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Achromatic contrast effects in infants: Adults and 4-month-old infants show similar deviations from Wallach's ratio rule

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Abstract

When adults view a disk of light embedded in a higher luminance surround, the perceived lightness of the disk is largely determined by the surround to disk luminance ratio (Wallach's ratio rule). In the present study, both adult and infant subjects were tested with multiple discrete trial procedures in which the surround luminance was decreased between the study and test phases of each trial. Tested with sequential lightness matching, adult subjects showed an approximate ratio rule, with a small but consistent deviation in the direction of a luminance match. Tested with a forced-choice novelty preference technique in combination with a cross-familiarization paradigm, 4-month-old infants showed preference minima that fell closer to the mean adult match than to the ratio rule. This finding suggests that, at least for a relatively simple visual display, 4-month-old infants' looking preferences are governed by an adult-like achromatic contrast system.

Keywords: Infant vision; Wallach's ratio rule; Achromatic contrast; Familiarization; Novelty effects; Cross-familiarization

1. Introduction

Using slide projectors with the projected light beam controlled through an episcotister, Wallach (1948) showed that the perceived lightness of a disk embedded in a higher luminance surround was determined by the surround to disk (S/D) luminance ratio. Two disks appeared equal in lightness when their S/D ratios were the same, even though their absolute luminance values were different. Wallach's ratio rule has been shown to hold to a good first approximation under a wide range of conditions (Sewall & Wooten, 1991).

Although S/D ratios are a powerful determinant of perceived lightness in disk/annulus displays, Wallach's ratio rule is imperfect, and small deviations from ratio behavior have often been reported. These include deviations in the direction of a luminance match (e.g., Arend & Goldstein, 1987; Gilchrist, 1988; Rudd & Arrington, 2001) and in the opposite direction (e.g., Arend & Goldstein, 1987). A variety of experimental parameters including the complexity of the stimulus display (e.g., Jameson & Hurvich, 1961), the use of lightness vs. brightness judgments (e.g., Jacobsen & Gilchrist, 1988), and the use of matching vs. scaling procedures (e.g., Sewall & Wooten, 1991), all influence the exact results (for a general review see Gilchrist et al., 1999).

The purpose of the present series of studies is to begin the study of achromatic contrast and related topics in human infants. In particular, we wished to know whether infants' perception of disks embedded in higher luminance surrounds follows Wallach's ratio rule; and when adult perception deviates from the ratio rule, whether infant perception deviates in a quantitatively similar way.

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A complication arises immediately in that the modern literature on adult achromatic contrast distinguishes between at least two perceptual components in the appearance of achromatic surfaces (e.g., Arend & Goldstein, 1987; Jacobsen & Gilchrist, 1988; Schirillo & Shevel, 1993). *Lightness* is the perceived reflectance, or perceived shade of grey, of a surface. When lightness is under study, the instructions to the subject emphasize judging the shade of gray and sometimes the material properties of the surface (e.g., "imagine that standard and test surfaces are cut from the same paper"). In contrast, *brightness* is the perceived luminance of a surface. When brightness is under study, instructions to the subject emphasize judging the brightness of the relevant surface and ignoring the surround. Depending on conditions, these percepts may diverge entirely or covary tightly (e.g., Sewall & Wooten, 1991).

In the present experiments, adults were instructed to make lightness rather than brightness matches, and we presume that they did so. However, infant subjects cannot be so instructed, and our data provide no direct evidence as to whether the infant looking preferences we measured were controlled by lightness, brightness, or other variables or combinations of variables. We return to this issue briefly in Section 6.

1.1. Novelty preferences and achromatic contrast effects in infants

It is well established in the developmental literature that young infants show novelty effects—looking preferences for novel as opposed to familiar stimuli—in a variety of stimulus domains (e.g., Cohen & Gelber, 1975; Fagan, 1970; Fantz, 1964; Hunter & Ames, 1988; Welch, 1974). In a recent study, we (Chien, Palmer, & Teller, 2003) developed a discrete trial, forced-choice novelty preference (FNP) technique (cf. Civan, Teller, & Palmer, 2005; Teller, 1979), and used it to determine whether novelty effects occur when infants are tested with stimuli varying only in luminance. On each trial, infants were first familiarized with a pair of disks of identical luminance, embedded in a higher luminance surround. They were then tested with two disks, one with the same luminance as the familiarized disks and the other with a different luminance. When a higher luminance disk was used in the familiarization phase, infants preferred a lower luminance disk in the test phase, and vice versa. That is, tested with FNP, infants indeed show consistent novelty preferences with luminance-defined stimuli.

