EFFECTS OF SUB-FUSIONAL INTERMITTENCY ON THE APPEARANCE OF TARGETS OF COMPLEX SPECTRAL COMPOSITION

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ABSTRACT

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By

Allen Louis Nagy

The effects of sub-fusional intermittency on the appearance of targets of complex spectral composition were observed in this study. Achromatic targets of varying spectral composition, purple targets, and metameric pairs were examined. A dual-beam optical arrangement was used in conjunction with narrow-band interference filters to produce complex targets with known spectral composition. Brightness matches and judgments of hue and saturation changes were made with four conditions of intermittency. Temporal effects on color and brightness do not appear to be dependent on the wavelength composition of the target in a simple way.

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by

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A THESIS

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Dedicated to my wife, Linda

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A. L. N.

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INTRODUCTION

Brightness Phenomena

A large amount of research concerning the effects of sub-fusional intermittency on the brightness of full-spectrum targets has been carried out by Bartley and his colleagues. Generally they have found that an increase in brightness occurs when full-spectrum photic stimulation is made intermittent. The effect was maximum when the target was pulsed at rates of approximately ten cycles per second with the pulse occupying 1/4 of the cycle. This phenomenon has been termed "brightness enhancement" or the "Bartley effect".

Much of this research has been devoted to delineating the particular stimulus characteristics important to the production of brightness enhancement. Pulse length, rate, target size, intensity level, and adaption level are some of the variables examined (Bartley, 1951a, 1951b, 1952, 1957; Valsi, Bourassa, and Bartley, 1959; Nelson, Bartley, and Jewell, 1963; Bourassa and Bartley, 1963; and Kazsuk and Bartley, 1969).

Ball (1964) extended this investigation to chromatic stimuli when he measured the brightness of intermittent monochromatic targets. His results show that brightness enhancement occurs with only one of the monochromatic stimuli observed. This was the waveband centered around 510 nm. Other monochromatic targets were observed to have a brightness quite close to

Talbot level brightness under the same conditions. The temporal conditions producing brightness enhancement in the 510 nm target were quite similar to those producing enhancement in the full-spectrum targets; rates of six to thirteen Hz. and a PCF or pulse-to-cycle fraction of approximately 1/4. Ball's findings suggest that temporally induced brightness in intermittent targets may be dependent on the spectral composition of the target, and that the inclusion of wavelengths around 510 nm is necessary to the occurrence of brightness enhancement.

Chromatic Phenomena

Bartley and Nelson's (1960 and 1961) initial observations on intermittent chromatic targets showed that the chromatic characteristics of a visual target could also be very dramatically affected by the same temporal conditions that produce brightness enhancement. Hue shifts and large amounts of desaturation were reported to occur. The first measurements of these phenomena consisted of verbal judgments made in Ball's 1964 study. Results showed that hue shifts revolved around two invariant points at approximately 510 nm and 575 nm. Hues of surrounding wavelengths shift toward the invariant hue at 575 nm and away from the invariant hue at 510 nm. Psychophysical measurements of these hue shifts have recently been accomplished by Horst and Muis (1969) and Nilsson and Nelson (1971). Their data show maximum shifts occurring in the red end of the spectrum with lesser magnitudes in other regions. Both studies confirm the two invariant hues at approximately 510 and 575 nm and Nilsson and Nelson suggest the possibility of another invariant hue in the deep violet region.

Measurement of saturation changes has not advanced beyond the judgment technique used by Ball (1964). His results show that large amounts of desaturation occur with blue-green and orange hues while little change occurs in the saturation of blue and yellow hues. These temporally induced chromatic changes do not appear to be directly related to the brightness changes, even though both phenomena occur under the same conditions (Nelson, 1971; Ball, 1964; Horst and Muis, 1969).

Problem

The first section of this study deals with the relationship between brightness and spectral composition of intermittent targets. Data were collected to determine whether the wavelengths around 510 nm have some special significance to the production of brightness enhancement. Six targets used in this portion of the study were all achromatic, but were composed of different complimentary wavebands. One of these targets included wavelengths around 510 nm while the others did not. In addition a full-spectrum target was also presented. All seven targets were equated in luminosity.

According to classical color theory, wavelength information is lost somewhere in the visual system and all seven targets should produce the same physiological activity at some point since they are identical in appearance. Thus it would be expected that temporal effects might be identical on all targets. On the other hand, Ball's results suggest that targets containing wavelengths around 510 nm might produce greater brightness than the other targets under intermittency. A psychophysical brightness matching technique was used to provide some data on this question.

In addition to the achromatic targets, temporal effects on the brightness of seven purple targets were examined. Purple hues are somewhat unique in that they cannot be produced with a single narrow band of wavelengths. They require the blending of wavelengths from opposite ends of the visible spectrum. Effects of temporal manipulation on these targets have not yet been examined. From examination of the results in Ball's study it might be expected that the brightness of intermittent purple targets should not reach enhancement level. The brightness of intermittent red hues conformed quite closely to Talbot level while that of the blue hues was only slightly above. If temporally induced brightness is additive, then summing the results in the individual cases suggests that the brightness of intermittent purple targets should not greatly exceed

Talbot level. The same psychophysical brightness matching technique was used here.

In addition to the brightness matches each observer was asked to make judgments on the chromatic quality of the target. For the achromatic targets this was restricted to a verbal description of any hue acquired by the target as a result of the intermittency. It is well-known that achromatic targets can acquire hue under certain conditions of intermittency. There is a large body of literature dealing with this phenomenon often called "Subjective Colors" (see Cohen and Gordon, 1949; Gebhard, 1943; and Festinger et al., 1971 for reviews). It is interesting to note that the temporal conditions necessary to this phenomenon are generally reported to be quite similar to those producing the brightness and chromatic phenomena discussed here. Reasoning from classical theory again, it would be expected that any hue induced by a particular temporal condition should be the same for all the achromatic targets despite differences in their spectral compositions.

Judgments on chromatic changes in purple targets were also made. The use of purple hues provides an opportunity to determine whether temporally induced changes in the appearance of monochromatic targets can be used to predict changes in the appearance of a composite target formed by their addition. It was noted that long-wavelength targets become quite desaturated and shift toward yellow in appearance while short-wavelength targets are only slightly desaturated and shift toward violet in appearance. Thus when a purple target is made intermittent, the long wavelengths should be much less effective in adding to its chromatic quality than the short wavelengths. Presumably then, a purple target made intermittent should shift toward a blue-violet hue and become somewhat desaturated. Judgments of the direction of hue shift and amount of desaturation in each of the purple targets were made for each temporal condition.

The final portion of the study is concerned with metameric hues. These are hues that have the same appearance but different spectral compositions. Traditionally it has been supposed that metameric hues are possible because of a loss of wavelength information in the visual system. Classical theory supposes that physiological activity is identical at some point in the visual system for two metameric hues. If this is true, temporal manipulation might result in identical changes in the appearances of two metmeric hues. Three pairs of metameric hues were observed to determine whether temporally induced changes were in fact similar in two metameric hues.

METHOD

Apparatus

The dual-beam apparatus diagrammed in Figure 1 consisted of two major sections. Section A allowed blending of two narrow wavebands while section B produced a circular divided target with the bottom half variable in luminosity and continuous in time and the top half intermittent.

