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DEVELOPMENTAL CHANGES IN THE PROCESSING OF VISUAL INFORMATION

by

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Abstract

Studies of developmental trends in visual information processing have tended to concentrate on subject populations less than 20 years of age. Techniques developed to examine temporal factors in visual persistence and visual masking are often employed, but rarely in concert in a manner which would help define the relationship between these phenomena. In the present study 48 subjects ranging in age from 19 to 83 years of age performed in three separate tasks. The tasks were designed, respectively, to investigate: (1) duration of visual persistence in segregation of events, (2) duration of visual persistence in integration of contours, and (3) duration of the interval in which backward masking may be effective. In all three tasks monotonic increasing functions over age were obtained, indicating decreased speed of processing as age increased beyond physiological maturity. The results support an active processing model of visual perception that interprets duration both of visual persistence and of interval in which backward masking is effective, as indicative of the time course in early visual processing of stimulus features. As well, however, differences in the shape of age-related functions among tasks indicate that persistence in temporal (segregation) and spatial (integration) resolution may be mediated by distinct mechanisms which operate in parallel,

and that backward masking performance represents the operation of a more complex combination of related mechanisms. These data thereby also support a model which conceptualizes the visual system as a multichannel processor. An integration of the active processing and multichannel models was proposed. In addition, it was suggested that investigation of developmental differences may prove to be a highly fruitful analytic tool in the future development of theories in human visual information processing.

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As Turvey (1977) indicates, a fundamental feature of contemporary theory in visual information processing involves "the analysis of visual perception into discrete temporal cross sections perpendicular to the flow of optical information." This approach implies a breakdown of visual information processing into an early stage which is purely visual, and later stages which may include interaction with memory, as well as interaction with the other sensory modalities. The temporal range of this early stage may correspond with persistence in the visual system, which, in the normal human adult, extends to a maximum of about one quarter second after stimulus onset under photopic conditions or one half second under scotopic conditions (Haber and Standing, 1970).

This period of persistence is also correlated with saccadic eye movements, which occur every quarter to half second and reposition retinal images on a fresh set of receptor cells. Visual persistence is thought to be indicative of the time required for completion of parallel processing in extracting features from visual stimuli (Di Lollo, 1977; Efron, 1973; Haber, 1971). The maximum duration of persistence, then, may represent a limit on time allocated for initial processing of a discrete visual array. This interval is not necessarily fixed, as amount of information to be analyzed and the demands of the task may vary between stimulus arrays. Tasks employed in measuring duration of persistence typically are of two types. The first employs successive presentation of spacially overlapping stimuli with the minimum interstimulus interval at which discontinuity of presentation is detected serving as an estimate of the lower limits of persistence. The second employs successive presentation of spacially adjacent contours of one stimulus figure with the maximum interval over which the figure may be integrated as a whole serving as an estimate of the upper limits of persistence. Studies in visual persistence, then, are concerned with how successive stimuli may be combined in the construction of images in perception.

Variations on the above techniques have evolved to examine how the effects of successive presentation of stimuli may interfere with the construction of images in perception, in studies concerned with what is termed visual masking. Visual masking refers to the diminished perceptibility of a brief visual test stimulus along such parameters as brightness, clarity, and detectability when either preceded or succeeded in close temporal order by a spacially adjacent or overlapping masking stimulus. Studies utilizing this technique are concerned with investigation of temporal and spacial factors in the perception of contours. Masking studies may provide indications of visual system capacity for temporal resolution (Eriksen and Spencer, 1969), segregation of contours (Breitmeyer and Ganz, 1976; Fehrer, 1965, 1966; Uttal,1970), and processing load (Scheerer, 1973; Spencer and Shuntich, 1970). The bodies of literature in visual masking and persistence complement one another in examination of temporal factors in early visual processing.

In the present study methodologies designed to investigate visual persistence and visual masking were used to examine developmental changes in processing speed among human adults. The temporal ranges over which visual persistence and visual backward masking are effective were examined in adults between 19 and 83 years of age. The intents of the study were: (1) to establish perceptual norms across this age range, (2) to further define relationships between persistence and masking effects, and (3) to determine whether examination of developmental performance functions may be of assistance in assessing the validity of current theoretical models of visual system operation.

Efficiency in Perception and Processing Speed

In any organism an effective perceptual system functions to provide a maximum amount of relevant information about the environment within a minimum period of time. Increases in the amount of information processed per unit of time or increases in the relevance of information processed would represent increased efficiency in the system.

In humans improvements occur as maturation progresses through late infancy to early adulthood (Mackworth and Bruner, 1970). Scanning eye movements of children appear to become less random as they mature and selective attention to aspects of visual stimuli which offer the most information develops concurrently. These improvements appear to be related to cognitive development and learning effects (Makcworth and Bruner, 1970; Vurpillot, 1968), and level off by late adolescence. Other improvements in perceptual efficiency such as reduced vulnerability to masking effects appear to be related to increases in speed of processing visual information correlated with physiological maturation and minimally to learning (Haith, Morrison and Sheingold, 1970; Liss and Haith, 1970; Pollack, 1965, 1968).