We then used a cross-familiarization paradigm (cf. Chien, 2003; Dannemiller & Hanko, 1987; Slater, Mattock, & Brown, 1990) to study achromatic contrast, by changing the luminance of the surround between familiarization and test phases of each trial. As before, on each trial infants were familiarized with a pair of disks of identical luminance. The surround luminance was then changed, and the infants were tested with two disks, one having a familiar luminance but a novel ratio to the new surround, and the other having a novel luminance but a familiar ratio to the new surround. The infants preferred the novel rather than the familiar ratio, suggesting that it is the novel ratio that produces the novel perception, and that infants' novelty preferences follow a ratio rule to a first approximation. However, since only two disk luminances were studied by Chien et al. (2003), only limited conclusions can be drawn.

In the present experiment we vary the luminance of the test disk more systematically, in order to find the luminance that produces the infants' preference minimum across the change of surround. The logic of the approach is that the infants' varying preferences correspond to varying degrees of perceptual similarity, with the preference maximum revealing the maximum perceptual difference, and the preference minimum revealing the maximal similarity, or identity, between familiarization and test stimuli. Seen in this light, infants' preference minima provide an analog of adult perceptual matches.

This study had two empirical and one methodological goal. In Experiment 1, adult lightness matches were measured under the stimulus conditions that would be used with infants. In Experiment 2, FNP and cross-familiarization were used in combination with multiple test disks, in order to measure infants' looking preference minima under the same stimulus conditions as used with adults. We were particularly interested in whether infants' preference minima would fall at a ratio rule match or at the mean adult lightness match, which was expected to deviate slightly from the ratio rule prediction.

At the methodological level, we wished to see whether FNP, cross-familiarization, and systematic stimulus variations can be used together to define the infants' preference minimum among a set of suprathreshold stimuli. If this approach to infant testing is feasible in practice, it could be broadly useful in studies of many suprathreshold phenomena in infant perception, including the ordering of perceptual similarities and differences (Civan et al., 2005), and studies of perceptual constancies (Dannemiller & Hanko, 1987).

2. Experiment 1: Adult lightness matches

2.1. Experiment 1: Methods

2.1.1. Subjects

Eight adult subjects of ages between 25 and 31 were tested in all three conditions of Experiment 1. Subjects' informed consent was obtained before testing. Those subjects who were not laboratory personnel received subject fees upon completion of the experiment. All subjects had normal or corrected-to-normal vision by self-report.

2.1.2. Apparatus and stimuli

As shown in Fig. 1, the stimuli in these experiments were pairs of disks embedded in a higher luminance surround. The surround filled the screen of a 19″ high-resolution black and white monitor (Apple Twopage, 75 Hz, non-interlaced, 1152×640 pixels), controlled by a Mac IIci computer. A standard gamma correction was performed using a Photo Research photometer (PR650). The CIE chromaticity coordinates of the disks and surrounds were $x = 0.331$, $y = 0.337$. The disks were 5.6 cm in diameter, or 8.5° at the viewing distance of 38 cm. The center-to-center distance between the two disks was 20.5 cm, or 35°.

In parallel to the infant experiment (Experiment 2), each trial consisted of a study (familiarization) phase and a test phase, as shown in Fig. 1. In the study phase, the luminances of the surround and disks were 60 and 10 cd/m^2, respectively, for a surround to disk ratio of 6. In the test phase, the surround luminance was 19 cd/m^2. Thus, the disk predicted to match the study disk by Wallach's ratio rule was $19/6 = 3.17$ cd/m^2. Nine test disk luminance levels—2.1, 2.4, 2.7, 3.3, 3.9, 4.5, 5.1, 5.7, and 6.3 cd/m^2—were used with the method of constant stimuli. The luminances of the to-be-ignored disks in the *Paired-with-LUM-disk* and the *Paired-with-BLK-disk* conditions (see below) were 10 cd/m^2 (the same as the study disk) and 0.37 cd/m^2 (the black level of the monitor), respectively.

