'baseline' item, an item that differs from the baseline only in color, and another item that differs only in luminance. These three items should also satisfy the following condition: the salience difference between the baseline and the color item should be equal to the salience difference between the baseline and the luminance item.

1.1. Methods

1.1.1. Subjects

Nine healthy, full-term, 6.5-month-old infants (three females) participated in this study (age: 180 days–210 days, mean: 194.1 ± 7.0 days). One additional infant was tested but was excluded due to fussiness.

1.1.2. Apparatus

Infants sat on their parent's lap 40 cm from a 17″ LCD monitor. Stimuli were designed using Macromedia Director MX and were presented on a Dell computer. A concealed video camera positioned above the monitor recorded infants' behavior. The room was dimly lit, and dark blue curtains isolated the testing area.

1.1.3. Stimuli and procedure

Computer displays of two static disks were presented on a uniform, brown background: a 'standard' red disk, isoluminant with the background,[3] and a lighter-brown (that is, yellow) 'comparison' disk. As shown in Figure 1b, the intensity of the luminance comparison was chosen

[2] Note that there are other ways to operationally define salience – one could measure overall looking time, for instance. However, since salience is typically thought to drive attention allocation and therefore eye movements, there is considerable face validity for measuring first looks. In any case, we would expect other measures to produce consistent results.

[3] Isoluminance was calibrated using the minimum motion technique on adults, which provides a valid estimate of infant values (Pereverzeva, Chien, Palmer & Teller, 2002).

Table 1 *The stimuli in CIE xyY coordinates: the first two values represent chromaticity, the third value represents luminance. Y1–Y5 refers to the 5 luminance levels for the comparisons*

Stimulus		CIE xyY	
red standard		(0.56, 0.34)	4.5
brown background		(0.44, 0.40)	"
yellow comparisons:	Y1	" "	9.1
	Y2	" "	11.3
	Y3	" "	13.5
	Y4	" "	16.1
	Y5	" "	18.6

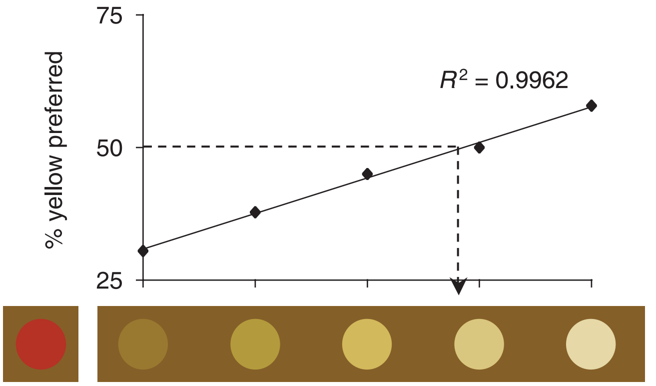

Figure 2 *The luminance value that was iso-salient to a predetermined color difference with respect to background brown color (at 50% preference value) was determined from the results of the preferential looking test.*

randomly from five predetermined levels[4] (see Stephens & Banks, 1985, for a similarly executed manipulation of contrast). The corresponding CIE xyY coordinates are listed in Table 1.[5]

Stimuli were calibrated with Pantone's GalleryCAL software and a Pantone Spyder calibration device. Disks subtended 4 degrees of visual angle and were 8 degrees apart. The side of the comparison vs. the standard (left/right) was randomized across trials.

A sound cued the beginning of each trial. Each stimulus pair (see Figure 1b for an example) was presented for 2 seconds. In between the trials, a black 4 deg × 4 deg fixation cross was presented in the center of the screen for 1 second. The dependent variable was the direction of the first look (left or right) for each trial. Parents were instructed to keep their eyes closed and to not interact with their infants during the experiment.

A maximum of 35 trials/subject were run. Twenty-five of these trials presented actual experimental stimuli (exactly 5 trials/stimulus pair); the other 10 trials were 'dummy' trials using one of the yellow comparison disks pitted against one of two novel red disks. Without the dummy trials, the standard red disk would have been presented as part of every trial display. Results from the dummy trials were not analyzed. Infants were video-recorded throughout the entire experiment. Later, offline, two trained observers, blind to the experimental stimuli, encoded infants' first look. Trials where there was a disagreement between the two observers were excluded (approximately 2% of all trials).

