Luminance noise as a novel approach for measuring contrast sensitivity within the magnocellular and parvocellular pathways

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This study evaluated the extent to which different types of luminance noise can be used to target selectively the inferred magnocellular (MC) and parvocellular (PC) visual pathways. Letter contrast sensitivity (CS) was measured for three visually normal subjects for letters of different size (0.8°–5.3°) under established paradigms intended to target the MC pathway (*steady-pedestal paradigm*) and PC pathway (*pulsed-pedestal paradigm*). Results obtained under these paradigms were compared to those obtained in *asynchronous static noise* (a field of unchanging luminance noise) and *asynchronous dynamic noise* (a field of randomly changing luminance noise). CS was measured for letters that were high- and low-pass filtered using a range of filter cutoffs to quantify the object frequency information (cycles per letter) mediating letter identification, which was used as an index of the pathway mediating CS. A follow-up experiment was performed to determine the range of letter duration over which MC and PC pathway CS can be targeted. Analysis of variance indicated that the object frequencies measured under the static noise and steady-pedestal paradigms did not differ significantly ($p \geq 0.065$), but differed considerably from those measured under the dynamic noise (both $p < 0.001$) and pulsed-pedestal (both $p < 0.001$) paradigms. The object frequencies mediating letter identification increased as duration increased under the steady-pedestal paradigm, but were independent of target duration (50–800 ms) under the pulsed-pedestal paradigm, in static noise, and in dynamic noise. These data suggest that the spatiotemporal characteristics of noise can be manipulated to target the inferred MC (static noise) and PC (dynamic noise) pathways. The results also suggest that CS within these pathways can be measured at long stimulus durations, which has potential importance in the design of future clinical CS tests.

Introduction

Contrast sensitivity (CS) is an important measure of visual function that is associated with the ability to perform tasks of daily living (Fletcher & Schuchard, 2006; Mones & Rubin, 2005; Szlyk et al., 2001). CS is most commonly assessed in the clinic using letter charts, such as the Pelli-Robson letter CS chart (Pelli, Robson, & Wilkins, 1988), and CS assessed with this chart has been shown to be reduced in patients with ocular disorders including glaucoma (Hawkins, Szlyk, Ardickas, Alexander, & Wilensky, 2003), diabetic retinopathy (Stavrou & Wood, 2003), and retinitis pigmentosa (Alexander, Derlacki, & Fishman, 1995). Although the Pelli-Robson CS chart is useful for routine CS measurement, the chart provides relatively little insight into which visual pathways are affected by retina and optic nerve dysfunction. Specifically, two post-receptor pathways largely mediate CS: the magnocellular (MC) and parvocellular (PC) pathways, and these two pathways have different response properties (Kaplan, Lee, & Shapley, 1990; Lee, 1996; Merigan & Maunsell, 1993). For example, at the level of the retina and lateral geniculate nucleus (LGN), the MC pathway

is characterized by high contrast gain, but response saturation is observed at relatively low levels of contrast. In comparison, the PC pathway has an approximately linear contrast response function and relatively minimal response saturation is observed, even at high contrast levels. In general, the MC pathway is associated with the detection and discrimination of briefly presented, achromatic patterns of low contrast, whereas the PC pathway is important for high spatial frequency resolution and chromatic processing (for review, see Lennie, 1993).

One possible approach to unraveling deficits that may be pathway specific is to design test conditions and stimuli that selectively target CS within the MC and PC pathways. A common technique has been to use the *steady-pedestal* and *pulsed-pedestal* paradigms introduced by Pokorny and Smith (1997) that were later modified by Leonova, Pokorny and Smith (2003). The steady-pedestal paradigm, which involves the brief presentation of a test target (typically 50 ms or less) against a steady luminance pedestal, is thought to favor the MC pathway, at least for low spatial frequency stimuli. In contrast, the pulsed-pedestal paradigm, which involves the brief presentation of a test target and luminance pedestal together, is thought to favor the PC pathway. The logic underlying the use of these paradigms to assess MC and PC pathway function is reviewed in detail elsewhere (Pokorny, 2011). In brief, the pedestal paradigms were designed to differentiate MC and PC pathway function based on their differences in contrast responsivity. Psychophysical contrast discrimination thresholds were compared with typical values from primate physiology to determine the extent to which they match the contrast gain signatures of the MC and PC pathways (Pokorny, 2011). The steady-pedestal paradigm is thought to favor the MC pathway because an achromatic test target is presented only briefly, whereas the pulsed-pedestal paradigm is thought to favor the PC pathway because the abrupt onset of the luminance pedestal saturates the MC pathway. Previous work using these paradigms has shown spatial CS losses under both the steady- and pulsed-pedestal paradigms in patients who have retinitis pigmentosa (Alexander, Barnes, Fishman, Pokorny, & Smith, 2004a), melanoma-associated retinopathy (Alexander, Barnes, Fishman, Pokorny, & Smith, 2004b), X-linked retinoschisis (Alexander, Barnes, & Fishman, 2005), glaucoma (McKendrick, Sampson, Walland, & Badcock, 2007), amblyopia (Zele, Pokorny, Lee, & Ireland, 2007), and diabetes (Gualtieri et al., 2011). Previous work has also shown selective deficits in CS discrimination only under the steady-pedestal paradigm in patients who have retinitis pigmentosa (Alexander, Pokorny, Smith, Fishman, & Barnes, 2001) and optic neuritis (Cao et al., 2011).