The study display was presented for about three seconds. In order to avoid startling the infants or providing them with temporal cues, at the transition from study to test display the test disks were slowly rendered from the bottom up; the transition took about 2 s. The test display remained on until the subject made a judgment, typically about 2–5 s. If the subject did not respond within 10 s the trial was aborted.

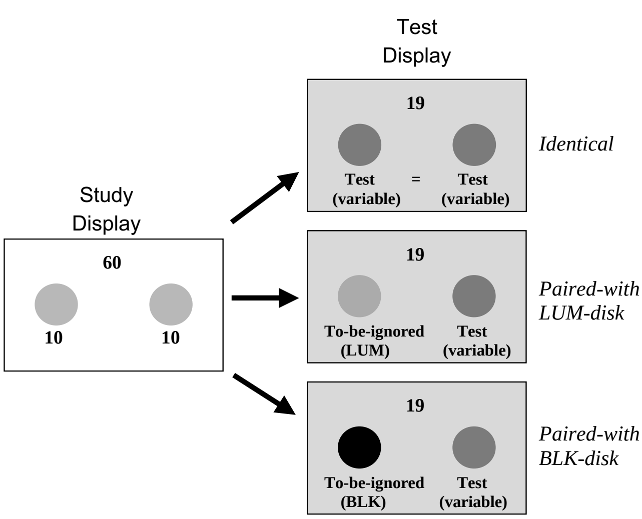

Fig. 1. The stimulus displays used for testing adult subjects in Experiment 1. See text for details.

2.1.3. Experimental design

The design of Experiment 1 is also shown schematically in Fig. 1. In order to mimic infant testing conditions, adult subjects performed a sequential lightness matching task between the study and test displays. When the study display appeared on each trial, the subject's task was to remember the lightness (shade of gray) of the two study disks. When the test display appeared, the task was to judge whether the test disks looked lighter or darker than the study disks.

Adults were tested with three conditions. In the main, or *Identical* condition (Fig 1, right, top panel), the test display was composed of two identical gray test disks embedded in the 19 cd/m^2 surround. The remaining two test conditions were designed as controls, to mimic the details of the two most extreme stimulus conditions used with infants. That is, in the infant experiments, of necessity two non-matching test disks were included in the test display on each trial. Therefore, adults were also tested with two non-matching test disks, but were instructed to ignore one of them. In the *Paired-with-LUM-Disk* condition (middle panel; cf. Experiment 2A), one of the test disks had the same luminance as the original study disk (although it appeared much lighter within the 19 cd/m^2 surround). Subjects were instructed to ignore it and judge the lightness of the other disk. In the *Paired-with-BLK-disk* condition (bottom panel; cf. Experiment 2B), one of the test disks was black, and the subjects were again instructed to ignore it and judge the lightness of the other disk. Although these conditions were important controls, we anticipated that the luminance of the to-be-ignored disks would have little influence on the adult matches, and this proved to be the case.

2.1.4. Procedure

The subject was seated 38 cm in front of the computer monitor, and instructed to keep his or her gaze on the center of the screen between trials. The subject pressed a key to initiate a trial at his or her own pace. Free viewing was allowed during trials.

Instructions were given before each condition. For example, the instruction for the *Paired-with-LUM-disk* condition was as follows: "... in the study phase you will see two identical gray disks. Your task is to memorize the lightness or shade of gray of the disks. In the test phase you will see two disks. One of them is always constant and appears much lighter than the disks you see in the study phase. The light disk can appear either on the left or on the right side of the display. Your task is to ignore it and compare the lightness of the other disk to the lightness of the study disks you have memorized".

The locations of the two disks was randomized from trial to trial, and subjects were instructed to proceed slowly to avoid judging the wrong disk.