In section A the radiation from a 100-watt concentrated arc-lamp is passed through a collimating lens (L_1). H_1 is a half-silvered mirror which splits the beam into two pathways that are blended together again at H_2, another half-silvered mirror. The two pathways produced (Channel A and Channel B in the diagram) are equal in length. Each beam passes through one half-silvered mirror and is reflected by another. Each is also reflected by one first surface mirror (either M_1 or M_2). The division into two beams allows placement of various chromatic interference filters and neutral density filters in the channels.

In section B the blended beam is divided in half spatially by the mirrored prism, P_1. One half of this blended beam is then chopped by a flag on a small pen motor driven by a Grass S-4 medical stimulator. The beam was focused at the point of chopping by a lens system (L_2) so as to produce short rise and fall times. The flag arrangement was calibrated with a Hewitt-Packard

120 B cathode ray oscilloscope and a cadium photocell. A check of rise and fall times showed that they were both approximately two milleseconds in duration.

The other half of the beam is passed through a circular neutral density wedge. The circular wedge is connected by a belt drive to a knob within reach of the observer and a circular dial with 360 degree markings. Thus, the observer can manipulate the brightness of the beam by turning the knob and the experimenter can obtain a reading from the dial. This arrangement was calibrated with a Pritchard photometer so that per cent transmission could be derived from the dial readings.

Finally, the two halves of the beam are reflected off another mirrored prism, P_2, and into an eye piece containing a lens arrangement, L_3. The result is a circular two degree target in Maxwellian view with a dark line dividing the intermittent top half from the continuous bottom half. The two halves have identical spectral composition.

The apparatus was calibrated for the conditions of this study with a Pritchard photometer. The interference filters to be used were placed in channels A or B and measurements of the luminosity at the eye piece were recorded. In addition visual matches were made using the cascade method of heterochromatic color matching. The two sets of data were in substantial agreement.

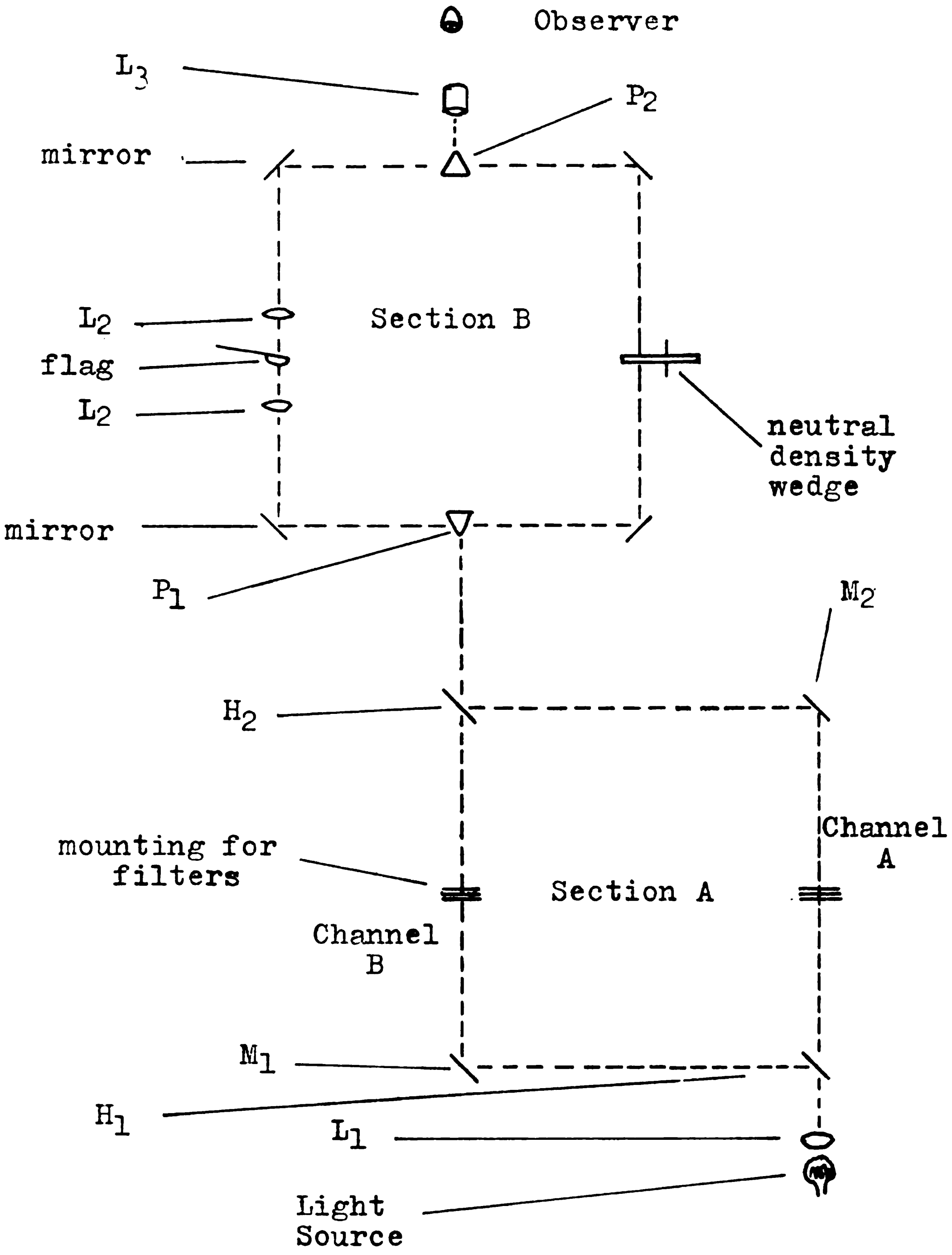

Figure 1 Schematic Diagram of Dual-Beam Apparatus

Specification of Stimuli

Three variables were manipulated in this study; rate, PCF, and spectral composition. The rates used were 8 and 20 Hz. with PCF's of 1/4 and 3/4. A description of the spectral composition of the targets is presented in Table 1. Two types of filters were used in production of the targets. The Oriel Narrow Band Interference filters pass very narrow bands of wavelengths. The band width at 50% peak transmission was 5 nm and at 1% peak transmission only 10 nm. Wratten gelatin filters allow much wider bands of wavelengths to pass. Descriptions of the passbands for these filters as measured using a spectometer are given in the table.

In the case of the purples composed using the interference filters, the contributions of the red and blue wavebands to the total luminosity of the resulting purple target are shown as percentages in parentheses. This has not been done with the Wratten filters. In the treatment of the data spectral compositions are indicated by the labels given in Table 1.

Observers

Four males served as observers. Two of them, M. E. and M. D., were undergraduate psychology students and had no previous experience in brightness or color matching experiments. The two other observers, R. B. and A. N., both had extensive experience prior to this study. All observers had normal color vision and hue

TABLE 1 Description of Spectral Composition of Targets

NAME	FILTERS	MAJOR WAVEBANDS	TOTAL LUMINANCE
		Achromatic Targets	
A	Interference	455-465 nm 565-575 nm	125 foot-lamberts
B	Interference	475-485 nm 575-585 nm	125 foot-lamberts
C	Interference	485-495 nm 605-615 nm	125 foot-lamberts
D	Interference and Wratten # 33	450-470 nm 495-505 nm 600-705 nm	125 foot-lamberts
E	Interference and Wratten # 33	450-470 nm 505-515 nm 600-705 nm	125 foot-lamberts
F	Interference and Wratten # 35	410-460 nm 555-565 nm 640-720 nm	125 foot-lamberts
G	None	Full Spectrum	
		Purple Targets	
Red Purple	Interference	475-485 nm(25%) 665-675 nm(75%)	30 foot-lamberts
Purple	Interference	475-485 nm(50%) 665-675 nm(50%)	30 foot-lamberts
Blue Purple	Interference	475-485 nm(75%) 665-675 nm(25%)	30 foot-lamberts
Xylene Red	Wratten # 33	450-470 nm 600-705 nm	120 foot-lamberts
Wratten D light	Wratten # 34	440-480 nm 630-720 nm	120 foot-lamberts
Wratten D	Wratten # 35	410-460 nm 640-720 nm	120 foot-lamberts
Methyl Violet	Wratten # 36	425-450 nm 650-715 nm	120 foot-lamberts

Table 1 (cont'd.)