In addition to evaluating CS losses within the MC and PC pathways in patient populations, the steady- and pulsed-pedestal paradigms have been used to study the spatial frequency information mediating letter CS. One consideration in using letter optotypes, such as those of the Pelli-Robson CS chart, is that their Fourier spectra contain a broad range of object frequencies, designated in cycles per letter (Parish & Sperling, 1991; Poder, 2003). The relationship between object frequency and CS can be complex and dependent on factors including letter size and the visual pathway mediating CS. For example, previous studies using the Landolt C (Alexander & McAnany, 2010; McAnany & Alexander, 2008), tumbling E (Alexander & McAnany, 2010), and letters from the Sloan set (Alexander, Xie, & Derlacki, 1994; Hall, Wang, Bhagat, & McAnany, 2014; Majaj, Pelli, Kurshan, & Palomares, 2002; Oruc & Landy, 2009) have shown that the band of object frequencies that mediates letter CS increases as letter size increases. Furthermore, for large letters, there is a marked difference in the object frequencies mediating CS measured under the steady-pedestal (inferred MC pathway) and pulsed-pedestal (inferred PC pathway) paradigms. Specifically, previous studies have shown that for a letter size equivalent to that of the Pelli-Robson chart, the object frequencies mediating CS for the Landolt C can be over two times higher for pulsed-pedestal measurements compared to steady-pedestal measurements (Alexander & McAnany, 2010; McAnany & Alexander, 2008).

Although the steady- and pulsed-pedestal paradigms have been useful for studying MC and PC pathway function in visually normal individuals and patient populations, one limitation of these paradigms is that a brief stimulus exposure duration is necessary to target the pathways individually. That is, as stimulus duration is increased, the difference in CS measured under the two paradigms becomes less; for durations greater than approximately 250 ms, CS is approximately equivalent for measurements performed under the two paradigms, suggesting that the same pathway likely mediates CS (Pokorny & Smith, 1997). Thus, the pathway mediating object frequency for letter identification cannot be controlled using the steady- and pulsed-pedestal paradigms for the extended exposure durations that are used clinically. Furthermore, patients who have marked CS losses as assessed with the Pelli-Robson CS chart (unlimited exposure duration) may have unmeasurably low CS for the short exposure duration required for the steady- and pulsed-pedestal paradigms.

In the present study, an alternative approach for assessing MC and PC pathway CS was examined that may permit measurements to be made across a broad range of durations. In this study, letter targets were presented in static and dynamic white luminance noise. This approach was selected because previous work has

shown fundamentally different characteristics of contrast sensitivity functions (CSF; contrast sensitivity across spatial frequency or letter size), as well as differences in temporal integration, obtained in *asynchronous static noise* and *asynchronous dynamic noise* (Manahilov, Calvert, & Simpson, 2003; McAnany & Alexander, 2009, 2010). Based on differences in spatiotemporal CS, it was suggested that asynchronous static noise may be useful for targeting the transient-like visual mechanism (MC pathway), whereas asynchronous dynamic noise may be useful for targeting the sustained-like visual mechanism (PC pathway; Manahilov et al., 2003; McAnany & Alexander, 2009, 2010). Thus, in the present study, CS was measured for letters presented in asynchronous static and dynamic noise, and these measurements were compared to those obtained under the steady- and pulsed-paradigms. This permitted a direct comparison of the two approaches (i.e., noise vs. steady- and pulsed-pedestal paradigms) and a determination of the extent to which noise can be used to assess MC and PC pathway CS.

Methods

Observers

Four subjects (S1, S2, S3, S4) who were 27, 27, 25, and 36 years of age, respectively, participated in the study. S1 and S4 were practiced psychophysical observers, whereas S2 and S3 had not participated in previous psychophysical experiments. S1, S2, and S3 participated in the primary experiment that compared letter CS measurements in noise and under the steady- and pulsed-pedestal paradigms, whereas S1, S2, and S4 participated in a follow-up experiment that examined the effects of target duration under the four paradigms. All subjects had normal best-corrected visual acuity assessed with the ETDRS distance visual acuity chart, normal CS assessed with the Pelli-Robson CS chart, and no history of ocular disease. The experiments were approved by an institutional review board at the University of Illinois at Chicago, and the study adhered to the tenets of the Declaration of Helsinki.