1.2. Results, data analysis and discussion

A total of 193 trials were collected. All of the infant subjects had valid responses (left/right looks where the two observers were in agreement) in at least 15 of the 35 trials. The average number of completed trials was 21.45 per subject.[6] The resulting psychometric function appears in Figure 2. The data were best fit by a linear regression function ($R^2 = 0.9962$). The horizontal axis represents the five luminance comparison values (for actual CIE coordinates, see Table 1). The vertical axis represents the percent of trials where the luminance comparison disk was preferred. The pattern of the results shows that when the luminance disk differed only slightly from the background brown, infants tended to look first at the red disk, while in those trials where it was much brighter than the background, infants looked at it first.

The 50% preference value taken from the psychometric function is our best estimate of the luminance stimulus that was 'iso-salient' to the color stimulus, with respect to the common background. This actual luminance value fell between the third (Y3) and fourth (Y4) comparison stimuli (CIE coordinates: (0.459, 0.422), 15.6). These results demonstrate that forced-choice preferential looking (FPL) can also serve as a salience calibration tool.

It is important to note that each test trial display included the same red disk paired with a randomly chosen luminance comparison (25 out of the 35 trials, since the 10 dummy trials used a different red disk, see above). Since during the test infants saw this red disk more often than any *particular* yellow comparison disk, it would be possible that the salience of the red disk decreased over time. In order to test this hypothesis, we conducted a split-half analysis. Averaged across subjects, the preference for the red disk in the first half of trials was 54.17%,

[4] The comparisons were equally spaced along the section of the luminance scale that we believed to have covered the ideal 0 and 100% preference values.

[5] The CIE xyY values describe the color and the luminance of our stimuli in a standard, device-independent color space.

[6] In the rest of the trials subjects looked away from the monitor.

and was nearly identical to the 55.67% preference in the second half. We also contrasted preference for the red disk for each subject in the first half of the trials to the second half with a paired two-sample *t*-test. The result of this test was not significant ($p = .733$, $t_8 = 0.353$). Therefore, we can conclude that the higher number of repetitions of the red disk did not influence its relative salience.

We were now able to construct the three stimuli needed for the memory task in Experiment 2 (see again Figure 1a). A 'baseline' stimulus was a disk that had the color and luminance of the brown background from Experiment 1, while the red disk and iso-salient yellow disk would serve as the color and luminance comparisons, respectively. The three stimuli so constructed had the following properties: (1) the red and the brown disk were isoluminant and only differed in chromaticity, (2) the yellow and the brown disk were isochromatic and only differed in luminance, and (3) the difference between the red and the brown disk was iso-salient to the difference between the yellow and the brown disk.

2. Experiment 2: Memory for color versus luminance

Memory tests consisted of computer-generated animations and used the violation-of-expectation method. To create two stimulus pairs – a 'color change' pair and 'luminance change' pair, that is – we pitted the iso-salient red and yellow 'comparison' disks each against the 'baseline' brown disk. Infants in the Color condition were familiarized to the color pair and saw three subsequent test trials (see Figure 3) using this pair, while infants in the Luminance condition were familiarized to the luminance pair and accordingly saw three trials with this stimulus pair.