NAME	FILTERS	MAJOR WAVEBANDS	TOTAL LUMINANCE
		Metameric Targets	
Yellow Orange A	Interference	525-535 nm 595-605 nm	160 foot-lamberts
Yellow Orange B	Interference	495-505 nm 565-575 nm	160 foot-lamberts
Yellow A	Interference	495-505 nm 595-605 nm	160 foot-lamberts
Yellow B	Interference	475-485 nm 575-585 nm	160 foot-lamberts
Yellow Green A	Interference	505-515 nm 595-605 nm	160 foot-lamberts
Yellow Green B	Interference	475-485 nm 525-535 nm	160 foot-lamberts

discrimination as measured by the HRR Pseudoisochromatic Plates and the Farnsworth 100-Hue Test.

The two inexperienced observers were given six hours of practice prior to the actual data collection. During this period they were presented with various monochromatic wavebands under temporal conditions identical to those used in the study. The same procedure was followed during practice sessions as in the actual data collection.

Procedure

During each experimental session only one spectral composition was observed. Prior to the data collection, the observer was adapted to the particular target chromaticity. All observations were made with the dominant eye, while an eye patch was worn over the other eye. After positioning and adaptation, the observer began by making six matches of the steady bottom to a steady top half. For all brightness matches the method of limits was used with three ascending and three descending matches.

After the initial set of steady matches, intermittency conditions were observed. Observers were asked to match the brightness of the continuous bottom half to the average brightness of the intermittent top half. The observer was adapted to each intermittency condition for one minute prior to the beginning of the brightness matching. The adaption period tended to eliminate successive changes in the brightness and chromaticity that occur in the early stages of stimulation with intermittent targets (Ball, 1964). All four combinations of rate and PCF were used in each session.

After each set of brightness matches the observer was asked for an estimation of desaturation and hue shift. For the judgment of desaturation a nine-point scale of none, slight, moderate, extreme, total, and the half steps between was used. This scale has been used in previous studies and found to be suitable (Ball, 1964). End points of the scale were anchored in a sense by instructing the observers to make a judgment of "none" if the intermittent target appeared to be as saturated as the steady half of the target. A judgment of "total" was defined as a complete loss of chromatic quality in the intermittent target.

A description of the hue shift was given after the desaturation estimate. The observer was asked to use the terms redder, greener, yellower, and bluer to describe the change in hue if any. During the period of both chromatic judgments the bottom half of the target was set at the brightness at which the observer made the last brightness match. Both judgments were made using the continuous bottom half of the target as the reference. As a methodological point this is important since the appearance of the top half is influenced to some extent by the presence of the bottom half.

Each spectral composition was observed under each temporal condition is two separate experimental sessions. Each of these sessions consisted of four intermittency conditions and one steady condition, totalling thirty brightness matches, four desaturation estimates, and four hue shift estimates. Thus, for each condition there were a total of twelve brightness matches, two desaturation estimates, and two hue shift responses. The order of presentation of the intermittency conditions within a session was counter-balanced between the two sessions so that order effects were balanced. The order of presentation of chromatic conditions was the same for all observers.

RESULTS

Brightness Data

The brightness matching data of this study are presented in terms of the brightness index derived by Bartley and Ball (1965). The brightness index is based on the Talbot-Plateau level as a standard reference point. The Talbot-Plateau law states that the brightness of an intermittent target above fusion frequency is matched by the brightness of a continuous target whose luminance is equal to the average luminance of the intermittent target over time. In other words, the law suggests that the visual system averages the incident luminosity over time to produce an average brightness which is then dependent only upon the PCF or portion of the cycle occupied by the stimulus. This empirical law has been found to apply over a very wide range of intermittency conditions (Hyde, 1906) and, thus, is useful as a standard reference point. At subfusional rates of intermittency, however, brightness deviates from the Talbot-Plateau level and becomes dependent upon rate as well as PCF. The brightness index is a useful means of describing this deviation. It may be considered as a measure of the visual system's efficiency in using photic energy to produce brightness. It is calculated as per cent of the expected Talbot-level brightness as expressed by the following equation:

$$\frac{L_2}{(L_1) \times (PCF)} \times 100\% = \text{Brightness Index}$$

where L_1 = luminance of intermittent test target
PCF = pulse-to-cycle fraction
L_2 = luminance of continuous comparison target matched in brightness

Figures 2 and 3 present brightness matching data for the achromatic targets of different spectral composition. Each figure presents the data for two observers. The six different compositions are presented along the abscissa and labeled as described in the section on experimental conditions. Brightness index is presented on the ordinate and each curve on the graph represents a different temporal condition. E is the target containing wavelengths around 510 nm and G is the full-spectrum target.

It is apparent that when the PCF was 3/4, brightness was approximately at Talbot level, a brightness index of 100, for all targets. The visual system may be said to be averaging the luminosity over time in this case. The results with a PCF of 1/4 are quite different. For the two observers in Figure 2 the brightness is clearly greater than Talbot level across all the target compositions when PCF is 1/4. In Figure 3, however, the curve for each 1/4 PCF condition tends to fall off toward Talbot level for compositions D, E, F, and G. There is some evidence to suggest that this result is due to a change in observer criterion over the course of the study. It may be remembered that data for each