Studies examining visual information processing in adults, however, indicate that while processing speed peaks at late adolescence, it begins to decrease at some point after middle age is achieved (Eriksen, Hamlin and Breitmeyer, 1970; Kline and Szafran, 1975; Wallace, 1956; Walsh, 1976; Walsh, Till and Williams, 1978; Welsandt, Zupnick and Meyer, 1973). The nature of this change has been explained in terms of increased duration of persistence delaying readiness to accept new stimuli, or increases in time required to process information in the feature extraction stage, or both (Gummerman and Gray, 1972).

The distinction between persistence and feature extraction processing time arose from the conceptualization of persistence as read-in time to a sensory store (iconic memory) which commences at stimulus offset, and feature extraction processing as read-out to longer term memory (Gummerman and Gray, 1972). However, Di Lollo (1977, 1979) obtained data indicating that persistence commences at stimulus onset. It is possible that persistence and feature extraction processing share similar time frames and that measures of both may be indicative of common or related components in early visual processing. In any case, demonstration of longer persistence in one observer versus another for the same stimulus would indicate that for the former, the interval between acquisition of input from visual stimuli and transfer of that input in feature analyzed form to the next stage of processing (i.e., interaction with memory) may be longer. Speed of visual information processing, and therefore, visual system efficiency, would be lower for the former observer.

Visual Persistence

Investigation of persistence effects has been approached using two distinct methodologies. One approach (e.g., Pollack et al., 1968, 1969), using segregation tasks, involves successive presentation of spatially overlapping or adjacent congruent stimuli to an observer. The interval between presentation of stimuli is adjusted until the observer just barely detects the successive presentation of events. The interval between presentation of stimuli then serves as a measure of minimum persistence duration since some element of persistence of a preceding stimulus must cease before onset of a succeeding stimulus may be detected. Tasks of this nature demonstrate temporal limits in segregation of events, and it is conceivable that extent of duration and developmental trends in this aspect of persistence may differ from those in integration of contours, although they have not been differentiated in the literature to date.

The second approach (e.g., Di Lollo, 1979) using *integration* tasks, involves successive presentation of contour components of a stimulus figure to an observer. The interval between presentation of components is adjusted until the observer successfully constructs the complete stimulus figure. The total interval over which components have been presented then serves as a measure of *maximum* persistence duration since the initial component must persist until the final component is included in the figure. Tasks of this nature demonstrate temporal limits in integration of contours and therefore may be indicative of temporal parameters in processing contours at the feature extraction stage.

There appear to be no studies on developmental trends in duration of visual persistence employing temporal integration tasks other than the study of Arnett and Di Lollo (1979) which demonstrated no significant differences in persistence in integration among children from 7 to 13 years of age. In two studies employing temporal segregation tasks, Pollack, Ptashne and Carter (1968, 1969) used darkness threshold between two successive light flashes as a measure of persistence among children and adolescents. In both studies a monotonic function of persistence decreasing over age was found through the full range of population tested (6 to 10 in 1968, 6 to 17 in 1969). These results could be interpreted as consistent with the concept of persistence as an indicator of processing time, as studies (Haith, Morrison and Sheingold, 1970; Liss and Haith, 1970) have demonstrated a correlation between maturation and increasing processing speed.

O'Niell and Stanley (1976) used pulsed lines rather than flashes of light to obtain measures of persistence among dyslexic and normal readers at 12 years of age. The dyslexics demonstrated significantly longer persistence than the normal readers and O'Niell and Stanley attributed this result to a lag in development of the visual system among dyslexic children. It appears, then, that decrements in duration of persistence and by inference, decrements in processing time, may occur concurrently with physiological maturation into late adolescence. The relationship between persistence and processing time at later ages is less clear, however, because to date, minimal research has been conducted on persistence in older adults.

There are some data on age-related changes in the human visual system in older subjects which may be interpreted in terms of persistence. The methodology used in examination of critical flicker frequency (CFF) involves successive presentation of a series of light pulses to an observer and variation of the frequency of the pulses. As pulse frequency increases, the observer reaches a point at which the pulse series appears to be a continuous light. At this point, segregation of events fails; therefore, the interval between pulses may serve as a measure of minimum duration of persistence. Data from developmentally oriented CFF studies indi-

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cates that as age increases beyond about 30, CFF decreases, which may be interpreted as indicative of increases in duration of persistence (Weale, 1965). This trend may be related to age-related trends in processing time which have been demonstrated in studies using backward visual masking techniques, which will now be considered.

Backward Visual Masking and Temporal Integration

In studies of backward visual masking, presentation of a brief test stimulus is succeeded in close temporal order by presentation of a spacially adjacent or overlapping masking stimulus. If the stimulus onset asynchrony (SOA) is sufficiently short, discriminability of the test stimulus may be degraded either through integration of its contours with those of the mask or through interruption of its processing due to introduction of novel contours from the mask. Failure to identify the test stimulus in the interruption case could indicate that feature extraction processing was terminated prior to completion, or that transfer of feature information to higher levels of processing was disrupted. At least some aspects of the test stimulus may be fully processed when interruption masking is effective, since observers may discriminate onset and location of test stimuli even when unable to identify contours (Fehrer and Raab, 1962).

Failure to identify the test stimulus in the integration case, however, appears to be due to failure to differentiate between test and mask contours because they are processed together as one event. It may be inferred then, that feature processing of the test stimulus probably had not ceased by the time the mask entered the visual system, and that therefore mask contours were incorporated in construction of the test stimulus pattern. The stimulus parameters and task requirements employed in obtaining integration and interruption masking effects are dissimilar, as are their magnitude functions across SOA (see Figure 1).