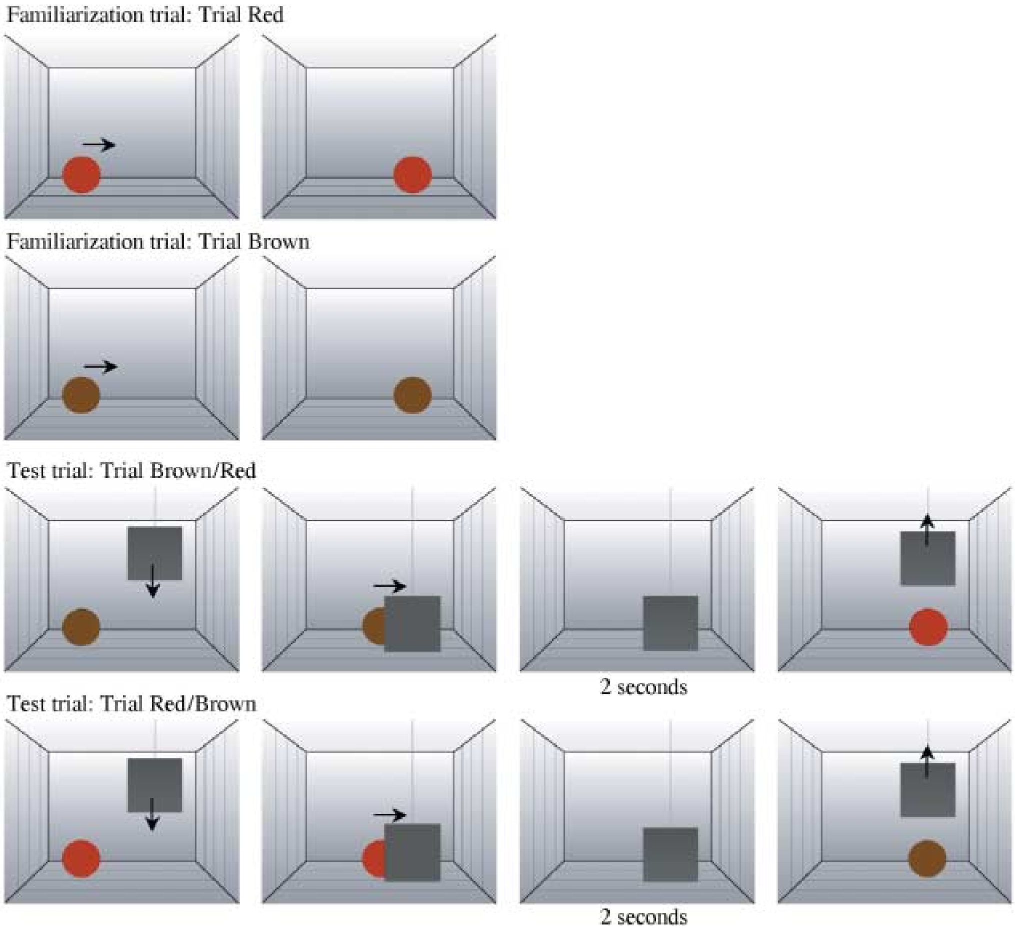

Figure 3 *Familiarization and test trials in the Color study of Experiment 2. Trials Red and Brown alternated during familiarization for a total of four trials. Trials Brown/Red and Red/Brown alternated during the three test trials. In the Luminance study of Experiment 2, all stimuli and events were identical, except the red disk was replaced by the iso-salient yellow disk.*

2.1. Methods

2.1.1. Subjects

Forty full-term, 6.5-month-old infants participated in this study (age: 180 days–210 days, mean: 191.0 days ±10.2 days). Subjects were randomly assigned to one of the following conditions: Color study (No change or Color change conditions) or Luminance study (No change or Luminance change conditions).

2.1.2. Apparatus

In addition to the same apparatus that was used in Experiment 1, a timing device was used to measure looking times in the outcome phase of the test trials.

2.1.3. Stimuli and procedure

Infants were familiarized to either the color or the luminance change pairs. During the four familiarization trials, infants saw alternating objects of the pair appear on one side of the stage and then move to the other side. Then, in the test trials, half of the infants saw an object disappear behind a screen and, once the screen was removed, saw the same object ('No change'); the other half saw the same sequence, except that when the screen was removed, the other object from the pair was revealed (producing a 'Color' or 'Luminance' change). Occlusion time was 2 seconds. All infants saw three test trials. Between each of the trials (familiarization and test), an animated blue curtain closed and reopened. Each time an object (disk, screen, curtain) moved on the screen, it was coupled with a sound effect in order to keep infants' gaze fixated on the monitor. All stimuli were presented on a light grey background (note that this is a change from the brown background that was used during the salience calibration in Experiment 1; please see Experiment 3 for a description of a control experiment that confirms that the calibrations we made there are still valid here).

An online observer, trained in recording infant looking times and blind to condition, reviewed the video of the infant's behavior. The observer operated a button box that triggered the computer to record looking times. A sound cued the observer when the screen moved upwards to reveal the object, at which point the observer would hold down the timing button whenever the infant looked toward the stage. Whenever the infant looked away from the stage, the observer released the button. Looking time was accumulated until the infant looked away for 2 seconds, at which point the computer turned off the stage lights, and recorded the accumulated looking time minus 2 seconds.