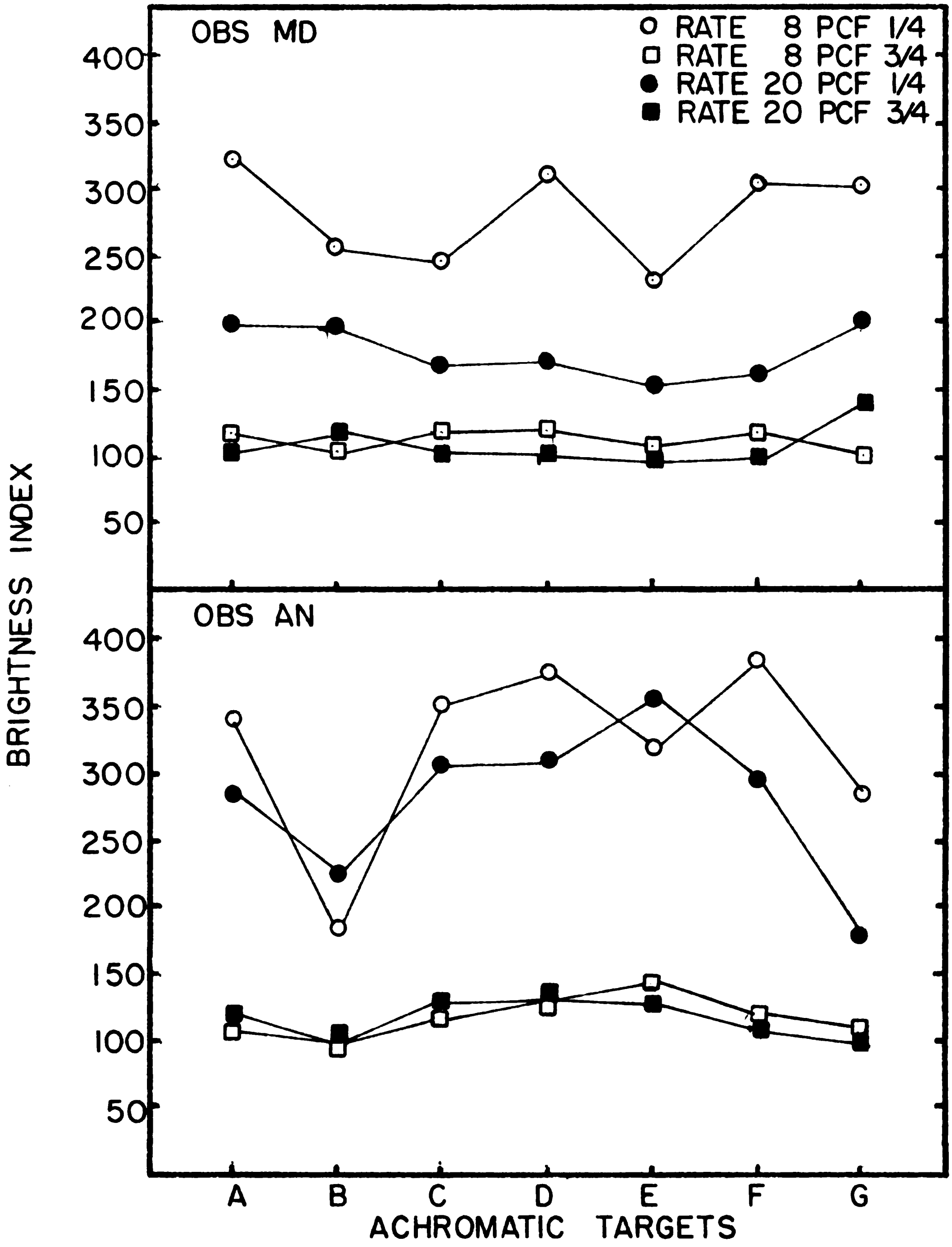

Figure 2 Brightness Index of Achromatic Targets For Observers M. D. and A. N.

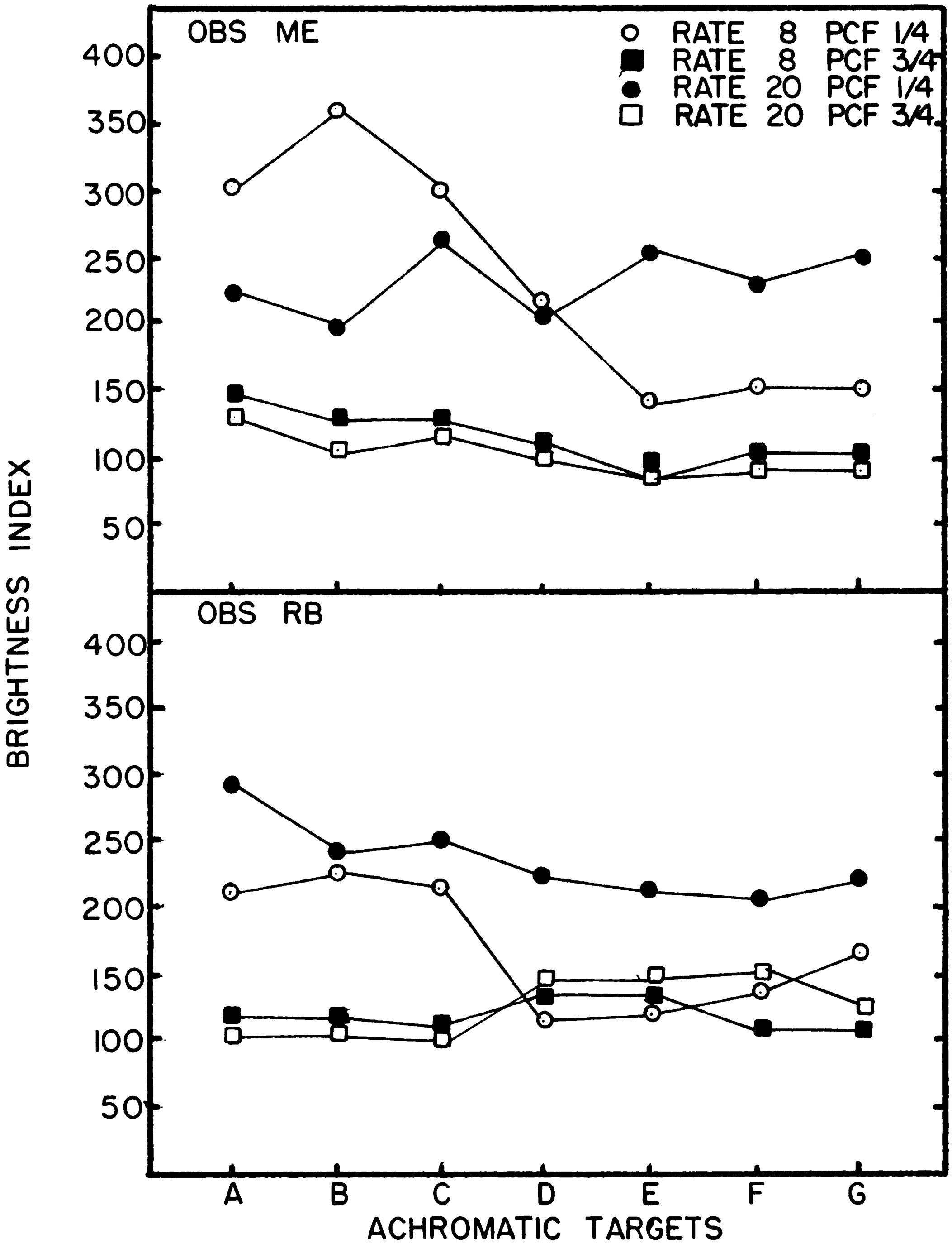

Figure 3 Brightness Index of Achromatic Targets For Observers M. E. and R. B.