Apparatus, stimuli, and procedure

Apparatus

All stimuli were generated using a PC-controlled Cambridge Research Systems ViSaGe stimulus generator (Cambridge Research Systems, Ltd., Rochester, Kent, UK) and were displayed on a Mitsubishi Diamond Pro (2070) CRT monitor (Mitsubishi Electric Corp., Tokyo, Japan) with a screen resolution of 1024 × 768 and a 100-Hz refresh rate. The monitor, which was the only source of illumination in the room, was viewed monocularly through a phoropter with the observer's best refractive correction. The luminance values used to generate the stimuli were determined by the ViSaGe linearized look-up table, which were verified by measurements made with a Minolta LS-110 photometer (Konica Minolta, Tokyo, Japan).

Letter targets

Test stimuli consisted of letters from the Sloan set (C, D, H, K, N, O, R, S, V, Z) that were constructed according to published guidelines (National Research Council Committee on Vision, 1980). Previous work has shown that these 10 letters are similarly visible for measurements made in the presence and absence of luminance noise (Hall, Wang, & McAnany, 2015). In the primary experiment, the letter size ranged from 1.0 to 1.8 log MAR in 0.2 log unit steps; this range is equivalent to a total letter width of 0.8°–5.3°. The Sloan letters had positive contrast (letter luminance was greater than background luminance). As discussed below, the letters were either unfiltered or spatially high- or low-pass filtered with a set of two-dimensional Gaussian filters. The frequency cutoffs of the 2-dimensional Gaussian filters ranged from 0.9–21.0 cycles per letter in 10 steps spaced approximately 0.15 log units apart. The filter was applied by convolution with the letter. For the unfiltered letters, contrast (C) was defined as Weber contrast: $C = (L_L - L_B)/L_B$, where L_L is the luminance of the letter and L_B is the background luminance. A relative definition of contrast was used to characterize the high- and low-pass filtered letters, as in previous studies (Chung, Legge, & Tjan, 2002; McAnany & Alexander, 2008, 2010), because the contrast of complex images is difficult to define (Peli, 1990). That is, when the contrast of the original unfiltered letter was 1.0, the filtered image was assigned a relative contrast of 1.0 without rescaling.

Steady- and pulsed-pedestal paradigms

Under the steady-pedestal paradigm, which was used to target the MC pathway, a letter was selected at random and presented against a steady 50 cd/m² luminance pedestal (Figure 1, top). Under the pulsed-pedestal paradigm, which is used to target the PC pathway, the subject first adapted to a 25 cd/m² adapting field and the letter and luminance pedestal (50 cd/m²) were presented simultaneously (Figure 1, bottom). This creates a large, brief change in luminance that saturates the sensitive MC pathway, leaving the PC pathway to mediate CS (Leonova et al., 2003; Pokorny, 2011).
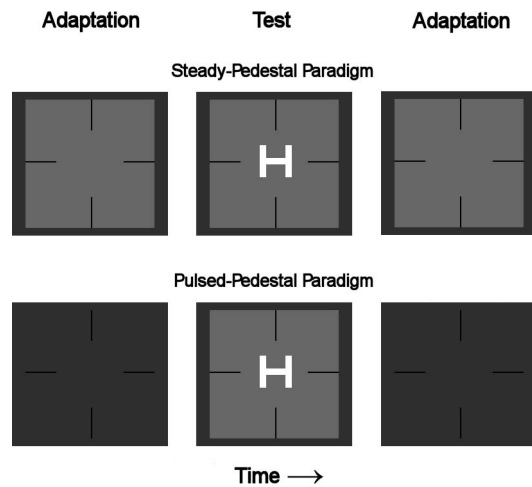
Figure 1. Steady- and pulsed-pedestal paradigms. Under the steady-pedestal paradigm (top), a letter target was presented against a constant luminance pedestal. Under the pulsed-pedestal paradigm (bottom), a letter target and luminance pedestal are presented simultaneously.