2.1.5. Data analysis

Individual subjects were tested with 210–270 trials in each condition, yielding 24–30 trials per point on the individual psychometric functions. The responses were tabulated into the proportion "lighter" responses for each test disk luminance. Probit analysis, with the upper and lower asymptotes of the cumulative normal curve fixed at 0% and 100%, respectively, was used to generate the best-fit cumulative normal curve for each individual data set. The test disk luminance that yielded 50% "lighter" trials was taken as the adult match.

3. Experiment 1: Results

Individual psychometric functions from two representative subjects in Experiment 1 are shown in Fig. 2. The overall shapes and slopes of the psychometric functions for the three conditions were very similar for each subject, and as expected, there were no consistent differences in match values among the three conditions.

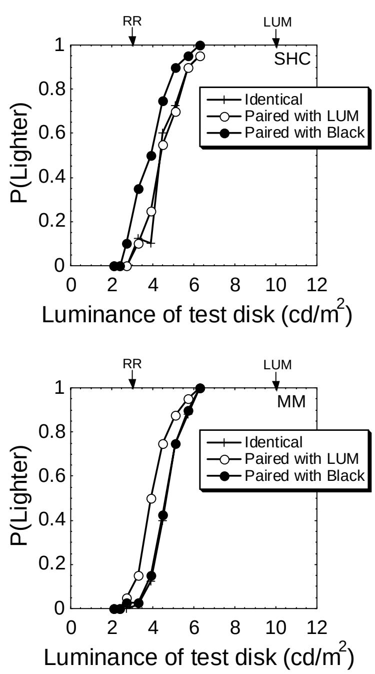

Fig. 2. Psychometric functions for two representative adult subjects in Experiment 1. The abscissa shows the luminance of the variable test disk. The ordinate shows the proportion of trials on which the variable test disk was judged to appear lighter than the disks in the study display. The arrows on the upper abscissa indicate the test disk luminances that correspond to a ratio rule match (RR) and a luminance match (LUM). The disk luminance at which $P(\text{Lighter}) = 0.5$ represents the lightness match. In each panel, the three curves represent data for the three experimental conditions. The data are similar in all three conditions, and deviate from the ratio rule match (RR) in the direction of the luminance match.

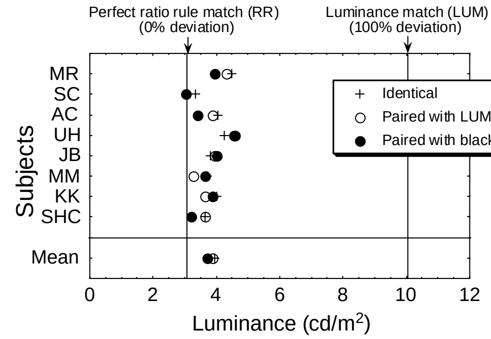

Fig. 3. Individual adult matches for all subjects in Experiment 1. The abscissa shows the luminance of the test disk required for a lightness match. Initials of individual subjects are displayed along the ordinate. Group means are shown at the bottom of the figure. The left vertical line represents the ratio rule match (0% deviation), and the right vertical line represents the luminance match (100% deviation). As in Fig. 2 the adult matches fall close to the ratio rule prediction, but are displaced slightly toward the luminance match prediction.

The individual matches for all subjects are shown in Fig. 3. The lightness matches from the three conditions were similar for all subjects. All matches fell much closer to the ratio rule than to the luminance match.

The group means of the adult matches are shown at the bottom of Fig. 3. The mean values for the *Identical*, *Paired-with-LUM-disk*, and *Paired-with-BLK-disk* conditions were 3.94 ± 0.13, 3.88 ± 0.16, and 3.70 ± 0.17 cd/m^2, respectively. The mean deviations from the ratio rule (3.17 cd/m^2) were 11%, 10%, and 8%, respectively, in the direction towards the luminance match. Based on these data, a value of 4.0 cd/m^2 was used as the adult match value (the AM condition) in Experiment 2.[1]

4. Experiment 2: Infants' preference minima

4.1. Experiment 2: Methods

4.1.1. Subjects

Sixteen-week-old infant subjects were recruited from the Infant Studies Subject Pool at the University of Washington. All infants were born within 14 days of