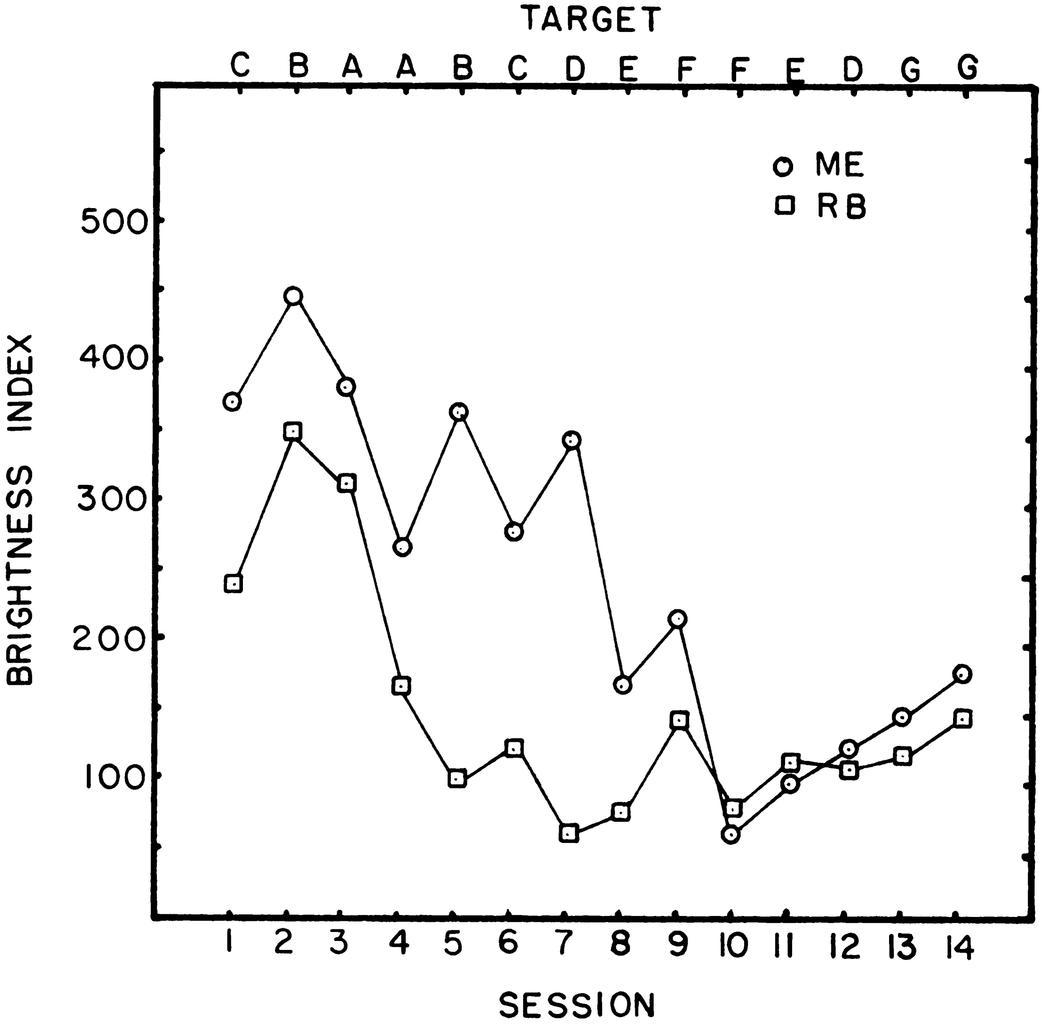

Figure 4 Change in Brightness Index Over Sessions For Observers M. E. and R. B.

condition were collected on two separate occasions. Figure 4 shows the brightness index for rate 8, PCF 1/4 for the two observers in Figure 3 plotted against the order of sessions for the achromatic targets. It can be seen from Figure 4 that the brightness index of these two observers tended to decline over the course of the experiment regardless of spectral composition of the target.

In any case the results in Figures 2 and 3 do show that the inclusion of wavelengths around 510 nm (Target E) is not necessary to the temporal production of brightness increments. In none of the cases does the brightness index for this target greatly exceed that for other targets when PCF is 1/4. Nor does restricting the wavebands used to produce the targets appear to have any effect. In no case does the brightness index for Target G (full spectrum) greatly exceed that for the other targets.

Figure 5 presents brightness matching data for the purple targets composed with narrow wavebands centered around 480 nm and 670 nm. At the left end of the abscissa is the reddest purple (.25 blue, .75 red) and at the right end is the bluest purple (.75 blue, .25 red). Brightness index is presented along the ordinate. When PCF is 3/4 it is again apparent that brightness deviates very little from that predicted by Talbot-Plateau level. With a PCF of 1/4, however,