Insert Fig. 1 about here

The function obtained in integration masking may be obtained by employing a masking stimulus of unpatterned random visual noise in a task which demands detection of features in the test stimulus. Discrimination of the test stimulus fails because the subject is unable to differentiate between features in the test and masking stimuli. The function obtained in interruption masking may be obtained by employing a contoured or patterned visual noise masking stimulus in a task which demands identification of features in the test stimulus. Discrimination of the test stimulus fails because commencement of processing for the masking stimulus interrupts initial processing and transfer of feature information to higher levels of processing (Kahneman, 1968). The shape of the magnitude function for integration masking at positive SOA is similar to that obtained in duration of persistence with maximum effect at 0 SOA decreasing monotonically to cease near 250 msec., while that of the interruption masking function is dissimilar with relatively low effect at 0 SOA, rising, then decreasing as SOA increases. Both techniques provide indices of speed of processing in the feature extraction stage, however, and similar developmental trends have been demonstrated in the literature.

In interruption masking tasks among younger subjects, Gummerman and Gray (1972) found processing speed to increase as a function of age among subjects ranging in age between 7 and 20 years. Liss and Haith (1970), Miller (1972), Munsinger and Gummerman (1967) found similar functions within age, ranging from 4 to 20 years. In an integration masking task Arnett and Di Lollo (1979) obtained similar results among children ranging in age from 7 to 13 years.

In studies which have produced results representative of performance in older subjects, Walsh (1976) found that 64 year olds required more time to process information than 20 year olds in an interruption masking task and Walsh, Till and Williams (1978) obtained similar results with equivalent age groups using an integration masking task. The combined data from among younger and older subjects suggest a hypothesis of processing speed increasing with age up to some point, perhaps middle age, then decreasing.

The developmental trends demonstrated in backward masking studies are relatively consistent. However, concentration on changes between infancy and early adulthood means that less information is available on changes later in life. As well there appears to have been no research conducted on persistence in temporal integration among older age groups. Comparison of methodology and results in studies of masking and temporal integration of contours (Di Lollo, 1979), suggests that the effects examined may involve related processes. A combined investigation might be productive in clarifying the relationship. Failure to escape the effects of a visual mask at brief SOA may also be related to failure to segregate events at brief SOA in tasks examining minimum duration of persistence. Thus, in the present study three tasks were employed to investigate developmental trends among older age groups: (1) segregation of visual events, (2) integration of contours, and (3) backward masking via integration of contours.

Methodology of the Present Research

To minimize biases related to experience, display configurations which should be equally unfamiliar to all observers were employed in the three tasks. The response options available to subjects in all three tasks were controlled through the use of forced choice techniques. Two of the tasks were designed to obtain indices of duration of visual persistence, one dealing with segregation of events and the other dealing with intergration of contours. The third task employed detection of a target stimulus which was followed by a field of random visual noise to obtain an estimate of processing time in backward visual masking by integration.

The subjects were grouped according to chronological age with group one at 19 to 31 years, group two at 45 to 57 years, group three at 58 to 70 years and group four at 71 to 83 years. Volunteers to complete an originally planned 32 to 44 age group were extremely difficult to obtain; therefore, examination of this age range was deferred for later investigation.

A. The Segregation Task. The task employed to examine minimum persistence in segregation of events was identical to that used by O'Niell and Stanley (1976), with the addition of brightness equalization procedures which they did not employ to minimize extraneous brightness cues (see Appendix A). The test stimulus consisted of a vertical line presented in two spacially overlapping 20 msec. bursts, with an inter-stimulus interval (ISI) which varied in duration between trials. A comparison stimulus identical in extent and brightness to the test stimulus and with duration equal to total duration of the test stimulus was presented either before or after the test stimulus. A subject's task was to identify which of the two line presentations in a trial involved a double flash. At sufficiently long ISI, the double presentation is easily detectable and accurately differentiated from the comparison stimulus. At shorter ISI, however, segregation of events in the test stimulus fails and performance in discriminating between the test and comparison stimuli falls to chance level. An accuracy criterion of 75% was used to determine at which minimum ISI each subject was capable of segregating events in the test stimulus.

B. The Integration Task. The task employed to examine maximum duration of persistence in integration of contours was identical to that used by Arnett and Di Lollo (1979). Two 5 x 5 square dot matrices were presented concurrently on an oscilloscope screen and in one of the matrices a randomly selected dot was missing. The dot locations in both matrices were filled sequentially in random order with interdot intervals which varied between trials. A subject's task was to identify which matrix was missing a dot. If total presentation time is sufficiently brief, the first dot presented remains available (i.e., persists) in the subject's visual system until the twenty-fifth dot is presented. In this situation all the dots presented may be integrated into one complete and one incomplete matrix, permitting accurate identification of the incomplete matrix. If, however, presentation time is extended, the first dots may no longer persist until the last dots are presented, and there appear to be a multiplicity of holes in both matrices. Performance at this point falls to chance level. An accuracy criterion of 75% was again applied to determine at which maximum total plotting time each subject was capable of integrating features in the stimulus.

