that is, all six items present and in the correct order.

8. A number of alternate scoring methods have seen use in the assessment of relative recall efficiency in split-span studies. [See, for example, N. Moray and T. Barnett, *Acta Psychol.* **24**, 253 (1963).] These range in rigor from a comparison of the number of lists perfectly recalled, with its emphasis on maintaining order information (64.1 compared to 16.7 percent), to simply the total number of digits recalled in any order, a score undoubtedly inflated by guessing (95.9 compared to 87.2 percent). The difference in these two recall conditions, however, is significant for all of the scoring methods used.
9. As seen in Fig. 2, the order of report does not always coincide with the total calculated time in storage. Time in storage is a function of both presentation rate and rate of recall. In successive report, for example, when the subject responds with the first digit of the first channel to be reported, the time in storage is equal to the 500 msec between the first and second stimulus pair, the 500 msec between the second and third pair, plus the time elapsed before his response. Because of the pattern of output rate, this first response has in fact to be retained longer than either his second or his third response.
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14. Supported by PHS grant NS-MH-09767-01 to A.W. and research fellowship 1-FL-MH-41, 1550-01 to D.L.B. We thank Marvin L. White for assistance in fitting the mathematical function in Fig. 2.

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Wavelength Effect on Visual Latency

Abstract. *Chromatic stimuli were matched in luminance to a homogeneous white background field. The relative visual latency, as measured by subjective simultaneity, of 621-nanometer (red) light was 20 to 25 milliseconds less than that for 549-nanometer (green) light. When the chromatic stimuli were different in luminance from the background field, no differences in visual latency related to the wavelength of light were observed. The procedure of matching the luminance of test fields to that of a background field appears to be crucial for observing a visual latency difference related to wavelength.*

Whether visual latency is affected by the wavelength of light is of importance both for theories of color vision and for the explanation of a number of visual effects, such as the Fechner-Benham colors. However, the literature concerning the effect of wavelength on visual latency is contradictory.

Piéron (*1*), using reaction time, reported that wavelength did affect visual latency, with the longer wavelengths having shorter latencies. On the other hand, Holmes (*2*), using the same measure of visual latency as Piéron, reported no dependence of visual latency on wavelength. The studies by Guth (*3*) and Pollack (*4*) appeared to have settled the issue when both investigators, controlling for equality of luminance of the stimuli, found no dependence of visual latency on wavelength. However, heterochromatic flicker experiments (*5, 6*), although not involving direct measurements of relative visual latency, yielded results which indicated that visual latency did, indeed, depend on the wavelength of the stimuli.

An examination of the procedures used in the experiments mentioned above indicates that visual latency differences related to wavelength are found only when the technique of hue substitution is used: a portion of an illuminated background field is replaced by a chromatic stimulus of equivalent luminance. In hue substitution a chromatic change is effected but the luminance remains constant across the entire field. The studies showing no chromatic effect (*2–4*) involved a method of incremental stimulus presentation: chromatic lights were added to a background field to produce test fields higher in luminance than the background field.

Table 1. Interstimulus intervals for perception of simultaneity. The mean and standard error (S.E.) of six points (representing six psychometric distributions) were calculated for each stimulus condition. Positive interstimulus intervals indicate that the top field was first. Negative interstimulus intervals indicate that the bottom field was first.

Subject	Stimulus condition (nm)		Interstimulus interval (msec)		Mean latency difference (msec)
	Top	Bottom	Mean	S.E.	
		Both test fields equal to the background field			
JA	549	621	24.7	1.40	
JA	621	549	−26.5	1.49	26.6*
MI	549	621	21.0	1.60	
MI	621	549	−22.3	2.36	21.7*
		Both test fields raised 0.5 log unit			
JA	549	621	0.5	1.38	0.5
MI	549	621	2.5	1.75	2.5
		Background field lowered 0.5 log unit			
JA	549	621	1.3	1.29	1.3
MI	549	621	1.8	1.04	1.8

* Indicates those latency differences significantly different from zero ($P < .01$).

The studies mentioned above differed with respect to variables other than the presence or absence of luminance increments. I report measurements of the effects of wavelength on visual latency both with and without luminance increments; the same apparatus was used for both measurements. Apparent movement was used as the measure of relative visual latency (*7*). Asynchrony of stimulus onset was manipulated to produce apparent simultaneity.