[1] In our initial set of experiments, a surround luminance of 36 cd/m^2 was used. To determine the AM value for infant Experiment 2A, an *Identical* condition with this surround luminance was initiated. Three initial adult subjects were tested, yielding a mean adult match value of 2.8 cd/m^2. This value was used as the AM value in Experiment 2A. The infant experiment was completed, but unfortunately no additional adult subjects could be tested due to equipment failure. The mean adult match showed a slightly larger percent of deviation from the ratio rule (18%) than the mean adult matches in Experiment 1. This difference is unexplained, but probably stems from the small sample of adults tested in the initial experiment.

their due dates, and had no health problem or family history of color blindness by parent's report. They were tested for 3 or 4 sessions within a one-week time span, between the 107th and 117th postnatal days. Informed consent was obtained from the parents on the first day of testing.

Four experiments were run (Experiments 2A–D). Each infant was tested in a single experiment. Data sets were excluded if the infant produced fewer than a total of 100 trials within the test week. Eleven infants were excluded due to insufficient number of trials (8), sickness (2) or program error (1). The numbers of infants retained in the final data set (and the total number tested) were 14(17), 5(8), 16(20), and 12(13) in Experiments 2A–D, respectively. Experiment 2B was terminated early when a ceiling effect became apparent (see below).

A mean of 210 trials per infant was obtained in the retained data sets. This number of trials yielded a mean of 52 trials per test pair in Experiments 2A and 2B (with four luminances of the comparison stimulus), and 70 trials per test pair in Experiments 2C and 2D (with three luminances of the comparison stimulus).

4.1.2. Experimental design and stimuli

The same video apparatus used with adults was used with infant subjects. As with the adults, the infants were tested with two 8.5° disks, separated center-to-center by 35°, at a viewing distance of 38 cm. The stimulus displays used for testing infants are shown schematically in Fig. 4.

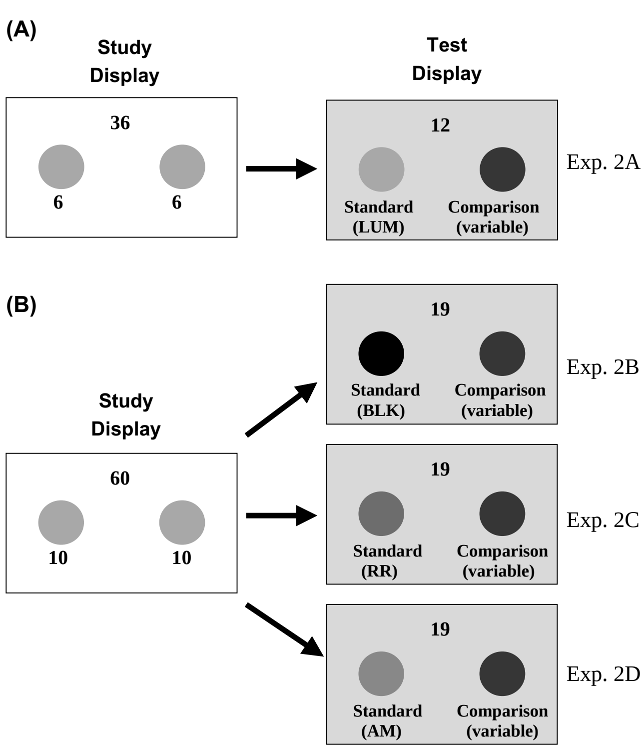

Fig. 4. The stimulus displays used for testing infant subjects in Experiments 2A (Panel A) and 2B–D (Panel B). See text for details.

As with adults, the two disks of the test display were rendered slowly from the bottom up over a period of about 2 s.

Infants were tested with a cross-familiarization paradigm, in which the luminance of the surround was changed between study and test phases of each trial. In the study phase of each trial, the infant was presented with two disks of identical luminance embedded in a higher luminance surround. In the test phase of each trial, the luminance of the surround was reduced by a factor of three, and the study disks were replaced with two test disks of different luminances. In each case, one of the test disks was a *standard disk* whose luminance was fixed within an experiment, but varied among Experiments 2A–D. The other was a *comparison disk* whose luminance varied from trial to trial. The goal of each experiment was to determine which comparison disk produced the infant's preference minimum. Thus, Experiments 2A–D can be considered four replications of a preference minimum experiment, using four separate standard disks.