Noise paradigms

A letter from the Sloan set was selected at random and presented in either a static or dynamic noise field that consisted of independently generated square checks with luminances drawn randomly from a uniform distribution (see Figure 2). The root mean square (rms) contrast of the noise was 0.18 and the mean luminance of the noise field was 50 cd/m^2. The noise field covered an area that was approximately 1.5 times larger than the letter, and the size of the noise checks was scaled with letter size such that there were always 15 noise checks per letter. Scaling was performed to ensure that a constant signal-to-noise ratio (SNR) was maintained across different letter sizes. The value of 6 checks per letter cycle used in the present study is consistent with that used by others (e.g., Pelli, Levi, & Chung, 2004) and exceeds the minimum number of checks per cycle needed to effectively produce white noise at all letter sizes (Kukkonen, Rovamo, & Nasanen, 1995). Static noise consisted of an unchanging field of noise, whereas dynamic noise consisted of a noise field that changed every 10 ms (similar to television "snow"). The letter was presented asynchronously with the noise field, such that the noise field preceded and followed the letter target by 100 ms. For the primary experiment, the letter duration was 50 ms, whereas the letter duration ranged from 50 to 800 ms in the follow-up experiment that evaluated the effect of target duration.

Procedure

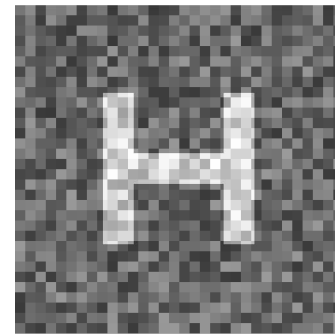The same general procedure was used for each of the four paradigms in both experiments. The start of each

Figure 2. Example letter (H) presented in white luminance noise.

stimulus presentation was signaled by a brief warning tone. For each trial, a single letter was selected at random from the Sloan set and presented. The observer's task was to identify the letter verbally, which was entered by the experimenter. No feedback was given and only letters from the Sloan set were accepted as valid responses. Contrast threshold for letter identification was measured using a 10-alternative forced-choice staircase procedure. An initial estimate of threshold was obtained by presenting a letter at a suprathreshold contrast level and then decreasing the contrast by 0.3 log units until an incorrect response was recorded. After this initial search, log contrast threshold was determined using a two-down, one-up decision rule, which provides an estimate of the 76% correct point on a psychometric function (Garcia-Perez, 1998). Each staircase continued until 16 reversals had occurred, and the geomean of the last 6 reversals was taken as contrast threshold. Excluding the initial search, the staircase length was typically 35–40 trials, which produced stable measurements. For each 1-hr test session, a letter size, paradigm (static noise, dynamic noise, steady-pedestal, pulsed-pedestal), and duration were selected pseudorandomly for testing. All cutoff object frequencies for both high-pass and low-pass filtered letters were evaluated in a random order within a session. For the primary experiment, each subject completed 20 test sessions, whereas each subject completed 16 test sessions for the follow-up experiment.

Derivation of the object frequencies mediating letter identification

The object frequency information mediating letter identification was derived and used as an index of the visual pathway mediating letter CS. Object frequency, rather than CS, was used because it is difficult to infer the pathway mediating CS from measures of CS alone, as CS depends strongly on stimulus parameters such as noise power, stimulus duration, and pedestal luminance. Furthermore, previous work has shown that different object frequencies can mediate letter CS under
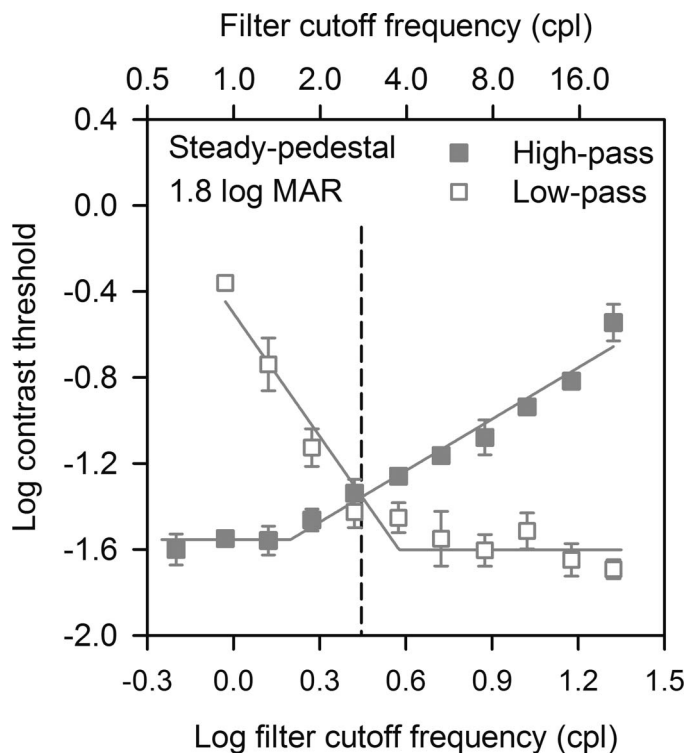
Figure 3. Derivation of center frequency. Mean log contrast threshold ($\pm$ *SEM*) for S1–S3 is plotted as a function of log filter cutoff. Data were obtained using a 1.8 log MAR (5.3°) letter under the steady-pedestal paradigm. The solid lines are two-limbed fits to the data, as described in the text. The vertical dashed line marks the crossing point, which was used as the measure of the object frequency mediating letter identification.

conditions designed to target the MC and PC pathways (Alexander & McAnany, 2010; McAnany & Alexander, 2008), permitting object frequency to be used as an index of the pathway mediating CS.

