Automated assessment of the visual contrast sensitivity function in the hooded rat

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Introduction

The perceptual characteristics of vision in rats have not been widely studied, yet the rat continues to be the most useful animal for physiological and behavioral research. This is an unfortunate oversight since the retina is the only directly visible brain structure, which renders vision uniquely suited to studying brain-behavior relations. A useful measure of visual function is the spatial contrast sensitivity function (CSF) which describes, in a single relation, the main determinants of spatial vision, sensitivity and acuity. The CSF could thus serve as a powerful behavioral correlate to lesion assessment and pharmacological or other manipulations. The rat's undervalued visual capabilities, however, have led to relatively few studies concerning its spatial vision.

A major problem in animal psychophysics is the collection of reliable data with a limited investment of time and physical resources. We developed a sufficiently automated process to allow accurate and practical threshold measurements. Our approach was to employ a standard computer monitor for stimulus display and an infrared touch screen as the response detector. Here we evaluate the effectiveness of this automated spatial vision test by measuring the hooded rat's CSF.

Methods

Subjects. Seven adult, male hooded rats were used. Rats were kept two per cage on a 12:12-h dark-light cycle at 24–26°C, 65% humidity, with food available *ad libitum*. Rats were handled and water deprived; water was withdrawn for 24 h the first day and then administered 10–15 min daily until they reached 85–90% of their *ab-lib* body weight (about 1–2 weeks). The animals were then trained on the behavioral apparatus. During testing, each pair of rats was given 20 min water access daily.

Apparatus. Experiments were carried out in a modular operant chamber (Coulbourn Instruments, USA) equipped with a water dipper (Fig. 1). The chamber was modified by adding a 2 by 3 array of 41-mm square openings centered in the wall opposite from the water dipper (Fig. 2).

Experiment control was carried out with an MS-DOS based PC and control software written in Turbo Pascal. A 14" VGA monitor was centered behind the array. An infrared touch screen constructed for 14" monitors (Carrol Touch, USA) was placed over the monitor face. Viewing distance at the moment of nose-poking was 70 ± 2 mm. The slight hyperflexion of the monitor screen did not significantly alter spatial frequency and was disregarded.

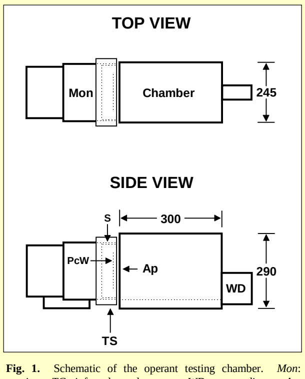

Fig. 1. Schematic of the operant testing chamber. *Mon*: monitor; *TC*: infrared touch screen; *WD*: water dipper; *Ap*: aperture (see Fig. 2); *S*: supports; *PcW*: polycarbonate window. All dimensions in mm.

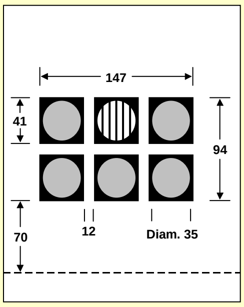

Fig. 2. Rats' view of the stimulus array. An aluminum plate was placed in the side of the chamber facing the monitor. Square openings cut into the plate allowed the rat to nose-poke stimuli appearing on the screen. View of the stimuli was further restricted with a poster-board sheet containing circular openings and affixed to the touch screen. Dashed line corresponds to the grid floor. All measurements in mm.

Stimuli. Stimuli were vertically oriented achromatic sine-wave gratings of varying spatial frequency and contrast. Monitor resolution was set to 640 by 480 pixels, and pixel width measured 0.39 mm. A standard VGA graphics board was used which offered a 6-bit gray palette, that is, 64 luminance levels (Gossen Panlux light meter). Grating contrast is defined in Michelson units, $C = (L_{max} - L_{min}) / (L_{max} + L_{min})$, where L_{max} and L_{min} are the grating's maximum and minimum luminance values, respectively. The contrast values used for testing were: 4%, 8%, 13%, 20%, 31%, 42%, 56%, 75% and 100%. Mean luminance was 51 cd/m^2.

Grating spatial frequencies were chosen such that cycle width was an integer multiple of the pixel width (Bach *et al.*, 1997); the grating with highest spatial frequency thus had a period of 2 by 0.39 mm. Nine spatial frequencies were used for testing: 0.04, 0.08, 0.10, 0.12, 0.17, 0.22, 0.31, 0.52, and 0.78 cyc/deg. The stimulus field consisted of six blocks, each masked by a poster-board sheet affixed to the inside face (towards monitor) of the touch screen. The sheet contained a separate array of 35-mm circular aperture openings centered behind the aluminum openings (see Fig. 2). This mask limited the view of the stimuli to 70° of visual angle at the closest viewing distance.

Behavioral Shaping. All training and testing took place within a dark, sound-attenuating room. Initial training involved establishment of the reinforcer and behavioral shaping to nose-poke. A maximum-contrast grating at 0.14 cyc/deg, known to be within the rat's range of sensitivity, was used for the training phases. Shaping involved a session displaying a solitary grating (the remaining positions were devoid of stimuli) which varied randomly in position. Following a short period of adaptation to the chamber, the reinforcer was established by manually operating the water dipper (0.06 cc dipper cup) via a toggle switch when the rat approached the array. Subsequent daily training sessions were performed independently and self-paced, consisting of 40 trials each. No response was recorded for 4 sec after the onset of stimulus allowing the rat to search the openings; stimulus presentation was terminated by the rat's response, after which followed a 5-sec water dipper activation and a 15-sec inter-trial interval. For this and the remaining training and testing sessions, nose-pokes to locations with an incorrect (non-reinforced) stimulus initiated a correction procedure. The trial in that case ended without a reinforcer, an error time-out (25 sec) was scheduled, and the trial was repeated with the grating in the same location. Rats were run daily on this session until performance stabilized at above 90% accuracy over three consecutive sessions. When shaping performance was stable, rats were run on sessions which included distractors equal in luminance to the grating mean. Testing began after discrimination performance stabilized.