The luminances of the various stimulus components varied across experiments. In the *study phase* of Experiment 2A the surround luminance was 36 cd/m^2 and the disk luminance was 6 cd/m^2. In the study phase of Experiments 2B–D the surround luminance was 60 cd/m^2 and the disk luminance was 10 cd/m^2. The surround/disk (S/D) ratio was six in both cases. In the *test phase* of Experiment 2A the surround luminance was 12 cd/m^2, whereas in Experiments 2B–D it was 19 cd/m^2, for a decrease of surround luminance of a factor of about three in both cases.[2]

In the *test phase* of each experiment, a fixed standard stimulus was paired with each of several comparison stimuli. In each of the four experiments a different standard stimulus was used. The luminances of these standard stimuli were 6, 0.37, 3.2, and 4.0 cd/m^2 in Experiments 2A–D, respectively. The reasons for choosing these four standard stimuli were as follows. In Experiment 2A (*LUM-disk-as-standard*), the standard disk was fixed at 6 cd/m^2, the luminance of the disks in the study display (LUM). In Experiment 2B (*BLK-disk-as-standard*), the standard disk was fixed at the black level, 0.37 cd/m^2 (BLK). These two standard disks were chosen to appear either much lighter or much darker than the study disks and all comparison disks presented against the test surround, and therefore were intended to appear distinctly novel (or non-matching) to the infants on all trials. If these standard disks indeed

[2] The change in luminance values between Experiment 2A and 2B–D was due to the failure of the original video monitor, plus our decision to take advantage of the higher luminance values available on the new monitor. Since it is unlikely that these small differences in overall luminance affected the outcome of the experiments, all four experiments are treated together.

appeared novel, the infants should prefer them to all of the comparison disks at a high preference level. Moreover, the comparison disk that appeared most similar to the study disks should compete least well for the infant's attention, and yield the infant's preference minimum. In Experiments 2C (*RR-disk-as-standard*) and 2D (*AM-disk-as-standard*), the standard disks were chosen to include a direct comparison between the ratio rule match (RR) and the adult lightness match (AM) within the stimulus set.

For each standard stimulus, a set of three or four *comparison stimuli* was selected from the following five options. The lowest luminance comparison stimulus (DRR) had a luminance slightly lower than the ratio rule match, and appeared darker than the ratio rule match. The second comparison stimulus was a ratio rule match (RR), which maintained the same 6:1 ratio used in the study display. The third was the adult lightness match (AM) obtained from the corresponding *Identical* condition of Experiment 1. The fourth (LAM) had a luminance slightly higher than the adult match, and appeared lighter than the adult match. The fifth was a luminance match to the disks used in the study phase of the experiment (LUM).

For Experiment 2A (*Lum-disk-as-standard*), the luminance values of the four comparison stimuli DRR, RR, AM, and LAM were 1.0, 2.0, 2.8, and 4.8, respectively. For Experiment 2B (*BLK-disk-as-standard*), the luminance values of the four comparison stimuli DRR, RR, LAM, and LUM were 1.0, 3.2, 4.0, and 6.9, respectively. In Experiment 2C (*RR-disk-as-standard*), the luminance values of the three comparison stimuli DRR, AM, and LUM were 1.0, 4.0, and 10 cd/m^2, respectively. In Experiment 2D (*AM-disk-as-standard*), the luminance values of the three comparison stimuli DRR, RR, and LUM were 1.0, 3.2, and 10 cd/m^2, respectively. The stimuli used in each experiment are indicated on the abscissae of Fig. 5 (below).

4.1.3. Procedure

Infant subjects were held by an adult observer in front of the video display at a viewing distance of 38 cm. The observer could not see the computer screen. She viewed the infant's face on an auxiliary video monitor displaying real-time images via a hidden camera system.