All experimental recordings were later re-scored in the same way by a second observer, also blind to condition. If inter-observer agreement between the online and the offline observer was lower than 95%, a third observer was used (approximately 10% of the cases) to break the tie. If the third observer's measurements had not agreed with either of the previous observers at higher than 95%, that subject would have been excluded from further analysis (however, no infants were excluded for this reason).

2.2. Results

In short, our main result is that mean looking times per trial were significantly different from baseline (No change) when the color of the object changed (Figure 4a), but not when the luminance of the object changed (Figure 4b). In this section, we will describe the results for the Color and the Luminance change study in turn.

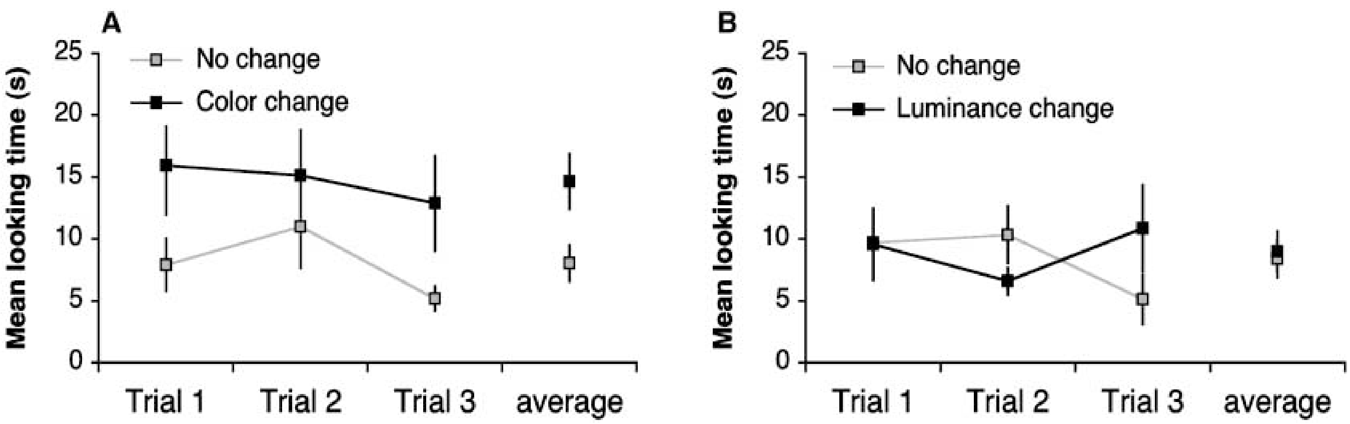

Figure 4 *Mean looking times (in seconds) in the color (a) and luminance (b) memory tests (±SE) show significant visual memory for color, but not luminance, differences in 6.5-month-old infants.*

2.2.1. Color change study

Preliminary analysis showed no effect of gender, age (infants closer to 6 months vs. 7 months), or first object shown (brown/red disk). These factors were dropped from further analysis.

Mean looking times with standard errors by condition and trial are shown in Figure 3a. Looking times were analyzed in a repeated measures 3 × 2 ANOVA with Trials (3) as within-subject factor and Color change (2) as between-subjects factor.

There was no main effect of Trials ($F_{2,36} < 1$, *ns*). There was a significant main effect of Color change ($F_{1,18} = 6.309$, $p = .022$). Trials and Color change did not interact ($F_{2,36} < 1$, *ns*).

Effect size was estimated using η^2: color change accounted for 26% of the variance over all three test trials.

Planned comparisons examined looking times across the three trials for the experimental groups versus the control group. One-tailed *t*-tests showed significant results in the first ($t_{18} = 1.87$, $p = .042$), and the third trials ($t_{18} = 1.84$, $p = .041$), as well as for the average of all three trials ($t_{18} = 2.51$, $p = .011$).

2.2.2. Luminance study

Preliminary analysis showed no effect of gender, age (infants closer to 6 months vs. 7 months), or first object shown (brown/yellow disk). These factors were dropped from further analysis.