C. The Backward Masking Task. The task employed to examine effects in backward visual masking by integration was also identical to that used by Arnett and Di Lollo (1979). The test stimulus consisted of two 5 x 5 square dot matrices with the centre dot missing from one matrix. A random visual noise masking stimulus of the same intensity, boundaries, and number of dots as the test stimulus succeeded presentation of the test stimulus with SOA which varied between trials. A subject's task was identification of the incomplete matrix. At sufficiently short SOA the test and masking stimuli may be integrated within a subject's visual system, so that the display appears to be two equally dense squares of randomly distributed dots. Performance should be at chance level in this condition. An accuracy criterion of 75% was once more applied to determine at which minimum SOA each subject was capable of escaping from the effect of backward masking by integration.

It should be noted that the test stimulus in the backward masking task differs from that of the preceding integration task in that missing dot location is fixed rather than random. In preliminary investigation with random dot location, Arnett and Di Lollo (1979) found that younger children were unable to consistently escape masking effects within the duration of one saccade. To preclude confusion with the effects of saccadic suppression the task was simplified. As this consideration might also apply to older adults in the present study, the simpler task was employed.

In all three tasks the SOA at which 75% accuracy is achieved served as an estimate of each subject's capacity for temporal segregation of events, temporal integration of features or escape from the effects of backward masking. Note that the total plotting time between first and last dots in the temporal integration task is equivalent to SOA between presentation of those dots.

Method

Subjects

Forty-eight subjects were tested, 12 in each of four groups corresponding to chronological age ranges of 19 to 31, 45 to 57, 58-70, and 71 to 83 years. The subjects were unpaid volunteers recruited from among members of Royal Canadian Legion Branch No. 97, Winnipeg, Manitoba, Canada and residents of retirement centres operated by Age and Opportunity Inc., in the same city. Additional volunteers were recruited through advertising and articles in the Winnipeg Tribune, Winnipeg Free Press, and staff and student newspapers at the University of Manitoba and the Health Sciences Centre, Winnipeg, Manitoba. Only subjects with normal or corrected to normal visual acuity were employed.

Apparatus

Visual stimuli were displayed on a Tektronix 602 oscilloscope with fast P15 phosphor. Data collection and control of displays were accomplished by a PDP 8/L computer.

The subjects sat in a dark room observing the displays at a distance of 50 cm. through a viewing hood. A foot pedal was provided to allow subjects control over display initiation and two hand held buttons were used for responding. A Baush and Lomb model 71-34-40 Snellen Chart projector was used to test for visual acuity.

Stimuli and Procedures

A. The Segregation Task. The test stimulus was a line of 2 cm (2.4° visual angle) vertical extent and .16 mm in width, centred on the screen. The full extent of the test stimulus was presented in two spacially overlapping 20 msec bursts, with an ISI between presentations which varied between 1 and 220 msec., for a maximum total time of 260 msec. [well within previously obtained limits of persistence (e.g., Pollack, 1968)]. The comparison stimulus was a vertical line of the same extent and location as the test stimulus, presented continuously over a duration equal to the presentation time of both portions of the test stimulus plus the interval between them. Intensity of the displays was sufficient for comfortable viewing and adjusted so that subjective brightness of test and comparison stimulus were matched (see Appendix A). The display surface was dimly illuminated to aid focusing and convergence. To aid and standardize subject fixation on the screen, two faint fixation dots flanking the location of the display stimuli were presented in the centre of the screen between trials.

Subjects were informed that their task was to observe two presentations of a vertical line, and to determine which of the presentations showed the line in a double flash. A subject pressed the foot pedal to initiate each presentation, and after presentation of both test and comparison stimuli, signified a double flash in the first by pressing a button in his left hand, or in the second by pressing a button in his right hand. The computer program randomized order of presentation of test and comparison stimuli and as well imposed a minimum 500 msec. delay between presentations. Each subject was familiarized with the display in a training condition in which SOA was long and segregation of events in the test stimulus could be performed without difficulty.

The extent of SOA within the test stimulus in each trial varied under the control of an adaptive psychophysical computer program developed by Taylor and Creelman (1967), termed PEST (for Parameter Estimation by Sequential Testing). A run would commence with the program randomly selecting an initial ISI between 1 and 220 msec. and conducting a block of trials at that ISI while recording subject performance. A Wald (1947) sequential likelihood ratio test (Wald) was integrated with the PEST program to determine whether subject performance was above or below a 75% correct accuracy criterion. If performance was above or below 75% the PEST program would increase or decrease ISI by 24 msec. and conduct a new series of trials. If a subsequent required change in ISI was in the same direction as the preceding, the change would be doubled to 48 msec. If the change required was in the opposite direction, it would be halved to 12 msec. This process of increasing and decreasing ISI continued until an adjustment of less than 12 msec. was required. The run would then end and the parameter estimate produced would be the SOA in effect prior to the required change, plus 6 msec. in a direction opposite to that chnage to split the difference between performance levels above and below 75%. To preclude premature ending of the run, trials were presented in blocks of six. Since fractions of six are either greater or less than 75%, not equal, accidental performance of 75% in the initial series could not be achieved.

Each subject performed four runs of the task to program exit. The average time per run was two to five minutes and the briefing lasted about ten minutes. Each subject then completed the task within one half hour. The mean of the parameter estimates from the four runs served as an estimate of the minimum duration of persistence for each subject.