A standard approach used previously (Alexander & McAnany, 2010; Anderson & Thibos, 1999; McAnany & Alexander, 2008) was used to derive the object frequency information mediating letter identification. First, letter contrast threshold was measured for each high-pass (Figure 3; filled squares) and low-pass (Figure 3; open squares) filtered letter. Each data point in Figure 3 represents the mean contrast threshold value for subjects S1–S3 and the error bars are ± 1 standard error of the mean (*SEM*). These data were obtained under the steady-pedestal paradigm with the largest letter size tested (1.8 log MAR; approximately 5.3°). The leftmost data point (filled square) and rightmost data point (open square) represent contrast threshold for letters that were minimally filtered. The other data points represent the effect of successively changing the cutoff frequency of the filter to remove either low object frequencies or high object frequencies. Figure 3 shows that there was a region over which threshold was independent of filter cutoff and a second

region over which log contrast threshold increased or decreased linearly with log filter cutoff. To derive the object frequency range that is used for letter identification, the data were fit piecewise with two linear functions using a least-squares criterion: one region was constrained to have a slope of 0, and the slope of the second region was unconstrained (Figure 3; solid lines). The cutoff object frequency at which the functions crossed (indicated by the vertical dashed line) was taken as an index of the center of the object frequency region mediating letter identification. This point, which was also used in previous reports (Alexander & McAnany, 2010; McAnany & Alexander, 2008), represents approximately equal elevations of log contrast threshold, compared to the threshold values obtained with minimally filtered letters.

Results

The analysis illustrated in Figure 3 was performed on data obtained at each letter size under each paradigm, with the results shown in Figure 4. In this figure, log object frequency is plotted as a function of log MAR for S1, S2, and S3. Measurements are shown for data obtained with the steady- (gray squares) and pulsed-pedestal paradigms (blue triangles), as well as for data obtained in static (red circles) and dynamic (green diamonds) noise. Each dataset was fit with an exponential function that transitioned from a slope of 0 for small letters to a positive slope for large letters. In general, the log object frequency mediating CS for all paradigms tended to increase as letter size increased. However, under the static noise and steady-pedestal paradigms, log object frequency increased slightly as letter size increased. In comparison, log object frequency increased sharply under both the dynamic noise and pulsed-pedestal paradigms. As can be seen from comparing the three panels, the pattern of data was consistent among the three subjects.