The primary difficulty in instrumenting a hue substitution experiment is in producing field substitutions without luminance transients. My solution (*8*) was to provide a rectangular background of white light reflected from the front of shutter faces and blades. When the shutter blades were opened by a solenoid, a circular beam of chromatic light from behind replaced the portion of the background white light reflected from the shutter blades. Figure 1 shows the temporal relationships of the test fields and the background field for the condition that green (549 nm) leads red (621 nm) by 25 msec. The image of the shutters was blurred to mask minor discontinuities and eliminate sharp edges (*9*). Before exposure of the test fields the background field was completely homogeneous. The retinal illuminance of the shutter image was 1.04 trolands with an artificial pupil 3 mm in diameter. Two test fields (shown as dotted circles in the inset of Fig. 1), each 0.72° in diameter, were separated vertically by 1° from center to center. A black fixation dot was centered in the space between the edges of the test fields. Chromatic stimuli were produced by Schott 549-nm and 621-nm interference filters (*10*) and heterochromatic flicker photometry was used to equate the chromatic stimuli to the background field. A single light source was used for both test and background fields. Because any variation in the light source affected all fields equally, the test fields remained equivalent in luminance to one another and to the background field. The substitution of the test fields for the background field was checked under the condition of equivalent chromaticity. By viewing through a yellow filter, I verified that the substitution was transient free.

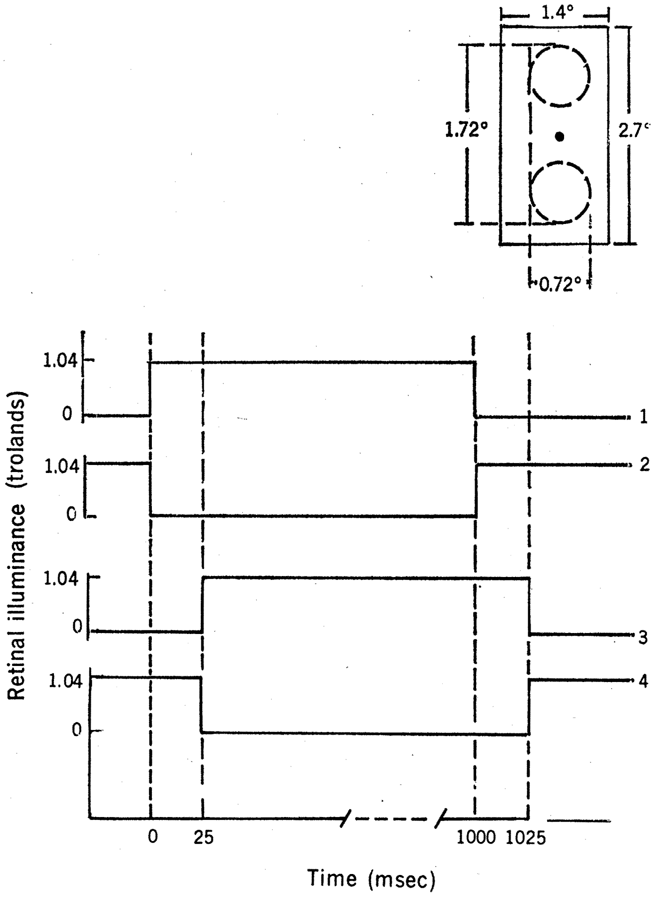
The subjects were two students with normal color vision, one male 23 years old and one female 20 years old, from the University of Chicago. Each had over 80 hours of training in the experimental task before the collection of data. The subject was seated in a darkened room and monocularly viewed the rectangular background (2.7° by 1.4°) through the artificial pupil. A chin-rest provided support. When ready, the subject initiated the trial by pushing a button that caused two colored disks to appear in the background. The subject was instructed to indicate by the words "down," "up," and "none" the appearance and direction of apparent movement (*11*). Each shutter was open for 1 second during each trial, and the subject was instructed to respond before the shutters closed.

The stimuli were presented either with top field 594 nm and bottom field 621 nm, or with top field 621 nm and bottom field 549 nm. Each trial set was composed of nine intervals of ten repetitions each presented by the method of constant stimuli. Trial sets were presented with three conditions: (i) the test fields were equal to the background field (hue substitution), (ii) the test fields were increased in luminance by 0.5 log unit, or (iii) the background field was decreased in luminance by 0.5 log unit.

Figure 2, consisting of data from a single experimental session for each subject, shows representative psychometric distributions for each of the three conditions. In estimating the interstimulus interval that resulted in subjective simultaneity, the time corresponding to the 50 percent "down" response was used.

