Notes and Comment

Two definitions of persistence in visual perception

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It is well known that the perception of a visual stimulus does not terminate with the offset of that stimulus, but decays with time. Although a variety of specific methods have been developed to study this phenomenon, these methods have not always yielded consistent results. We believe that some of the discrepancies in the literature on visual persistence have arisen because different researchers have based their estimates of persistence on qualitatively different features of the visual residual. Efron (1970) asked subjects to temporally align the onset of a click with the offset of a brief flash. Persistence, defined as the interval between flash offset and onset of the indexing click, was found to decrease with increasing flash intensity. Bowen, Pola, and Matin (1974) asked subjects to adjust the temporal placement of a probe flash so that it was coincident with the apparent offset of a spatially separated test flash. Persistence was defined as the interval between test flash offset and onset of the indexing flash. Again, measured persistence decreased with increasing test stimulus intensity. The same result has been reported by Hansteen (1971) using a procedure resembling that of Bowen et al. In a somewhat different approach, Haber and Standing (1969) presented a repetitive cycle in which a stimulus was followed by a blank interval. Subjects were asked to adjust the duration of the blank interval between successive stimulus presentations so as to produce a discontinuity. Once again, persistence, defined by the duration of the blank interval between successive stimuli, declined with increases in the intensity of the test stimulus.

Other researchers, however, using different procedures, have reported that stimulus intensity has the opposite effect on persistence. In one of a series of experiments, Sakitt (1976) asked observers to temporally align the onset of a click with the disappearance of the residual (icon) of a briefly exposed letter array. Her measure of persistence, the temporal inter-

val between the offset of the stimulus array and the onset of the indexing click, increased with stimulus luminance. In a separate experiment, observers were required to adjust the intensity of a 50-msec test stimulus so that its residual filled a click-indexed 500-msec interval. As with the previous procedure, increasing the intensity of the test stimulus produced increased persistence. A similar relation has been reported by Keele and Chase (1967) using the partial report procedure of Sperling (1960): Increases in the intensity of the stimulus array yielded increased persistence, as indexed by the maximum cue delay yielding partial report superiority over full report.

It is possible to reconcile these contradictions with reference to the parameters of the hypothetical persistence decay functions shown in Figures 1a-1c. Three assumptions regarding function parameters are represented graphically in Figure 1a: (1) The strength of the sensory residual of an abruptly terminated visual stimulus is assumed to decay as a negatively accelerated function of time (Brown, 1965); (2) the initial strength of the residual varies with stimulus intensity; and (3) the rate parameter of the persistence function does not decline with increases in intensity. This third assumption implies that the time required for the function to decay by any fixed amount will vary as the inverse of the initial value of the function. Depending upon the task and the specific instructions given, either of two distinct features of the functions shown in Figure 1a could serve as the basis of the persistence judgment elicited from an observer. First, persistence can be defined as the temporal disparity between the objective and phenomenal durations of a stimulus. By this definition, persistence (see Figure 1b) is governed by the minimal interval (i_a) following stimulus offset necessary to yield a detectable decrement (d_a) in the strength of the sensory residual. The detection of this decrement represents the subject's experience of stimulus offset. Procedures tapping this property of the decay functions shown in Figures 1a-1c are measuring what we will call Type I persistence. A second type of persistence relates to the duration of the aftereffect of the stimulus rather than to the phenomenal duration of the stimulus itself. Tasks focusing on aftereffects require the subject to extract information from a visual residual *after* the phenomenal offset of the external stimulus. This type of persistence can be defined as the interval between stimulus offset and the point at which information of a particular (task-dependent) type no longer remains in the fading sensory residual. In terms of the depiction in Figure 1c,

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Figure 1. The effect of stimulus luminance on (a) the decay of the sensory residual following stimulus offset, (b) the measured duration of Type I persistence, and (c) the measured duration of Type II persistence.

measures of this second type are estimating the time (t_b) required following stimulus offset for the strength of the sensory residual to decay below some functional minimum (m). The minimum will, of course, be located according to the informational demands of the observer's task. If the task is to report the identity of a set of alphanumeric symbols, the minimum might be expected to be higher (more stringent) than when the task is to report the disappearance of the residual icon. We will refer to procedures tapping this quality of the sensory residual as measures of Type II persistence.