To evaluate differences among the paradigms quantitatively, a two-way repeated measures analysis of variance (ANOVA) was performed that compared the object frequencies measured under the four paradigms at the five letter sizes. The ANOVA indicated statistically significant effects of size, $F(4, 24) = 98.40$, $p < 0.001$, and paradigm, $F(3, 24) = 93.00$, $p < 0.001$. There was also a significant interaction between size and paradigm, $F(12, 24) = 15.88$, $p < 0.001$, indicating that the differences among the four paradigms depended on size. Bonferroni-corrected follow-up comparisons are shown in Table 1, which indicate that the object frequency values obtained under the static noise and steady-pedestal paradigms were not significantly different (the average difference in object frequencies
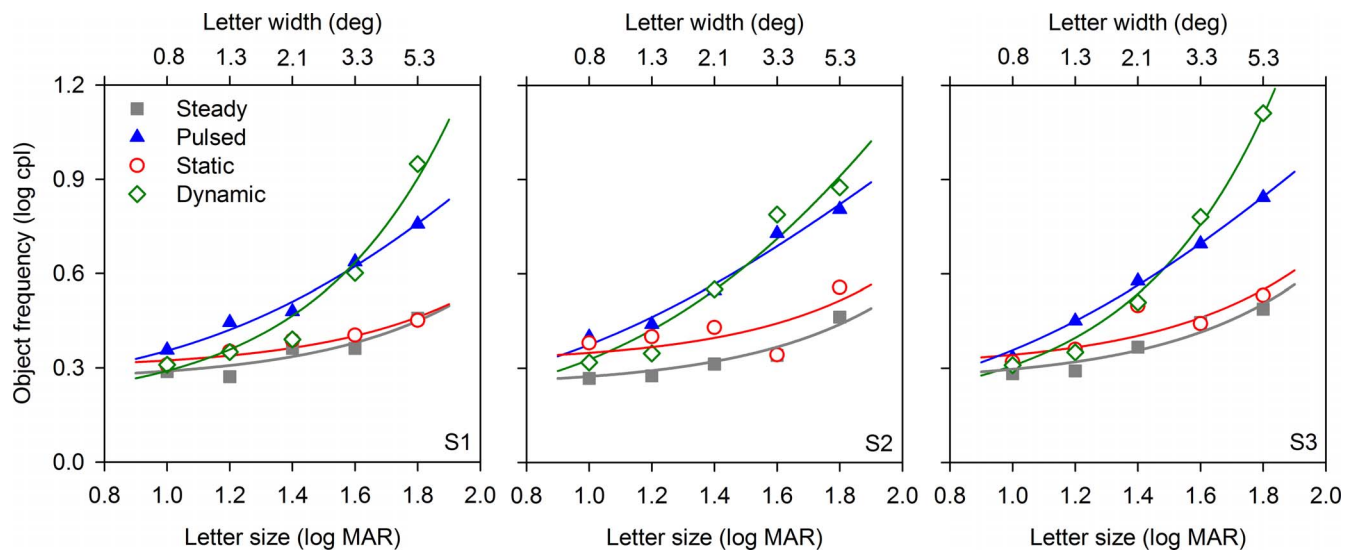
Figure 4. Log object frequency is plotted as a function of log MAR letter size for S1 (left), S2 (middle), and S3 (right). Equivalent letter widths (deg) are show along the top x-axis. Data were obtained under the steady-pedestal (gray squares), pulsed-pedestal (blue triangles), static noise (red circles), and dynamic noise (green diamonds) paradigms. Lines represent exponential fits to the data, as described in the text.

was 0.06 log units). Follow-up comparisons also indicated that the object frequency values obtained under the pulsed-pedestal and dynamic noise paradigms were not significantly different (the average difference in object frequencies was 0.01 log units).

The data shown in Figure 4 were obtained with a single presentation duration (50 ms) at a series of letter sizes. Figure 5 plots log object frequency for a series of exposure durations obtained at a single letter size (1.8 log MAR). In the upper panels of this figure, data obtained under the steady-pedestal (gray squares) and pulsed-pedestal (blue triangles) paradigms are shown, whereas the lower panels show data obtained in static (red circles) and dynamic (green diamonds) noise. Data obtained under all four paradigms for each subject were fit with linear regression lines. However, the slopes of the regression fits were not significantly different from zero for any subject for data obtained under the pulsed-pedestal paradigm, in static noise, and in dynamic noise (all $t < 1.58$, all $p > 0.21$). As such, these datasets were fit with linear regression functions of zero slope. In comparison, the slope of the regression fit was

significantly greater than 0 for each subject under the steady-pedestal paradigm (all $t > 3.69$, all $p < 0.03$).

The upper panels show marked differences in object frequency measured under the steady- and pulsed-pedestal paradigms for short exposure durations, as expected from previous work (Alexander & McAnany, 2010; McAnany & Alexander, 2008). However, the object frequencies mediating CS became similar under the steady- and pulsed-pedestal paradigms for long exposure durations. This is because the object frequencies mediating letter identification gradually increased with duration under the steady-pedestal paradigm. In comparison, the lower panels show that the object frequencies mediating letter CS were essentially constant in noise, with the static and dynamic noise functions separated by approximately 0.3 log units across duration.

Discussion

The present study sought to determine the extent to which the temporal characteristics of white luminance noise can be manipulated to allow measurement of CS within the inferred MC and PC pathways. In general, the results indicated that similar object frequency information was used for letter identification in static noise and under the steady-pedestal paradigm (inferred MC pathway mediation). Additionally, similar object frequency information was used for letter identification in dynamic noise and under the pulsed-pedestal paradigm (inferred PC pathway mediation). Thus, for

Comparison	Difference in means	t	p
Dynamic vs. pulsed	0.01	0.20	1.00
Static vs. steady	0.06	3.65	0.065
Dynamic vs. steady	0.22	13.45	<0.001
Dynamic vs. static	0.16	9.80	<0.001
Pulsed vs. steady	0.21	13.25	<0.001
Pulsed vs. static	0.16	9.60	<0.001