Mean looking times with standard errors by condition and trial are shown in Figure 3b. Looking times were analyzed in a repeated measures 3 × 2 ANOVA with Trials (3) as within-subject factor and Luminance change (2) as between-subjects factor.

There was no main effect of Trials ($F_{2,36} < 1$, *ns*) or Luminance change ($F_{1,18} < 1$, *ns*). Trials and Luminance change did not interact ($F_{2,36} = 1.1$, $p = .296$, *ns*).

2.3. Discussion

Results of Experiment 2 show that when 6.5-month-old infants are presented with an equally salient color change versus luminance change, they remember the color change, but not the luminance change. In other words, infants tended to notice when the brown disk changed to red or red changed to brown, but not when brown lightened to yellow or yellow darkened to brown. Of course, this does not imply that color is always remembered, while luminance is never remembered. Further studies with other stimulus pairs are required to make such broad claims. We are optimistic that the methodology exhibited here permits formal exploration of this parameter space; experiments are ongoing.

3. Experiment 3: Confirming iso-salience

Salience is not an absolute quantity and it can be influenced by local context (as too, of course, may be appearance; see Pereverzeva & Teller, 2004). In Experiment 1, a red and a yellow disk were calibrated to iso-salience, with respect to a common brown background. However, in the subsequent memory tests of Experiment 2, it was necessary to use a new background (light grey). Given this, it was necessary to run a control experiment to ensure that our iso-salient stimuli were, indeed, still iso-salient on this new background. Our assumption was that the grey background was sufficiently different from both the red and yellow disks as to not affect their relative salience. This control experiment confirmed that iso-salience was preserved on the new background.

3.1. Methods

3.1.1. Subjects

Thirteen healthy, full-term, 6.5-month-old infants (seven females) participated in this study (age: 180–210 days, mean: 192 ± 9.1 days).

3.1.2. Apparatus, stimuli and procedure

This additional preferential looking study was conducted to cross-check the iso-salience of the calibrated red–yellow pair on the new grey background using the same apparatus. A maximum of 24 test trials were run. Mixed in with 12 test trials, there were six dummy trials of red–brown and six dummy trials of yellow–brown pairs of disks (on the same grey background). The experimental procedures were otherwise identical to those described in Experiment 1.

3.2. Results, data analysis and discussion

The results are based on 105 completed test trials. All of the subjects gave valid responses in at least 15 trials (test and dummy trials combined). The two-tailed one-sample *t*-test showed that the results were not significantly different from an equal (50%) preference ($t_{12} = 0.313$, $p = .76$). In brief, the salience relationship that we established in our calibration experiment remained valid, even when the surrounding context was changed from brown to light grey.

Of course, one cannot be cavalier in general with such changes of context – it is all but certain that if the background had been changed to a shade of red or a shade of yellow, that the two stimuli would no longer be iso-salient. In the present case, however, the fact that the new background was both neutral and very different in appearance from both stimuli helped assure that the salience relationship was preserved.

4. General discussion

We have described and applied a novel salience calibration method. We argue that visual working memory can only be legitimately assessed if the relative salience of objects and their features is taken into account. Our calibration method (or a version of it, adapted to the experimental context in question) can provide a rigorous way to establish a metric for visual inter-dimensional salience in infants.

In addition to introducing this new method, our results point to an interesting aspect of infant visual memory: when salience is properly controlled, visual memory for color not only exists at 6.5 months, but may be better than that for luminance. Indeed, psychophysical studies with adults have shown that not all perceptual dimensions are retained in visual working memory equally (Stefurak & Boynton, 1986; Magnussen, 2000). Though a more extensive exploration of color vs. luminance memory is required for robust conclusions, the current findings bring infants' abilities into line with those of adults. It has been found that memory for color in adults is better than for luminance (Sachtler & Zaidi, 1992) and memory for colored scenes is about 5–10% better than for black and white images (Wichmann, Sharpe & Gegenfurtner, 2002), even when salience is controlled. We speculate that infants' better memory for color is adaptive, since the local luminance of an object can and often does change from one moment to the next (subject, as it is, to the vagaries of shadows and illuminants), while local chromaticity is a relatively more stable identifier. Therefore, prioritizing color memory over luminance seems quite plausible.