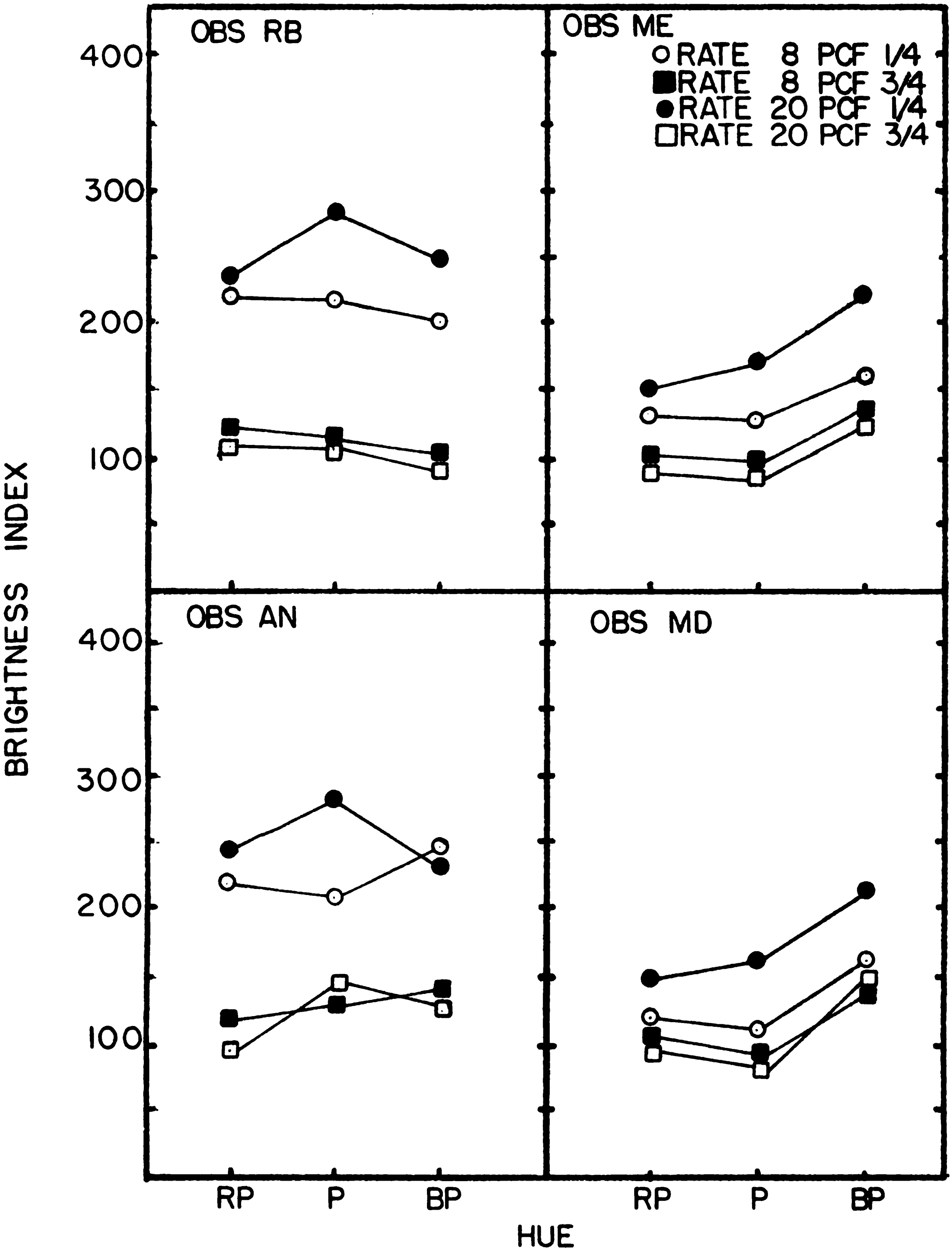

Figure 5 Brightness Index of Narrow-Band Purple Targets

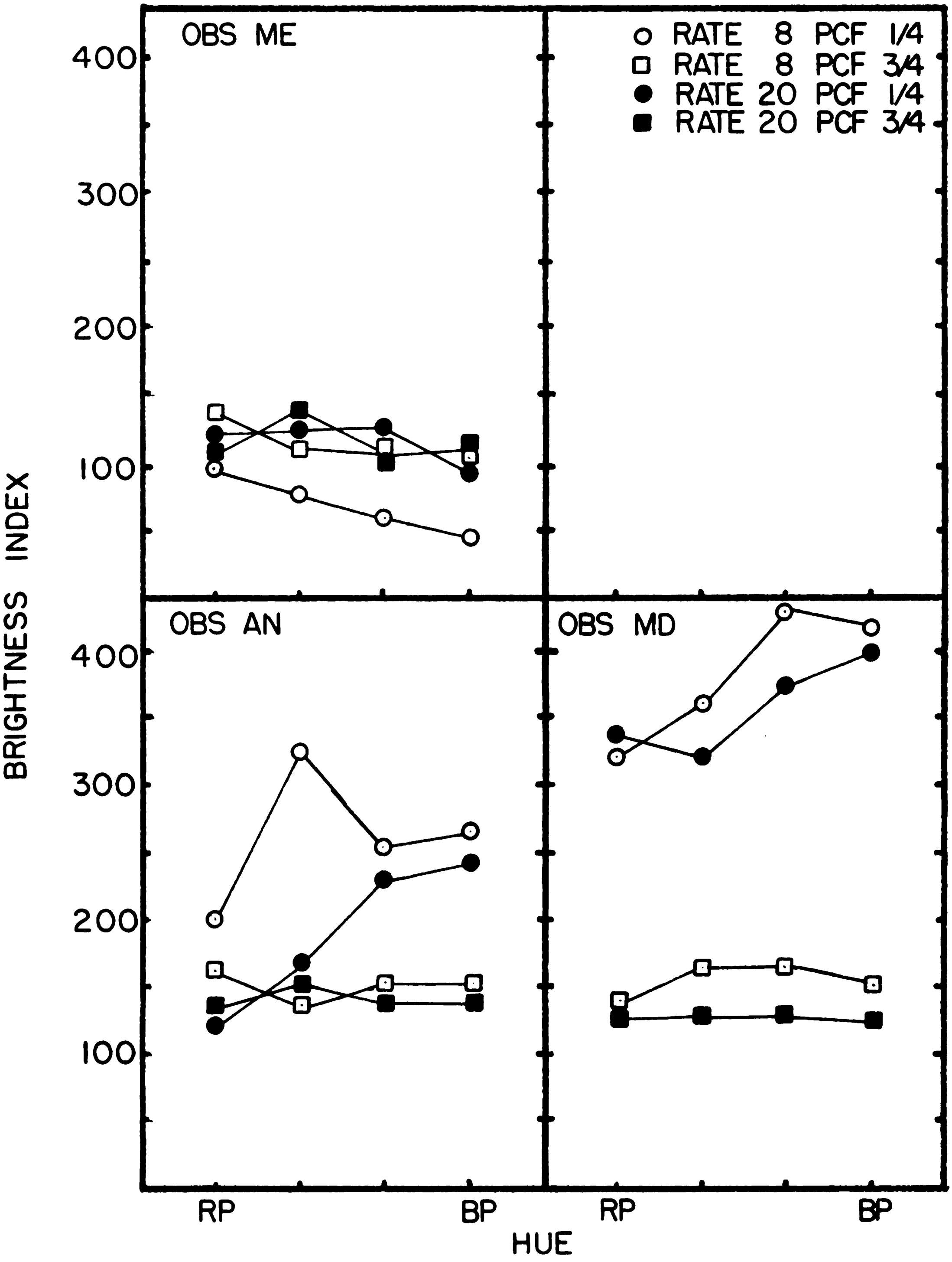

Figure 6 Brightness Index of Wratten Purple Targets

brightness index ranges from 150 to 300 for the four observers. It is clear that in every case brightness index is higher with a PCF of 1/4 than with a PCF of 3/4 though in no case does the increment in brightness reach enhancement level (greater than the brightness of the target when it is continuous in time).

Since luminance was quite low for the narrow-band purples, at the low end of the range in which brightness enhancement has been observed, similar data was collected using Wratten gelatin filters to produce purple hues. These filters allow much wider bands of wavelengths to pass and thus, higher luminosities can be obtained. The data are shown in Figure 6 with red purple to blue purple presented from left to right along the ordinate. Only three observers participated in this portion of the study. The data here generally agree with that collected using the narrow-band purples. With a PCF of 3/4 brightness again deviates very little from Talbot level. With a PCF of 1/4 brightness indices for two of the three subjects again range from 150 to 300. The third subject, M. E., differs dramatically here. Observer M. E. is the subject who was suspected of changing criterion as shown in Figure 4.

In any case it appears from Figures 5 and 6 that increments in brightness do generally occur when a PCF of 1/4 is used with low rates of stimulation and purple hues. Little change in the size of the increment occurs with changes in the degree of redness or blueness of the hue. One rather unexpected result throughout this data is the effectiveness of rate 20. Brightness index is as high or higher with a rate of 20 Hz. as with a rate of 8 Hz. In previous investigation lower rates were found to be clearly more effective (Ball, 1964).

Chromatic Data

Table 2 contains hue data for the various achromatic compositions under the four conditions of intermittency. The observers were asked to report any hue that might be acquired by the targets. The four temporal conditions are listed across the top of the table and the seven target compositions occur in the left-hand column. Within each cell the responses of each of the four observers is listed. Three of the four observers consistently report a blue or purple hue when the PCF is 1/4. Observer M. E. is again deviant reporting a purer white as a result of the intermittency. When the PCF is 3/4 several reports of yellow occur, though observers more often report no hue acquisition here. The most important point here is that for all of the observers the spectral composition of the target appears to have no effect on the hue reported.

Table 3 presents hue shift data for each of the

TABLE 2 Hues Acquired by Achromatic Targets

White Target	Obs.	Rate 8 PCF 1/4	Rate 8 PCF 3/4	Rate 20 PCF 1/4	Rate 20 PCF 3/4
A	ME	whiter	none	whiter	whiter
	MD	blue	whiter	purple	whiter
	AN	blue	none	purple	none
	RB	violet	none	violet	none
B	ME	whiter	none	whiter	whiter
	MD	blue	whiter	purple	whiter
	AN	blue	none	violet	none
	RB	violet	none	violet	creamy
C	ME	whiter	none	whiter	whiter
	MD	purple	yellow	purple	whiter
	AN	purple	none	violet	none
	RB	violet	none	violet	none
D	ME	whiter	none	whiter	whiter
	MD	purple	none	purple	none
	AN	blue	yellow	purple	none
	RB	purple	whiter	violet	whiter
E	ME	whiter	whiter	whiter	whiter
	MD	white	none	purple	whiter
	AN	violet	yellow	purple	none
	RB	violet	none	violet	none
F	ME	whiter	yellow	whiter	greener
	MD	purple	none	purple	purple
	AN	blue	yellow	purple	yellow
	RB	violet	none	violet	none
G	ME	blue	none	purple	none
	MD	whiter	green	none	yellow
	AN	blue	none	violet	none
	RB	grey	none	violet	none