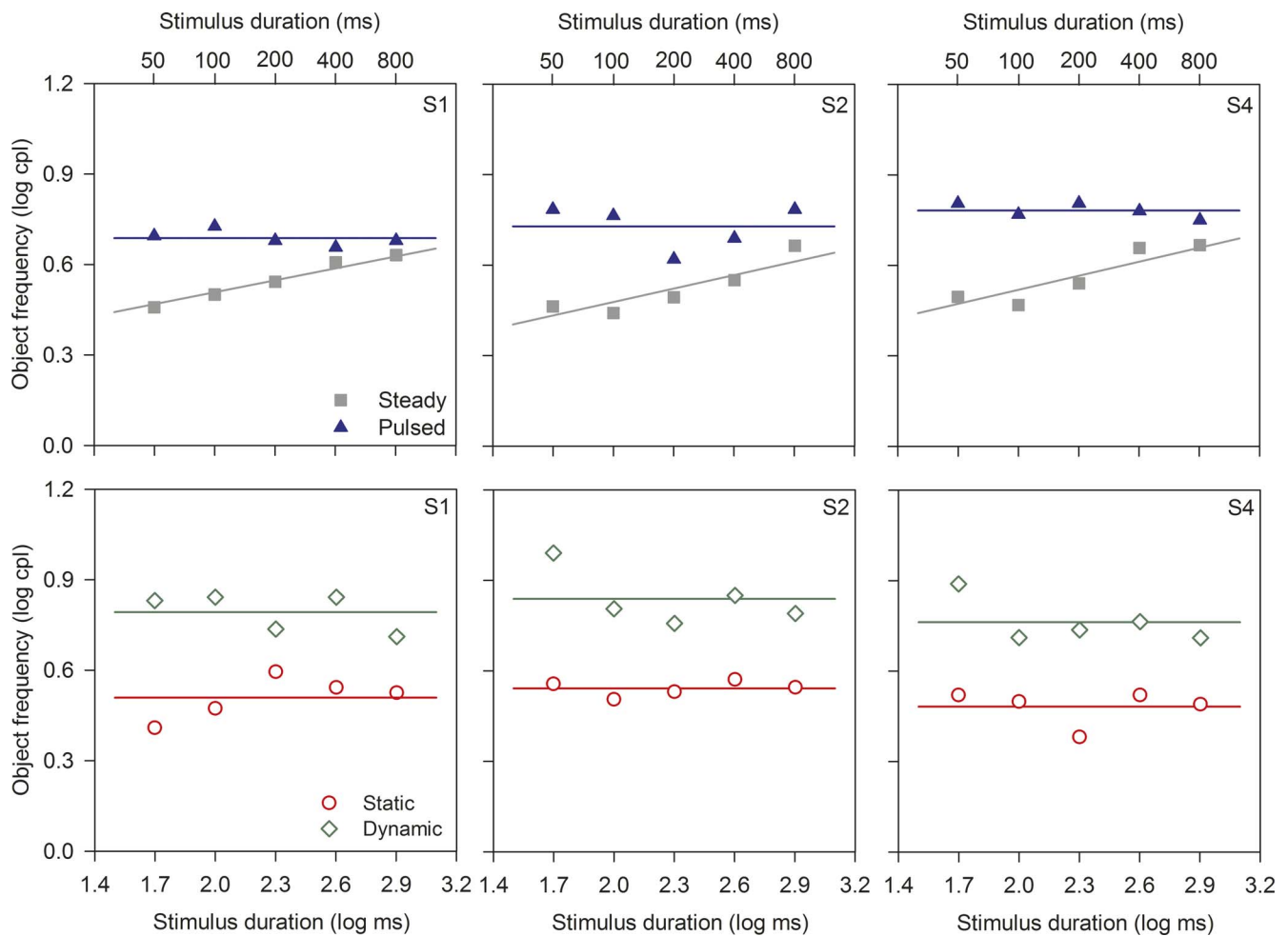Table 1. Pairwise multiple comparisons.

Figure 5. Log object frequency as a function of log target duration (linear duration values are shown on the top *x*-axis). Lines represent linear regression fits to the data, as described in the text. Other conventions are as in Figure 4.

the asynchronous visual noise paradigms employed herein, static and dynamic white luminance noise appear to target MC and PC pathway CS, respectively, at least for moderate to large letter targets (e.g., larger than 1.4 log MAR; 2.1° of visual angle). Furthermore, the results of the follow-up experiment showed that MC and PC pathway CS can be assessed across a broad range of stimulus durations, which is not possible with the standard steady- and pulsed-pedestal paradigms.