The results are summarized in Table 1. When the test and background fields were equal in luminance, the subjective simultaneity threshold occurred when green (549 nm) led red (621 nm) by 25.5 msec for subject JA and by 21.7 msec for subject MI. A difference of 0.5 log unit in the luminance of the test fields relative to the background virtually eliminated any subjective difference in latency between the 549-nm and the 621-nm light (*12*). This was true whether the luminance of the test fields was increased or the luminance of the background field was decreased. As can be seen in Fig. 2, the slope of the psychometric function obtained with the condition of hue substitution is shallower than the slopes obtained with the conditions of luminance increments. Even at the largest interstimulus intervals, the frequency distribution for hue substitution never went below 20 percent nor above 80 percent. Both subjects reported greater difficulty in making judgments under the hue substitution condition, which is consistent with the shallower slope of the psychometric function.

The results of this experiment indicate that there are latency differences related to the wavelength of light. The



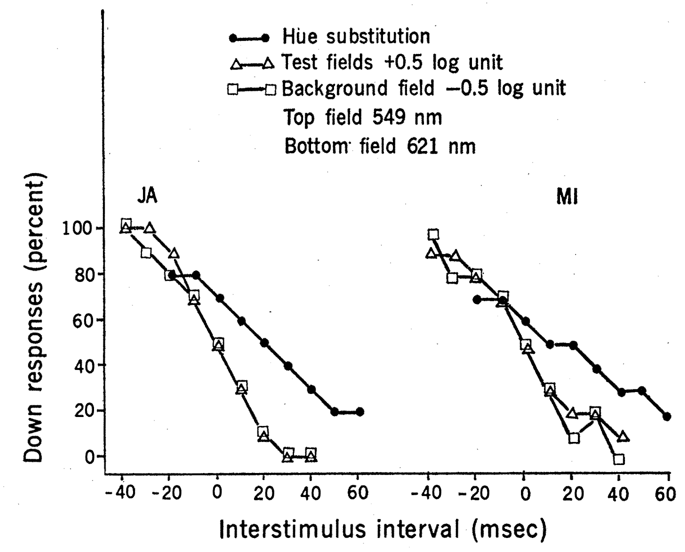


Fig. 1 (left). Presentation of stimuli for the condition green (549 nm) leading red (621 nm) by 25 msec. 1, Onset and offset of 549 nm; 2, offset and onset of the portion of the background replaced by the 549-nm test field; 3, onset and offset of the 621-nm test field; 4, offset and onset of the portion of the background replaced by the 621-nm test field. The portions of the background that were not replaced by the test fields remained at the same luminance throughout the presentation of the stimuli. The inset shows the background field with fixation dot. The dotted circles indicate the areas substituted for by the chromatic test fields. Fig. 2 (right). Representative psychometric distributions for each observer. The frequency of "down" responses as a function of the interstimulus interval is shown for two conditions of incremental stimulus presentation and the condition of hue substitution. Each curve represents a single trial set. Positive abscissa values indicate 549 nm leading 621 nm.

small (1.72°) area subtended by the greatest extent of the test fields makes it unlikely that the results can be explained as being due to rod intrusion. The results I obtained when I increased the test-field luminance are contradictory to those expected for rod intrusion. Decreasing the background luminance by 0.5 log unit should decrease the latency differences if rod intrusion occurs, but it would not produce the 20-msec shift necessary to eliminate latency differences (*13*). Finally, subject JA was tested for two trial sets with the background luminance raised 0.5 log unit above the test-field luminance. Again latency differences were eliminated, contrary to what would be expected from intrusion.

In referring to the effects of wavelength on visual latency, no distinction has been made between effects of wavelength per se, that is, hue, and those of differences in saturation. Since only two wavelengths were used, 549 nm and 621 nm, and these are not of equal saturation, the importance of saturation cannot be evaluated on the basis of these experiments. The results of Vos and Walraven (*5*) and Walraven and Leebeek (*6*) indicate that relative visual latency is inversely proportional to the wavelength of light. Since the relationship between wavelength and saturation does not follow such a relationship, I think that the differences that are reported in this experiment are due primarily to hue and not to saturation.

The discrepant results obtained with the various methods of measuring wavelength effects on visual latency (*1–6*) can be reconciled by my results. Visual latency differences related to the wavelength of light exist, but they cannot be demonstrated if luminance increments are present. Apparently the luminance cues take precedence because they have a shorter latency than chromatic cues.