TABLE 3 Hue Changes in Purple Targets as a Result of Intermittency

Hue	Obs.	Rate 8 PCF 1/4	Rate 8 PCF 3/4	Rate 20 PCF 1/4	Rate 20 PCF 3/4
Red Purple	ME	bluer	none	none	none
	MD	bluer	bluer	blue	bluer
	AN	blue	none	blue	bluer
	RB	blue	violet	blue	violet
Purple	ME	bluer	none	none	none
	MD	bluer	blue	blue	bluer
	AN	bluer	none	blue	bluer
	RB	violet	violet	blue	violet
Blue Purple	ME	none	none	none	none
	MD	bluer	blue	blue	bluer
	AN	bluer	none	violet	none
	RB	violet	violet	violet	violet
Wratten Xylene Red	ME	none	redder	none	none
	MD	bluer	bluer	bluer	bluer
	AN	violet	none	violet	none
Wratten D(light)	ME	none	redder	none	none
	MD	bluer	none	blue	none
	AN	bluer	none	violet	bluer
Wratten D	ME	none	redder	none	none
	MD	blue	redder	blue	redder
	AN	violet	none	blue	none
Wratten Methyl Violet	ME	none	redder	none	redder
	MD	blue	none	blue	bluer
	AN	blue	none	blue	bluer

purple hues. Observers were asked to report any change in hue that occurred in the target by indicating the direction of the shift. Temporal conditions are again listed across the top of the table and the names of the hues occur in the column at the left. Within each cell the responses of each observer are listed. It is clear that with a PCF of 1/4, all of the purple hues generally become bluer in quality. With a PCF of 3/4 a shift toward blue is often reported but reports of no hue shift are more frequent.

Figures 7 and 8 present the desaturation estimates for the narrow-band purples and Wratten purples respectively. The data represent judgments made on a nine-point scale which is presented on the ordinate. Hues are again presented along the abscissa with each curve representing a different temporal condition. It is clear that greater amounts of desaturation occur with a PCF of 1/4 than a PCF of 3/4. The difference is larger with the Wratten purples than with the narrow-band hues. No change in amount of desaturation appears to occur with change in the quality of the purple. Though the data on chromatic changes presented here are only qualitative, they demonstrate that a shift toward blue occurs along with a significant amount of desaturation when purples are temporally manipulated.

Table 4 contains judgment data on saturation and hue for the yellow-orange, yellow, and yellow-green