The relationship between object frequency and letter size measured under the steady- and pulsed-pedestal paradigms is consistent with previous work using the Landolt C and tumbling E optotypes (Alexander & McAnany, 2010; McAnany & Alexander, 2008). That is, under both paradigms, log object frequency increased as letter size increased, such that letter identification was mediated by low object frequencies (general shape information) for small letters and by high object frequencies (edge information) for large letters. For large letter sizes (1.4 log MAR or greater), there were marked differences in object frequency under the pulsed-pedestal/dynamic noise paradigms

compared to the steady-pedestal/static noise paradigms. These larger letter sizes are likely to be most useful for selectively targeting MC and PC pathway CS in noise. For smaller letter sizes (approximately 1.0 to 1.4 log MAR), there were relatively small differences in object frequency among the four paradigms and the visual pathway mediating letter identification cannot be determined unequivocally. Minimal differences at relatively small letter sizes were also reported previously using the Landolt C and tumbling E optotypes (Alexander & McAnany, 2010; McAnany & Alexander, 2008). Additionally, previous work with stimuli that were limited in spatial frequency content (sixth derivative of Gaussian gratings) also showed minimal to no differences in CS at high spatial frequencies (equivalent to small letters) under the steady- and pulsed-pedestal paradigms (Leonova et al., 2003). That study concluded that the PC pathway likely mediates CS for high frequencies under both the steady- and pulsed-pedestal paradigms.

Of note, the dependence of object frequency on letter size has been reported in numerous studies under

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conditions similar to the steady-pedestal paradigm (Alexander et al., 1994; Chung et al., 2002; Hall et al., 2014; Majaj et al., 2002). These studies reported a linear relationship between log object frequency and log letter size that had a slope of approximately 1/3. Refitting our steady-pedestal and static noise data with linear functions resulted in reasonable fits with slopes ranging from 0.15 to 0.28, a range that is generally consistent with previous findings. Linear fits to the pulsed-pedestal and dynamic noise data resulted in steeper slopes of 0.50 to 1.0.

As noted previously (McAnany & Alexander, 2006), the asynchronous dynamic and asynchronous static noise paradigms bear procedural similarities to the pulsed-pedestal and steady-pedestal paradigms, respectively. Under the pulsed-pedestal paradigm, a letter target is briefly presented simultaneously with a luminance pedestal. The abrupt luminance change drives the MC pathway toward saturation, leaving the PC pathway as the most sensitive mechanism. Similarly, the rapidly changing increment and decrement luminance checks of dynamic noise may desensitize MC pathway, leaving the PC pathway to mediate performance. The desensitization likely occurs due to masking of the onset and offset transients of the letter target by the dynamic noise, as proposed previously (Manahilov et al., 2003). In contrast, under the steady-pedestal paradigm and in asynchronous static noise, the temporal transients generated by the onset and offset of the letter target presented against the static noise field (or unchanging steady luminance pedestal) are preserved, favoring mediation by the MC pathway. Thus, from this view, it is reasonable to expect that performance would be similar under the pulsed-pedestal and asynchronous dynamic noise paradigms and for the steady-pedestal and asynchronous static noise paradigms.

An important limitation of the steady- and pulsed-pedestal paradigms is the requirement of a brief stimulus presentation duration (generally 50 ms or shorter) to clearly separate MC and PC pathway function. For moderate to long durations, previous work has shown that the ability to separate MC and PC pathway function deteriorates (Pokorny & Smith 1997). The data of Figure 5 are consistent with these previous findings, showing clear differences in object frequency only at short durations (less than approximately 300–400 ms) under the two paradigms. In contrast to these findings, the object frequency information mediating letter identification was generally independent of duration in static and dynamic noise for all durations examined. Thus, luminance noise appears to be a promising approach for targeting the MC and PC pathways at long durations, which may facilitate clinical testing or testing under other circumstances that require extended exposure durations.

The primary finding, that asynchronous static noise can target inferred MC pathway function and asynchronous dynamic noise can target inferred PC pathway function, has implications for the more general use of these paradigms. Specifically, comparisons of CS in the presence and absence of noise have been used to estimate the internal noise and efficiency of the visual system (Pelli & Farell, 1999). Often, the temporal characteristics of the noise (static vs. dynamic; synchronous vs. asynchronous) are not considered directly in the design of noise-based studies. However, the present results show that consideration of the noise type can be important, as this may affect the visual pathway mediating CS, and possibly estimates of internal noise and efficiency.

In summary, the temporal characteristics of white luminance noise can be manipulated to target inferred MC and PC pathway CS. The ability to target the MC and PC pathways at long stimulus durations is a potential advantage of the use of luminance noise, compared to the more common steady- and pulsed-pedestal paradigms. Finally, the temporal characteristics of the luminance noise should be considered in the design of tests that measure equivalent intrinsic noise, as different noise types appear to target different post-receptor pathways.

Keywords: contrast sensitivity, magnocellular/parvocellular, luminance noise, letter identification, object spatial frequency

Acknowledgments

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