Testing. Testing sessions consisted of a simple, non-algorithmic adaptive procedure. For each of the nine tested spatial frequencies, grating contrast was systematically reduced (descending series) until the rat's performance fell below chance (16.7%).

Results

Learning. Rats learned to discriminate after preliminary training in two to three weeks. During the first shaping sessions, subjects obtained an accuracy of 90% or better in five to eight sessions (Fig. 3). Sessions lasted approximately 20 to 30 min, and the rats showed little motivational loss during the task.

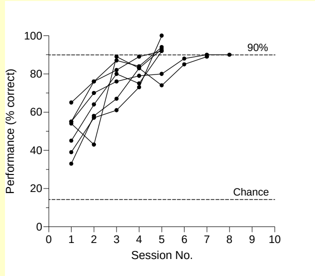

FIG. 3. Behavioral training data showing performance scores from the first shaping sessions of naive rats. The dashed horizontal lines indicate 90% performance and the chance level, 16.7%. Rats learn the nose-poking and tracking paradigm to a high accuracy in five to eight daily sessions.

Psychometric Functions. Psychometric functions were generated by fitting, individually for each rat, a logistic function to the total binary response data for each spatial frequency. As Fig. 4 illustrates, a greater number of alternatives increases the psychometric function's slope and makes the inflection point (i.e., threshold) more apparent. We used the maximum-likelihood fitting program, MLPFIT, available with the ML-PEST package designed by Harvey (1997). Fig. 5 shows a typical resulting psychometric function for one rat at a spatial frequency of 0.17 cyc/deg. As is common use, the point of inflection is taken as the threshold.

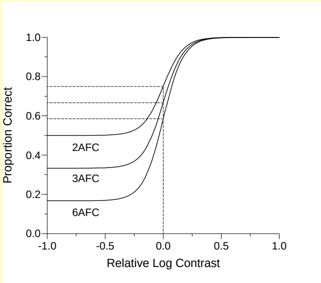

FIG. 4. Comparison of logistic functions for two-, three-, and six-alternative forced-choice tasks. Functions are normalized to a threshold of 0.0 log-contrast (1% Michelson contrast). The inflection point in each function is marked with a horizontal dashed line. The inflection point's x-coordinate is the threshold (vertical dashed line). The higher-alternative forced-choice paradigm has a steeper slope with a more sharply defined threshold.

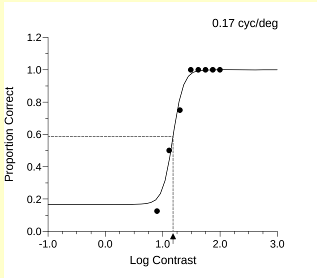

FIG. 5. Binary response data for one rat at a spatial frequency of 0.17 cyc/deg. A logistic function is fit to the data, and the inflection point determined (dashed lines); an arrow marks the threshold (14.8% Michelson contrast).

Contrast Sensitivity Function. Contrast sensitivity functions for each rat were generated by plotting the inverse contrast-threshold values as a function of spatial frequency; functions are conventionally represented on a log-log plot as contrast sensitivity (reciprocal of contrast threshold) *vs.* spatial frequency (cyc/deg of visual angle). The group mean is shown in Fig. 6. The function has the expected inverse-U shape with peak sensitivity occuring at about 0.10 cyc/deg. A third-order polynomial regression line was fit by least squares to the log data (r^2 = 0.946): $\log[f(x)] = 0.1086 - 1.648\log(x) + 0.03871\log(x)^2 + 0.7875\log(x)^3$. Maximum acuity was estimated to be 1.16 cyc/deg.

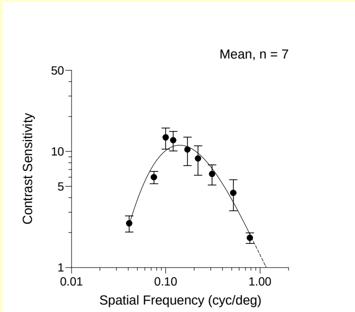

FIG. 6. Mean contrast sensitivity function of seven animals generated with our behavioral paradigm. The data are fit with a third-order polynomial regression line (least squares), and acuity is estimated by extrapolating this function to the spatial-frequency axis (dashed line). The function has the typical inverse-U shape. Bars represent SEM.

Conclusions

- The overall characteristics of the CSF generated for the hooded rat by this procedure are comparable to data previously generated by other groups. Peak sensitivity is 7% contrast and occurs at 0.10 cyc/deg, similar to what others have reported (Silveira *et al.*, 1987; Legg, 1986; Birch and Jacobs, 1979). We found acuity to be 1.16 cyc/deg; others have determined acuity to be about 1.00 cyc/deg (Silveira *et al.*, 1987; Dean, 1981; Birch and Jacobs, 1979; Lashley, 1930).
- A computer monitor is well suited for testing spatial vision in rats. Technological monitor limitations that need special consideration with humans (Bach *et al.*, 1997) and other animals with high visual capabilities play a minor role with rats.
- The use of an adaptive procedure and PC make this a simple and efficient method for taking psychophysical measurements of rat visual function.
- Future improvements might include an algorithmic adaptive procedure (Treutwein, 1995) and a higher resolution (both in contrast and pixel width) graphics card. Possible applications of this paradigm include the behavioral assessment of lesion or pharmacological studies.

References

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