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10. The stimulus conditions were chosen on the basis of the results of the experiments of Vos and Walraven (*5*) and Walraven and Leebeek (*6*). These stimulus conditions maximized the possibility of finding an effect of wavelength on visual latency. It would be expected that latency differences would decrease with either an increase in overall luminance level or a decrease in wavelength differences between stimuli.
11. Although the response "none" (indicating no apparent movement) was allowed, it was rarely used by either subject; practically all responses were either "up" or "down"; thus, a forced-choice situation was essentially created.
12. A few trial sets were done with 621 nm on top and 549 nm on the bottom, with a luminance difference provided, to check the possibility of a response bias. The results were similar to those obtained with 549 nm on top and 621 nm on the bottom.
13. When both test fields were 621 nm, 0.5 log unit above background, no latency differences were found. Raising the top test field to 1.5 log units above the background resulted in a latency difference of 10.0 msec ($P < .01$). Thus, a difference of 1.0 log unit in luminance was equivalent to a difference of 10 msec in visual latency. With other equipment and a method of incremental stimuli, a difference of 2.5 log units in luminance was necessary to produce a difference of 20 to 23 msec in visual latency, and a difference of 0.5 log unit in luminance did not significantly change the visual latency. These results were reported in F. S. Weingarten [dissertation, University of Chicago, (1971)].
14. Support for this work was provided in part by PHS grants EY-0523-09 and EY-00277-05. I thank Joel Pokorny and Robert Shlaer for their suggestions in the design and execution of this experiment, Nicholas Yasillo for the design of the electronic circuitry, and my wife, Darlene, for encouragement during the course of this work. Jack Altman and Margaret Ikeda served as subjects. This report is based on a dissertation submitted to the department of psychology, University of Chicago, in 1971.

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Dual Mechanisms of Ion Absorption

In his report (*1*) describing a dual pattern of rubidium absorption in *Chlorella*, Kannan states that the species *C. pyrenoidosa* is "nonvacuolate and hence devoid of an inner tonoplast membrane." This key point in his argument that the plasma membrane is the seat of both absorption mechanisms is supported only by citation of a paper (*2*) in which a similar statement appears, but without any evidence or further reference.

In view of the current controversy [references in (*1*)] concerning whether the two types of absorption mechanisms operate in parallel in the plasma membrane or in series in this membrane and the tonoplast, it may be useful to point out that vacuoles have in fact been reported many times to occur in members of the Chlorococcales related to *Chlorella* (*3*, *4*) and in *Chlorella* itself. Ultrastructural evidence for their existence is available for cultures named as *C. ellipsoidea* (*5*), *C. pyrenoidosa* (*6–8*), and *C. vulgaris* (*9*) [an Emerson strain which may not be the same Emerson strain used in (*2*)]. We can add unpublished observations on *C. pyrenoidosa* strain 211-8p (Fig. 1) which show

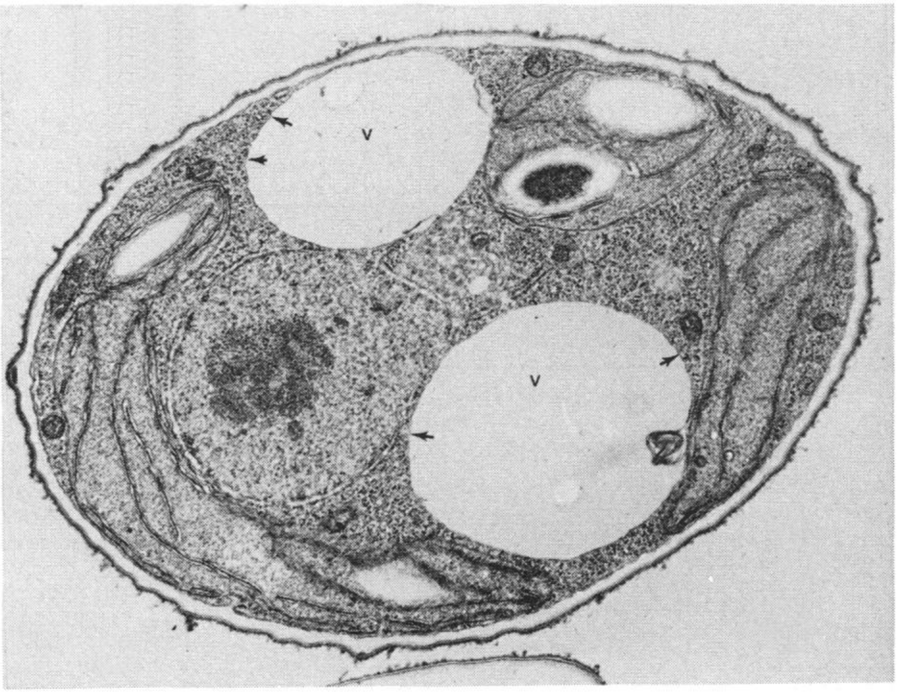

Fig. 1. *Chlorella pyrenoidosa* strain 211-8p showing vacuoles (*V*) and tonoplasts (arrows). Glutaraldehyde-osmium fixation (× 17,000).