B. The Integration Task. The test stimulus consisted of two 5 x 5 square dot matrices arranged side by side about the centre of the screen and with a separation of 1 cm. (1.2° visual angle). Each matrix was 1 cm. square, for a total horizontal extent of 3 cm. (3.6° visual angle). In each trial one dot of the 50 possible dot positions was not presented. The location of the missing dot varied randomly from trial to trial under computer control. Pairs of dots from both matrices were presented in sequential order with an inter-dot-interval which varied from trial to trial so that the total presentation time ranged from 3 msec. to 3.175 μsec. Each dot was plotted once only for 1.5 msecs, with intensity equal and of sufficient magnitude to make the display comfortably visible. The oscilloscope was calibrated so that a standard square test patch yielded a reading of .42 lux on a Tektronix J16 digital photometer. Figure 2 is an example of the display configuration in task 2.

Insert Fig. 2 about here

To aid and standardize fixation on the screen a faint fixation dot was presented in the centre of the screen between trials. As well, the display surface was dimly illuminated to aid focusing and convergence.

At commencement of the task subjects were informed that they must determine whether a dot was missing from the matrix on the left or the matrix on the right. Prior to familiarization with the equipment, they were introduced to the task through the use of flash cards analogous to display stimuli.

Subjects were then introduced to the oscilloscope display in a training condition in which presentation of all dots was effectively simultaneous. Once subjects indicated that they were sufficiently familiar with the display arrangement and equipment they proceeded to perform the task proper. Subjects were instructed to initiate a display by pressing the foot pedal, to observe the display and to decide which matrix was missing a dot, and then to indicate an incomplete right matrix by pressing a button in their right hand, an incomplete left matrix by pressing a button in their left hand.

The PEST program controlled duration of inter-dot-interval in the same fashion as ISI was controlled in the segregation task. The maximum sequencing step was 4.8 msec., the minimum 1.2 msec., to permit reasonably fine changes in total duration of the display.

Each subject performed four runs of the task to program exit. The subject running time was approximately the same as that for the first task. The mean of the parameter estimates produced over four runs was multiplied by the number of dots in a complete matrix -1, to derive total plotting (presentation) time. This index served as an estimate of the maximum duration of persistence in integration of contours for each subject.

C. The Backward Masking Task. The test stimulus consisted of two 5 x 5 square dot matrices identical in extent to the configuration in the integration task. Presentation of all dots was effectively simultaneous over 3 msec. and the centre dot was missing from the left or right matrix in each trial. Selection of the matrix to be presented incompletely varied randomly from trial to trial under computer control. Following an SOA which varied between 4 and 512 msec., a random visual noise masking stimulus consisting of 50 dots and within the same bounds as the test stimulus was presented over 3 msec. Light intensity of the test and masking stimuli were equal and sufficient to permit comfortable viewing. To preclude subjective brightness differences due to temporal summation, dot locations plotted in the test stimulus were excluded from presentation in the masking stimulus. As in the integration task a single fixation dot was presented between trials, and the display surface was dimly illuminated.

Subjects were informed that the task they must perform was determination of whether the centre dot was missing from the left matrix or the right matrix. Familiarization proceeded as in the integration task, with a training condition in which the masking stimulus was not presented. Instructions for interacting with the equipment were essentially the same as those for the integration task. The PEST program controlled SOA duration in the same fashion as ISI and total plotting interval were controlled in the persistence tasks with maximum sequencing steps of 48 msec. and minimum steps of 12 msec.

Each subject performed four runs of the task to program exit. Subject running time was approximately the same as that for the previous two tasks. The mean of the parameter estimates produced over four runs served as an estimate of the minimum SOA for escape from the effects of masking by integration in each subject.

Each subject completed the entire experiment within two hours, including time for briefings and rest. The order of task presentation was counterbalanced between subjects to compensate for fatigue and practice effects.

Results

No member of the 71-83 age group was able to complete the integration or backward masking tasks and, in fact, no one was able even to discriminate between complete and incomplete matrices in the instrument training conditions for these tasks. One subject in the 58-70 group (age 63) was unable to complete both these tasks, and another in the same group (age 66) was unable to complete the integration task. To permit retention of data for these latter two subjects in computerized statistical tests, group means were substituted for the missing data. As everyone in the 71-83 age group was able to complete the segregation task, a one-way analysis of variance (ANOVA) across all age groups was employed for the data on this task, in addition to omnibus and trend multivariate analysis of variance (MANOVA) for all three tasks across the first three age groups. Pairwise between-group comparisons using the Tukey method (Kirk, 1968) were also employed to substantiate differences between age-related performance functions in each task. Appendix B contains: Table 1 with performance means and standard deviations for each group within each task, and Tables 2, 3, and 4 with between-group comparisons for, respectively, the segregation, integration and backward masking tasks.

The indices of performance in the three tasks are not identical. However, their relationship is sufficiently close to permit comparison. Inter-Stimulus Interval is the measure of choice in the segregation task because the duration of the dark interval necessary to permit detection of offset of the initial test stimulus line has been generally accepted as the dependent variable in segregation tasks (Pollack et al., 1968, 1969). Total Plotting Interval is the measure of choice in the integration task because pattern integration commences at onset of the first dot. It should be noted that total plotting interval in the integration task is equivalent to SOA between the first and last dots in the test stimulus. Stimulus Onset Asynchrony (SOA) is used in the backward masking task because the interval between commencement of test stimulus processing and commencement of mask stimulus processing is of interest. The essential difference between these measures lies in definition of when the processes under investigation commence. Figure 3 is a graph in which mean performance is described as duration of effect (i.e., largest interval at which 75% accuracy performance was maintained) this permits simultaneous plotting of results for the three tasks for the first three age groups.