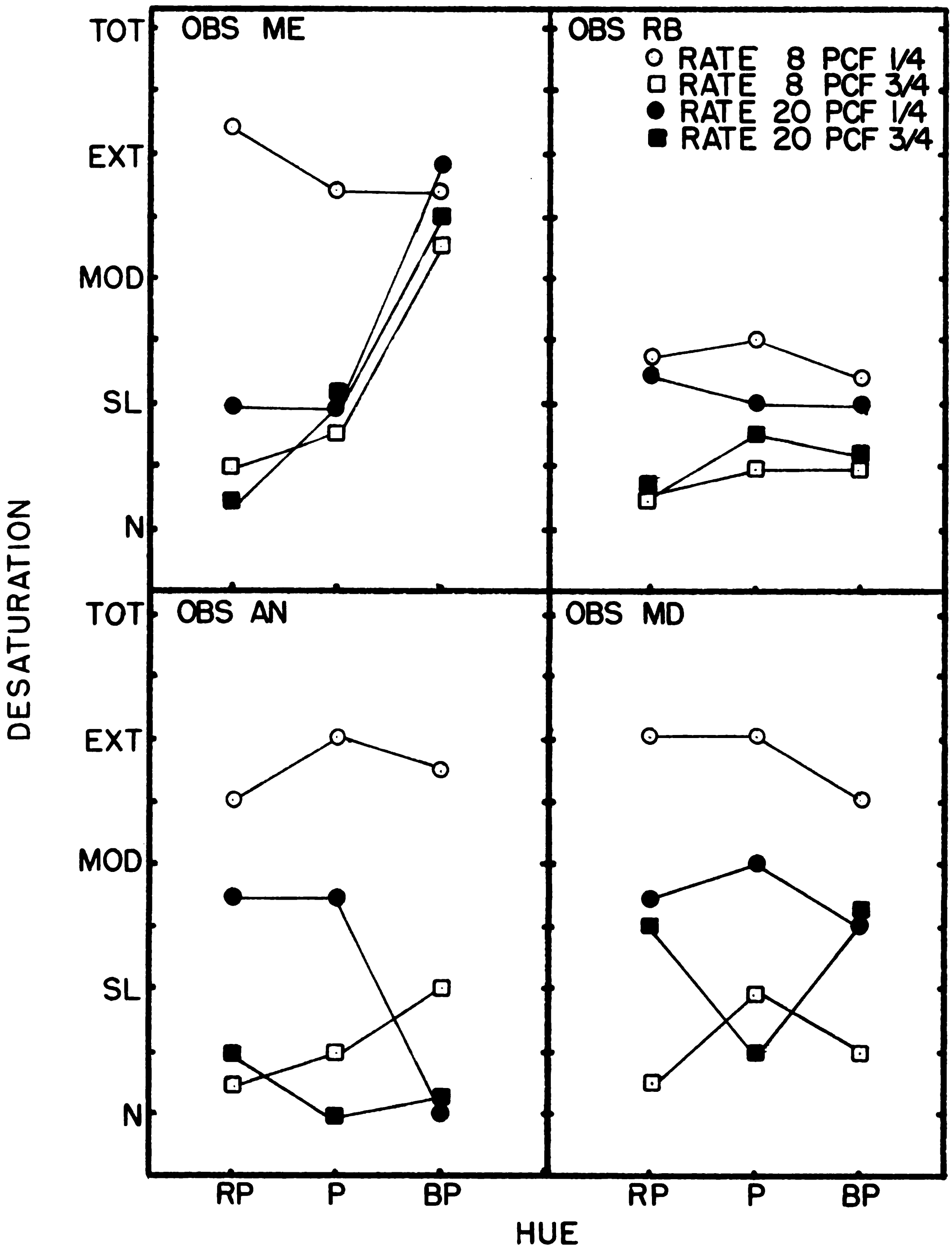

Figure 7 Desaturation Estimates for Narrow-Band Purple Targets

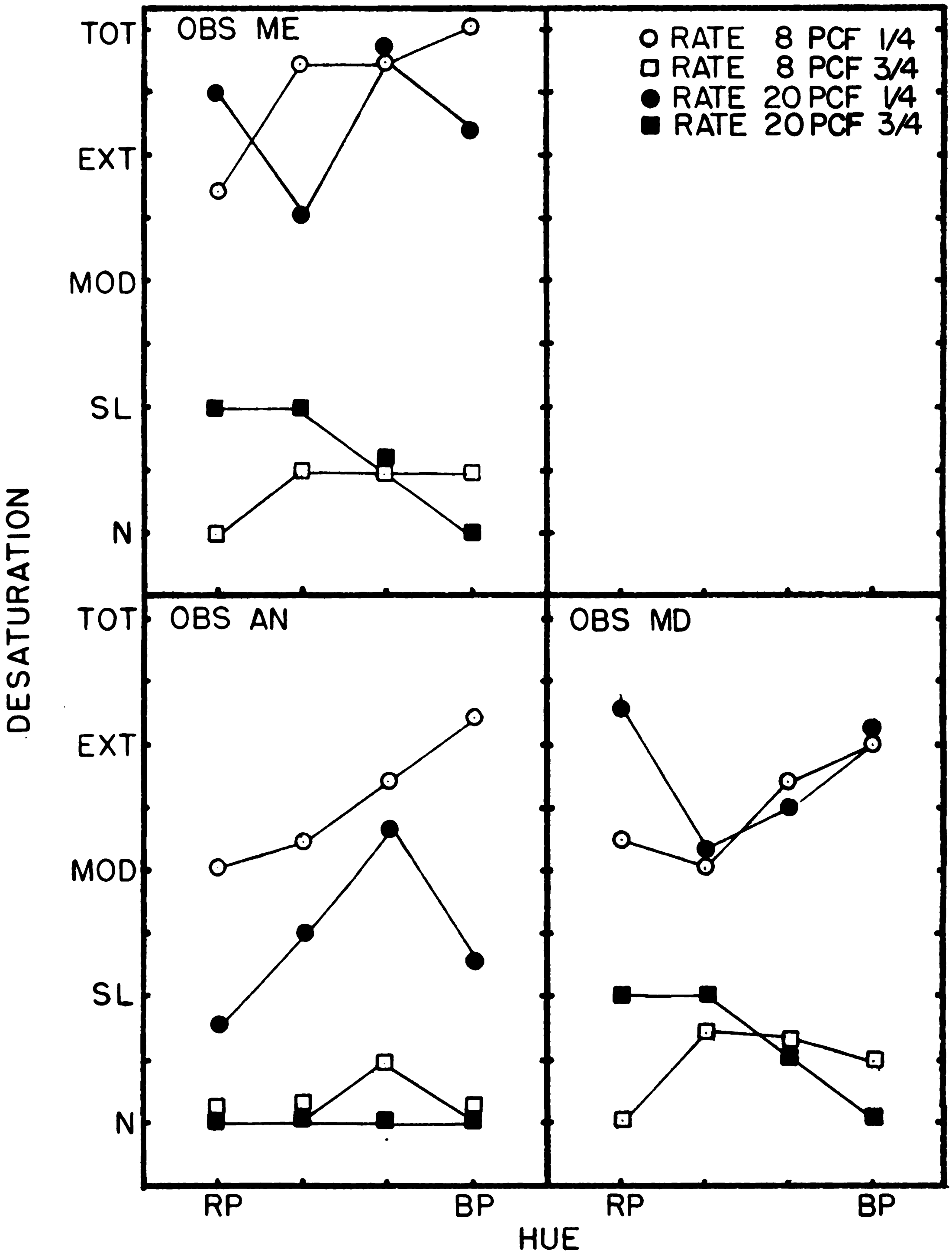

Figure 8 Desaturation Estimates for Wratten Purple Targets

TABLE 4 Comparison of Changes in Chromaticity of Metameric Hues

	Rate 8 PCF 1/4		Rate 8 PCF 3/4		Rate 20 PCF 1/4		Rate 20 PCF 3/4	
Observer	A	B	A	B	A	B	A	B
				ORANGE-YELLOW				
				Hue Shift				
ME	O	O	O	O	←	O	O	O
MD	←	←	←	O	←	←	O	←
AN	←	O	O	O	←	←	←	O
				Desaturation Level				
ME	9	7	1	4	5	5	3	1
MD	5	7	1	3	3	3	3	2
AN	4	8	3	1	4	6	1	1
				YELLOW				
				Hue Shift				
ME	O	O	O	O	O	O	O	O
MD	O	O	O	O	←	←	←	←
AN	←	←	O	O	←	←	O	O
				Desaturation Level				
ME	9	9	1	1	9	9	3	1
MD	7	9	2	2	5	5	1	1
AN	5	5	1	1	1	1	1	1
				GREEN-YELLOW				
				Hue Shift				
ME	O	O	←	←	O	O	O	←
MD	←	←	←	←	←	←	←	←
AN	←	←	O	→	←	←	O	O
				Desaturation Level				
ME	9	9	1	1	9	9	1	1
MD	5	5	1	1	7	7	1	2
AN	5	5	1	1	7	6	2	1

metameric pairs respectively. The major emphasis in this section of the study was to determine whether the temporal programming of the target would differentially effect the two members of a metameric pair. Each rate and PCF is listed again across the top of the table. Columns A and B under each condition contain the data for the two spectral compositions which produce the same hue. Observers are listed along the left-hand edge of the table. The uppermost section under each hue contains hue shift judgments and the lower section the desaturation estimates for each temporal condition and observer. Arrows pointing to the left indicate a shift to a hue of shorter wavelength and arrows pointing to the right indicate a shift toward a hue of longer wavelength. Numbers indicate the level of desaturation on a nine-point scale. Comparison of columns A and B under each hue and condition shows that no consistent differences occur between the two members of a pair. It appears that if there are differential temporal effects, a more sensitive method must be used to detect them.

DISCUSSION

The brightness matching data of this study suggest that temporally induced brightness changes are not dependent in a simple additive way upon the wavelength composition of the stimulus. The results of Ball's 1964 study on spectral stimuli show that the only spectral stimulus whose brightness reaches enhancement level under temporal manipulation has a dominant wavelength of approximately 510 nm. However, the results of this study show that under the same temporal conditions an achromatic target which includes wavelengths at 510 nm does not appear brighter than achromatic targets which do not include wavelengths at 510 nm. Thus, the results tend to suggest that spectral compositions of the target has no direct effect on temporally induced brightness of achromatic targets though chromatic appearance of the target is important. This conclusion must be presented rather tentatively, however, since the data of two of the subjects do show some change with spectral composition of the achromatic target. Earlier in this paper it was suggested that a change in the matching criterion of these subjects occurred during the course of the experiment. It is well-known that variance within a single subject's data is quite high in brightness-matching tasks under these conditions (See Schneider, 1971, for a discussion) and changes in criteria do occur. Evidence for the criterion change was presented in Figure 4, but no explanation can be offered as to why it occurs. In any case it appears that wavelengths around 510 nm are not necessary to temporally induce brightness in achromatic targets.

The brightness matches for intermittent purple targets also show that under some conditions (PCF of 1/4) brightness is two to three times Talbot Level Brightness. This finding was unexpected since in Ball's data (1964) brightness of monochromatic stimuli from either end of the spectrum conform quite closely to Talbot-level predictions. Temporally induced brightness does not appear to be additive in a simple way. The results as a whole seem to suggest that brightness enhancement is directly related to the chromatic appearance of the target but not the spectral composition of the target. Further work on this problem may provide information on the relationship between brightness and hue.

Chromatic judgment data presented in the results section showed that all achromatic targets acquired the same hue as a result of the temporal programming. This result is what might be expected on the basis of classical theory, which supposes that physiological activity within the visual system would be identical for all achromatic targets of equal brightness. It was also found that changes in the chromatic appearance of the purple targets agreed with what might be predicted from temporally induced chromatic changes in the individual monochromatic wavebands of which the target was composed. These results are relevant to the question of the relationship between the hue-saturation shifts and the Subjective Colors phenomena. Nelson (1971) has suggested that both phenomena may result from the same mechanism even though elicited by different spectral conditions. Subjective Colors may be the result of temporal events being selective with respect to hues. That is, "Subjective Colors" may simply result as the summation of the effects on individual hues. The fact that changes in purple hues appear to be the result of just such a process lends support to Nelson's hypothesis. These results suggest that the chromatic appearance of intermittent targets may be vector additive as it is in the color space of classical color research. Further work in this direction may be profitable.

In the final section of this study, it was found that temporally induced changes in chromatic appearance appear to be similar for metameric hues. This conclusion is by no means firm since the data consist of a small number of verbal judgments. It does however lend further support to trends exhibited in all the data on chromatic changes. Results as a whole are consistent with the hypothesis that wavelength information is lost in the visual system.

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