The timing of the experiment was under the control of the observer. In the study phase, the infant was allowed to view the video screen for about 3 s (10 s on the very first trial). At the end of this time period, at a moment at which the infant was judged to be attentive to the screen, the observer triggered presentation of

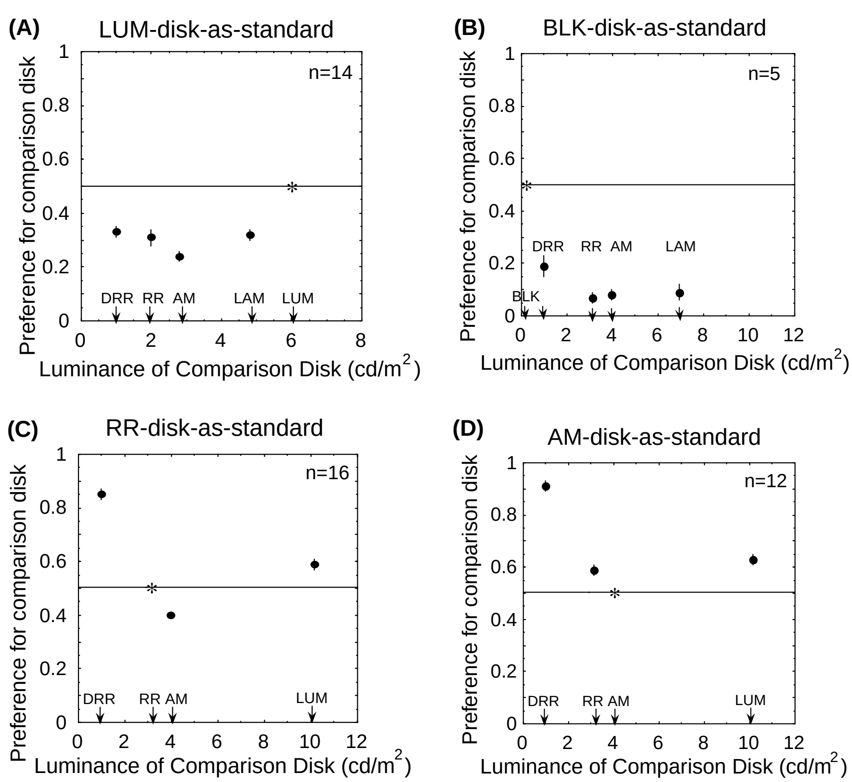

Fig. 5. The results of Experiment 2. Panels A–D show the results of Experiments 2A–D, respectively. The abscissae show the luminances of the comparison disks. The ordinates show the proportion of trials on which the infant was judged to prefer the comparison disk to the standard disk. In each panel, the asterisk lies above the luminance of the standard disk. In all cases, the infants' preference minima fall closer to AM than to RR. The minimum is statistically reliable in Experiments 2A, C, and D.

the test display. The duration of the test phase of each trial was unlimited, but in practice lasted for 2–5 s. The observer's response triggered the next trial of the experiment, after an intertrial interval of about 1 s.

During the test phase of each trial, the observer's task was to integrate all possible infant looking cues (e.g., the direction of the first look, the duration of fixation to each side, the number of looks to each side, etc) to make a forced-choice judgment of the side of the display at which the infant preferred to look. Two well-trained observers were involved in data collection. One observer who was blind to the purpose of the experiment collected the majority of the infant data (Experiments 2A–C, and part of 2D), and the other observer who was the first author collected the remaining data in Experiment 2D.

4.1.4. Data analysis

Preference values were averaged across infants. An arcsin transformation was used to increase the homogeneity of variances contributed by individual subjects. Differences between individual pairs of preference values near the preference minimum were evaluated with *t*-tests.

5. Experiment 2: Results

The results of Experiment 2 are presented in Fig. 5. The results of Experiment 2A, the *LUM-disk-as-standard* condition, are shown in panel A. The mean preferences for the DRR, RR, AM, and LAM disks were 0.33 ± 0.02, 0.31 ± 0.03, 0.24 ± 0.02, and 0.32 ± 0.02, respectively ($N = 14$). There were two main findings. First, as expected, the preferences for all four comparison disks were below 0.5, meaning that the LUM disk (the standard disk) was seen as the novel stimulus in all pairs. This result is consistent with the main findings from Experiment 2 of Chien et al. (2003). Second, the preference for AM was reliably below that for all other test stimuli including RR ($t(13) = 2.1$, $p < 0.05$ between RR and AM). That is, the infants' preference minimum occurred at the adult match value AM.