Insert Fig. 3 about here

Figure 3 shows that performance in the segregation task does not change appreciably as a function of age between 19 and 70, increasing slightly from 50 to 55 msec. between the first two age groups, then remaining at 55 msec. in the 58-70 group. The absence of age-related effects over this age range in the segregation task is confirmed by statistically non-significant results in the MANOVA (univariate F = 1.15, $p < .3296$, Standardized Discriminant Coefficient (SDFC) = -.1936). The group mean for the 71-83 group (not plotted in Figure 3) rose to 72 msec., however, indicating a relatively sharp change in performance. This suggests that while performance in segregating temporally discrete events may remain stable in humans up to approximately the age of 70, it may decline thereafter. This inference was supported statistically by results of the one-way ANOVA applied to data across all four groups completing the segregation task [$F(3,44) = 9.37$, $p < .0001$]. Pairwise between-groups comparison in the segregation task also confirmed that no significant change in performance occurred prior to that of the 71-83 age group (see Table 2 in Appendix B).

While data from the 71-83 group could not be obtained in the integration task, Figure 3 shows that in contrast to results of the segregation task, performance in integration of contours does change within the 19-70 year range. Duration of persistence in integration of contours rises from 61 to 65 to 85 msec. across the groups tested to produce a monotonic increasing function across age within the 19-70 year range. Note that increase in duration of persistence in the integration task represents an increment in performance, such that on average, a 20 year old could not perform the integration task at the longer total plotting intervals as well as a 70 year old. The increase in duration of persistence in integration of contours as a function of age is confirmed by results of the omnibus MANOVA (univariate $F = 9.39$, $p < .0006$, SDFC = .4981) and MANOVA trend analysis indicates that the age-related function demonstrates a significant linear trend ($F = 14.25$, $p < .0007$, SDFC = .4455). Between-groups comparisons in the integration task confirm that a significant change in performance occurred between the 45-58 and 58-70 age ranges (see Table 3 in Appendix B).

Data for the 71-83 age group were also unobtainable in the backward masking task, but Figure 3 shows that across the age range 19-70, time required to complete processing of the test stimulus changes markedly with age, rising from 62 to 112 to 140 msec. Furthermore, the magnitude of change appears to be considerably greater than that in either of the persistence measuring tasks. Age-related changes in performance in the backward masking task were confirmed by statistically significant test results in the omnibus MANOVA (univariate $F = 16.56$, $p < .0001$, SDFC = .8357) and the age-related function possesses a significant linear component (univariate $F = 33.10$, $p < .0001$, SDFC = .8669). Note that the SDFC for this task in both omnibus and trend MANOVA is extremely high, indicating that a large portion of the variance in performance in this task is not shared with other tasks. Between-groups comparisons in the backward masking task indicate that all three groups which completed the task performed differently. However, while group means for the 45-57 and 58-70 groups are different, variability in other groups was relatively high, such that statistical significance of the difference between groups did not attain the $p < .05$ level (see Tables 4 and 1 in Appendix B).

In summary, significant age related changes in performance across the age range 19-70 were demonstrated in both the integration and masking tasks, with magnitude of change in the latter being considerably more prominent than in the former. Performance in the segregation task did not change between 19 and 70, but a shift did occur between 70 and 83. Although the direction of change in all three tasks showed age-related increases in visual processing time, individual task functioning appear sufficiently divergent to indicate that each task tapped some different components in early visual processing.

Finally, a note on the statistical analyses employed is in order. The use of repeated measures ANOVA has been recommended for use in studies with multiple or repeated measures when the measures possess a comparable scale of measurement and when the assumption of homogeneous covariance is reasonable. The MANOVA has been recommended for use in such studies when conditions for repeated measures, such as homogeneity of covariance, are not met because MANOVA accurately estimates the experimentwise probability of a type 1 error across the package of dependent variables simultaneously (Gabriel and Hopkins, 1974). Variance between tasks in the present study was not homogeneous; therefore, MANOVA was selected (see Table 1 in Appendix B). The omnibus and trend MANOVA employed in analyzing the results of the present study provided reliable overall error terms in both the omnibus [$F(6.62) = 6.21$, $p < .0001$] and trend [$F(3,31) = 12.91$, $p < .0001$] analyses. Univariate statistics and multivariate discriminant function coefficients for the three tasks among the first three age groups are included in Table 5 in Appendix B.

The standardized discriminant function coefficients included in Table 5 may permit some determination of how much variance in each task was unique to that task. These coefficients represent weights applied to each measure in a linear combination of variables which best discriminates between groups of subjects. The high coefficient for performance in the masking task within the linear combination suggests that the task measure includes components which are not common to the other tasks. The moderately high coefficient for the integration task suggests some sharing of variance while the low coefficient for the segregation task suggests that this measure accounts for little of the age-related changes across the groups tested in the MANOVA.

Discussion

In general, the results of the present study may be interpreted as supportive of an active processing model in early visual information processing. Performance in backward masking tasks is generally accepted as indicative of the time course of early visual processing (Gummerman and Gray, 1972; Liss and Haith, 1970; Spitz and Thor, 1968) and developmental masking functions have demonstrated increases in duration of processing as a function of age beyond maturity (Walsh, 1976; Walsh, Till and Williams, 1978). Increases in time required to process the test stimulus in a backward masking task accompanying increases in age have been demonstrated in the present study, in conformity with previous results.