The particular calibration procedure used in this study need not be followed to the letter, but, instead, is offered as a suggestive paradigm for salience calibration in general. Just as there have emerged many iso-luminance calibrations, some more straightforward than others, some more appropriate for certain experimental questions (see e.g. Cavanagh, MacLeod & Anstis, 1987; Chaudhuri & Albright, 1990), so too are there likely to emerge various iso-salience calibrations. What we have hoped to establish here is an existence proof of sorts for the value and validity of salience calibration.

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References

Aslin, R.N., & Fiser, J. (2005). Methodological challenges for understanding cognitive development in infants. *Trends in Cognitive Sciences*, **9**, 92–98.

Atkinson, J., Hood, B., Wattam-Bell, J., & Braddick, O. (1992). Changes in infants' ability to switch visual attention in the first three months of life. *Perception*, **21**, 643–653.

Cavanagh, P., MacLeod, D.I., & Anstis, S.M. (1987). Equiluminance: spatial and temporal factors and the contribution of blue-sensitive cones. *Journal of the Optical Society of America A*, **4**, 1428–1438.

Chaudhuri, A., & Albright, T.D. (1990). A new technique for estimating chromatic isoluminance in humans and monkeys. *Visual Neuroscience*, **5**, 605–608.

Dannemiller, J.L. (1998). A competition model of exogenous orienting in 3.5-month-old infants. *Journal of Experimental Child Psychology*, **68**, 169–201.

Dannemiller, J.L. (2000). Competition in early exogenous orienting between 7 and 21 weeks. *Journal of Experimental Child Psychology*, **76**, 253–274.

Gazzaniga, M.S., Ivry, R.B., & Mangun, G.R. (2002). *Cognitive neuoscience: The biology of the mind* (2nd edn.). New York: W.W. Norton.

Itti, L., & Koch, C. (2001). Computational modelling of visual attention. *Nature Reviews Neuroscience*, **2**, 194–203.

Kaldy, Z., & Leslie, A.M. (2003). Identification of objects in 9-month-old infants: integrating 'what' and 'where' information. *Developmental Science*, **6**, 360–373.

Kaldy, Z., & Leslie, A.M. (2005). A memory span of one? Object identification in 6.5-month-old infants. *Cognition*, **57**, 153–177.

Magnussen, S. (2000). Low-level memory processes in vision. *Trends in Neuroscience*, **23**, 247–251.

Pereverzeva, M., Hui-Lin Chien, S., Palmer, J., & Teller, D.Y. (2002). Infant photometry: are mean adult isoluminance values a sufficient approximation to individual infant values? *Vision Research*, **42**, 1639–1649.

Pereverzeva, M., & Teller, D.Y. (2004). Infant color vision: influence of surround chromaticity on spontaneous looking preferences. *Visual Neuroscience*, **21**, 389–395.

Ross, S.M., & Dannemiller, J.L. (1999). Color contrast, luminance contrast and competition within exogenous orienting in 3.5-month-old infants. *Infant Behavior and Development*, **22**, 383–404.

Sachtler, W.L., & Zaidi, Q. (1992). Chromatic and luminance signals in visual memory. *Journal of the Optical Society of America*, **9**, 877–894.

Stefurak, D.L., & Boynton R.M. (1986). Independence of memory for categorically different colors and shapes. *Perception and Psychophysics*, **39**, 164–174.

Stephens, B.R., & Banks, M.S. (1985). The development of contrast constancy. *Journal of Experimental Child Psychology*, **40**, 528–547.

Teller, D.Y. (1979). The forced-choice preferential looking procedure: a psychophysical technique for use with human infants. *Infant Behavior and Development*, **2**, 135–153.

Teller, D.Y. (1997). First glances: the vision of infants. *Investigative Ophthalmology and Vision Science*, **38**, 2183–2203.

Treue, S. (2003). Visual attention: the where, what, how and why of saliency. *Current Opinion in Neurobiology*, **13**, 428–432.

Wichmann, F.A., Sharpe, L.T., & Gegenfurtner, K.R. (2002). The contributions of color to recognition memory for natural scenes. *Journal of Experimental Psychology: Learning, Memory and Cognition*, **28**, 509–520.

Wilcox, T. (1999). Object individuation: infants' use of shape, size, pattern, and color. *Cognition*, **72**, 125–166.

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