The techniques used by Bowen et al. (1974), Efron (1970), Haber and Standing (1969) and Hansteen (1971) probably measure Type I persistence. While the specific instructions, response criterion,¹ and indexing procedure differed across the studies, in all four cases the observer's task was to indicate when the test stimulus had terminated, not when its aftereffects had ceased. In all cases, persistence was found to last about 400 msec or less (often much less), and in line with the representation given in Figure 1b, all show declining persistence with increased stimulus intensity.²

Further, we suggest that the click indexing procedures used by Sakitt (1976) as well as the more indirect partial report procedure used by Keele and Chase (1967) both entail the measurement of Type II persistence. As implied by a comparison of Figures 1b and 1c, under favorable conditions, Type II persistence can extend across intervals well in excess

of those associated with Type I persistence measures. Averbach and Sperling (1961), for instance, have reported persistence values of about 5s using the partial report procedure with dark pre- and poststimulus fields, while Sakitt (1976) has obtained click-indexed aftereffects extending out to almost 10s with test stimuli of relatively high luminance. As noted previously, studies of Type II persistence may be further distinguished from those measuring Type I persistence in terms of the effects of stimulus luminance. As implied by the three assumptions listed above, Type I persistence declines with increasing stimulus intensity, whereas Type II persistence increases with intensity.

As we described them, Type I and Type II persistence measures are ideal types. In practice, persistence judgments may often be based on some combination of the two. As ideal types, they may be related to two other temporal phenomena in visual perception—critical flicker fusion (CFF) and positive afterimages. CFF increases with stimulus modulation depth or contrast—the more intense the stimulus at the height of its oscillatory swing relative to its time-averaged luminance, the higher the flicker rate at fusion (Kelly, 1972b).³ Thus, as in Type I persistence, increasing contrast reduces the time needed to reach the decrement threshold. (Note that high CFF values correspond to short persistence values.) Similarly, Kelly finds that CFF decreases with increases in spatial frequency, while Meyer and Maguire (1977), using the Haber and Standing technique, have reported that persistence increases with spatial frequency. The suggestion here is not that Meyer and Maguire are measuring CFF, but that both CFF and the Type I persistence measured by the Haber and Standing method may be similarly influenced by experimental manipulations.

Conversely, Type II persistence seems more akin to positive afterimage phenomena, in that both may last for several seconds under favorable circumstances and both are enhanced by increasing stimulus intensity (Alpern & Barr, 1962; Brown, 1965). There is an intriguing study by Brindley (1962) that measured the duration of afterimages of square-wave gratings by determining the time interval at which the orientation of the grating could no longer be distinguished. He found that this time interval decreased as spatial frequency increased. This result implies that persistence of orientation information decreases as spatial frequency increases, the opposite of Meyer and Maguire's finding. Brindley's procedure measures Type II persistence, as we have defined it, while Meyer and Maguire's method measures Type I persistence, or perhaps some mixture of the two.

Finally, it should be noted that the ideas depicted by Figures 1a-1c represent a highly abstracted functional model of some of the processes involved in visual persistence. No structural assumptions are made. For example, we have not considered the possible involvement of offset transient phenomena in

the determination of Type I persistence, nor have we dealt with the specific mechanisms underlying Type II persistence under varying conditions of stimulation (e.g., Adelson, 1978; Sakitt, 1976). Rather, the major point of this note is that, depending upon the task, instructions, and possibly even the variables that are manipulated by the experimenter, subjects may use different aspects of the sensory residual upon which to base their estimates of persistence. A failure to distinguish Type I and Type II persistence can easily lead to apparent empirical contradictions.

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NOTES

1. Efron (1970), Bowen et al. (1974), and Hansteen (1971) specifically asked subjects to judge stimulus offset. The instructions given by Haber and Standing (1969) are less clear. In their case, the subject was required to manipulate the interval between successive stimulus presentations so that a clear discontinuity was apparent. While this instruction possibly is subject to more than one interpretation, the measured persistence values yielded by it agree reasonably well with those of Bowen et al. (1974).
2. This implication does not critically depend upon the simplifying assumption, depicted in Figure 1b, that detectable decrements (d_a) in the strength of the sensory residual remain invariant across levels of stimulus intensity. The implication requires only that the increases in d_a produced by increasing stimulus intensity do not fully compensate for associated increases in the rate at which the residual decays with time.
3. The relationship of CFF to time-average stimulus luminance or adaptation level, as opposed to modulation depth, is quite different. Kelly (1972a) reports that CFF values are unaffected by the average retinal illuminance under photopic conditions. In general, studies of visual persistence have not systematically separated the effects of luminance from those of contrast. Researchers using tachistoscopes (Haber & Standing, 1969) have generally varied luminance while keeping contrast constant (Dick, 1974). Researchers who have used lights or lamps (Bowen et al., 1974) as target stimuli have changed both luminance and contrast.

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