Duration of persistence in integration of contours is also thought to provide an index of the time required to complete feature extraction processing of visual stimuli (Di Lollo, 1977, 1979; Efron, 1973; Hogben and Di Lollo, 1974). Since processing time in backward masking studies has been shown to increase as a function of age, consistency in the model would require that similar functions be demonstrated with duration of persistence in integration of contours. The age-related increase in duration of persistence demonstrated in the integration task of the present study provides evidence to indicate that the active processing model of persistence is viable. However, the considerable difference in the slope of the masking and integration age-related functions may indicate that the masking task may involve more complex levels of processing than the integration task.

Persistence in integration of contours increases in duration with increases in age. If persistence were a unitary phenomenon it might be expected that persistence in segregation of temporally discrete events would tend to increase in the same manner. The results of studies in the area of CFF may be interpreted as providing some support for this concept (Weale, 1965). However, the contrast between integration and segregation age-related functions in the present data with the segregation function remaining virtually flat to age 70, indicates that the phenomenon of persistence is not unitary. While performance in both persistence tasks in the present study indicates that persistence increases with age, the divergent developmental functions of the two tasks imply that different mechanisms my be involved in integration of contours and segregation of events.

Each of the tasks in the present study, then, appears to be providing information on at least some different components in early visual processing. Since each task apparently provides some measure of distinct processes, further discussion will involve detailed analysis of each task in turn, in the order in which they were originally presented in the present paper. Cross comparisons of tasks will be made as the sequence of discussion makes it appropriate.

A. The Segregation Task

Previous studies into minimum duration of persistence in segregation of events have concentrated on younger observers and extrapolation of trends into older ages has varied with the theoretical orientation of the experimenter. Pollack et al., (1968, 1969) explained decreasing persistence between 6 and 17 years as a function of deterioration due to aging in the receptor system and predicted a continued decreasing trend beyond maturation. They were aware that CFF studies indicated that persistence in fact increased with age beyond approximately 30, but were unable to resolve the discrepancy. Interpretation of these results within an active processing model would treat decreasing persistence towards maturity as indicative of an increase in processing speed correlated with maturation. Furthermore, the model would predict increasing persistence to accompany aging beyond maturity, indicating decrease in processing speed correlated with reductions in post-maturational neural efficiency.

Results in the segregation task of the present study indicate that persistence does in fact increase with age, but differ from CFF literature in that the latter indicates changes commence at about age 30 while results of the present study show little or no change before 70. One possible explanation for the disparity may be related to the stimulus conditions, in that subjects observe a continuous series of light flashes in CFF studies whereas in the present study subjects were required only to discriminate between a double or single presentation of the stimulus. It is possible that differences in light adaptation level between continuous and discrete stimuli may contribute to differences between the derived developmental functions (e.g., differences might include changes in neural relative refractory periods).

B. The Integration Task

The data from the present study indicate that duration of visual persistence in integration of contours remains relatively stable at 60-65 msec. from the late teens to 45-57, then increases to 85 msec. by 58-70 years of age. In comparison with the flat function in segregation of events over the same age range this suggests that age-related changes in the nervous system may begin to affect performance in pattern integration tasks earlier in life (57-70) than in temporal segregation tasks (71-83). This raises the possibility that the two tasks tap the functioning of different mechanisms which may be differentially sensitive to age-related changes in the nervous system. Current theory (e.g., Pollack et al., 1968, 1969) treats visual persistence as a unitary phenomenon rather than postulating a system which responds differentially to situations involving temporal discrimination (the segregation task) and pattern discrimination (the integration task). There is some evidence from studies investigating spatial frequency effects that may indicate that differential mechanisms operate in parallel in processing spatial and temporal information (King-Smith and Kulikowski, 1975; Kulikowski and Tolhurst, 1973).

Spatial frequency refers to the density of discrete visual contrasts per degree of visual angle. In studies investigating spatial frequency phenomena (e.g., Legge, 1978a; Sharp and Hart, 1973), a sine wave is typically employed to generate an array of vertical gratings on an oscilloscope screen with each cycle producing two contrast borders. Sharpness of the contrast border is manipulated by varying amplitude of the sine wave. Spatial frequency of the stimulus is expressed in terms of cycles per degree of visual angle, such that a low spatial frequency display might involve generation of one contrast per degree and a high spatial frequency display might involve generation of 30 contrasts per degree (Legge, 1978a). The dependent measure is detectability of the contrast at specific combinations of sine wave amplitude and spatial frequency. Studies in spatial frequency provide data which indicate that contrast sensitivity of the visual system varies as a function of the spatial frequency of a stimulus display. It appears that this function is a composite from a series of visual system channels, each differentially sensitive to a limited region of the spatial frequency spectrum (Sekuler, 1974; Tolhurst, Sharp and Hart, 1973).

Sekuler (1974) describes this spatial frequency organization of the visual system as analogous to that for colour vision, in which the overall sensitivity function of the photopic system is a combination of three colour sensitive channels. If the human visual system is organized in multiple channels for processing of spatial information, then the possibility that separate (albeit, parallel) mechanisms for temporal and spatial discrimination exist may be a viable concept. Temporal discrimination in flicker detection thresholds and spatial discrimination in pattern recognition thresholds occur at differential sine wave amplitude and vary independently as a function of spatial frequency (contrasts per degree of visual angle) and temporal frequency (temporal frequency is contrast shifts per second, equivalent to flicker frequency in CFF studies). Flicker detection at a constant temporal frequency (flicker rate) is maximal at low and medium spatial frequencies while pattern discrimination is maximal at medium and high spatial frequencies (King-Smith and Kulikowski, 1975; Kulikowski and Tolhurst, 1973; Legge, 1978a; Tolhurst, Sharp and Hart, 1973).