The results for Experiment 2B, the *BLK-disk-as-standard* condition, are shown in panel B. The mean preferences for the DRR, RR, AM, and LAM disks were 0.19 ± 0.04, 0.07 ± 0.02, 0.08 ± 0.02, and 0.09 ± 0.03, respectively ($N = 5$). Again as expected, the black standard disk was preferred to all of the comparison disks, and again the lowest preference occurred at the adult match AM. However, the data showed a floor effect. The standard black disk was so strongly preferred that there were no reliable differences in preference among the RR, AM, and LAM stimuli.

The results for Experiment 2C, the *RR-disk-as-standard* condition, are shown in panel C. The mean preferences for the DRR, AM, and LUM disks were 0.85 0.02, 0.40 ± 0.01, and 0.60 ± 0.02, respectively ($N = 16$). The infants preferred both DRR and LUM when paired with RR, suggesting that DRR and LUM were seen as perceptually more novel than RR. Moreover, in the critical RR vs. AM pair, the preference for AM was reliably below 0.5 ($t(15) = 7.7$, $p < 0.001$). In other words, infants showed a small but reliable preference for RR over AM, consistent with a preference minimum at AM.

The results for Experiment 2D, the *AM-disk-as-standard* condition, are shown in panel D. The mean preferences for the DRR, RR, and LUM disks were 0.91 ± 0.01, 0.59 ± 0.01, and 0.64 ± 0.02, respectively ($N = 12$). Again, infants preferred DRR and LUM when paired with AM. Most importantly, in the critical RR vs. AM pair, the preference for RR was significantly above 0.5 ($t(11) = 6.8$, $p < 0.001$). This result was also consistent with a preference minimum at AM.

Data from individual subjects support the same conclusion. In Experiment 2A, 9 out of 14 individual infants had preference minima at AM, whereas 4 of 14 had preference minima at the ratio rule match RR. In Experiments 2C and 2D, all infants tested (16 out of 16 and 12 out of 12, respectively) had preference minima at AM.

Statistically, the data from the FNP/cross-familiarization paradigm are remarkably well behaved. The standard error of the group mean depends on the true variability among infants as well as the sample size. However, in the present experiment, groups of 5–16 subjects consistently gave standard errors between 2% and 4%, suggesting that individual differences are small. Thus, under the conditions of the present experiment, it was possible to establish the statistical significance of mean differences in preference on the order of 5%.

6. Discussion

In the present work, we have tested both infant and adult subjects with highly similar disk/surround stimuli of the kind classically used to study simultaneous achromatic contrast. Tested with a sequential lightness matching technique, adults adhered approximately to Wallach's ratio rule, but showed a small but consistent deviation, with their lightness matches being drawn about 10% of the way from the ratio rule match toward the luminance match. Tested with and a FNP/cross-familiarization technique, 4-month-old infants' preference minima fell at the mean adult match, and not at the ratio rule match. Thus, both adults' and infants' performances were governed by the same inexact ratio rule. This correspondence suggests that for the simple visual displays used here, infants' and adults' performance are governed by similar achromatic processing systems.

Does the infants' preference minimum correspond to a lightness match, a brightness match, or some other perceptual variable or combination of variables? Unfortunately our data do not address this question. In designing this study, our goal was to use conditions in which achromatic contrast effects are large in adults, and to develop a test procedure that could define the correspondence of adult matches and infant preference minima, rather than to distinguish among these more sophisticated options. Indeed, under the S/D ratio conditions of this study, lightness and brightness judgments are similar in adults (e.g., Sewall & Wooten, 1991). Therefore, we expect that in adults both judgments would be similar under our conditions, and our conditions are therefore poorly suited to distinguishing among these options.

In future studies it would be interesting to explore a stimulus regime in which there are major differences among lightness and brightness matches in adult subjects. Such stimuli should allow one to distinguish the correspondence of infant preference minima to one as opposed to the other of the adult perceptual matches (cf. Teller, Pereverzeva, & Civan, 2003).

Acknowledgments

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