The segregation task in the present study may be conceptualized as a flicker detection task with a low spatial frequency stimulus, and therefore might tap the functioning of a discrete visual system mechanism which is optimized for temporal discrimination. Further, this mechanism may be less affected by age-related changes in the visual system than a pattern discrimination mechanism, since performance in the segregation task remained relatively stable to the 58-70 age group. Insofar as accurate performance in the integration task is contingent upon pattern resolution, and horizontal spatial frequency of the stimulus is moderately high (about four elements per degree of visual angle), the integration task may be conceptualized as fitting some parameters of pattern resolution tasks in spatial frequency studies. As will be recalled, the segregation task fits some parameters for temporal resolution tasks; therefore, the proposition that differences in performance between the two tasks over age may indicate the operation of differentially optimized mechanisms may be valid.

It is possible that mechanisms involved in processing spatial configurations are more complex than those which process temporal variations. If so, perhaps the earlier onset of age-related changes in the integration task may be due to greater vulnerability of these mechanisms to the loss of efficiency in the nervous system which accompanies aging.

In addition to differences in the derived developmental functions in the integration and segregation tasks over the 19-70 year age range, it is interesting to note that significant change in segregation task performance did not occur before the 71-83 age group, and that no member of that same group was able to complete either the integration or backward masking tasks. It should be emphasized that failure to complete these tasks did not appear to be related to loss of motivation in the face of increased difficulty, as subjects in this group were persistent in attempting to perform the task, with some members insisting on continuing in the training condition for up to half an hour. It may be that visual system efficiency within this age range has declined to the point where highly complex stimuli can no longer be rapidly processed. However, as the integration task was designed to permit subjects to use lower processing speed to achieve higher performance, the predicted result under such conditions would be improved performance relative to subjects with faster processing rather than inability to complete the task. An explanation which deals in terms of reduced acuity might provide a simpler resolution of the problem, and will be discussed in detail following examination of the backward masking task.

C. The Backward Masking Task

In the present study performance in the backward masking task declined steadily across the age range 19-70 and the magnitude of the age-related change was markedly greater than that in either of the persistence tasks. The direction of the change was as predicted, but the magnitude of difference between masking and integration functions was not predicted within the active processing model.

It is interesting to note that performance levels for the integration and masking tasks are very similar in the 19-31 age group. On the basis of like similarities in previous literature (Di Lollo, 1979), and the paucity of developmental literature on these phenomena, it was originally expected that the two tasks would produce similar developmental functions. The backward masking task is conceptualized as involving backward masking through integration of contours, and since test stimulus configurations in the masking and integration tasks are similar, it was thought that the derived functions would be similar. The added complexity of the masking stimulus was not expected to appreciably extend time of processing of the test stimulus if that processing was completed before masking stimulus onset. In view of the relatively large differences between the functions obtained, it appears possible that in addition to reducing test stimulus discriminability through integration, the effect of the masking stimulus also included components which interfered with, or interrupted, resolution of the test stimulus at more central levels of processing. If this is so, then the increased complexity of the processing mechanisms involved might result in even more vulnerability to age-related loss of nervous system efficiency than in the integration task, and demonstrate proportionally greater age-related changes in performance. The function derived in the backward masking task, then, might represent components of the combined operation of mechanisms involved in discrimination of temporally discrete events and discrimination and feature acquisition processing of contoured visual stimuli. As such it may involve processing at both peripheral and central levels. The masking task, then, may have been the most sensitive of the three tasks employed in the present study in terms of discriminating between age groups, but may conversely have been the least discriminating between structures functioning within the visual system, since tasks which could isolate those mechanisms might permit more analytic separation of effects.

It is essential to note that while longer test-mask effective SOA in the masking task reflects a decrement in performance, integration over a longer total plotting interval in the integration task represents an increment in performance. The integration task was designed to permit subjects with longer persistence in pattern discrimination (by implication longer processing time) to perform better at longer total plotting intervals than those with faster processing. This means that a 70 year-old can perform better in the integration task than a 20 year-old.

Increases in processing speed in the masking task and the integration task have opposite effects upon the performance of these tasks but since performance in both tasks is plotted as an index of processing speed, their developmental functions change in the same direction. However, other common contributing factors may tend to increase the disparity between these developmental functions. Masking effectiveness over age may be increased by age-related decreases in acuity and reduced light level at the retina (Weale, 1965) while the same factors may counter improvements in the integration task. This may be exemplified by the failure of subjects in the 71-83 age group to discriminate between complete and incomplete matrices in the training condition of both tasks. Subjects in this group invariably reported being unable to detect a missing dot despite scoring 20/30 or better on a Snellen eye test. The matrices in the masking and integration tasks are relatively unfamiliar to all observers, and provide little in the way of extraneous cues to identity of the incomplete figure. A Snellen eye test, however, uses alphabetic characters which are almost invariably highly familiar to observers and which may include a wide variety of configurational cues to identity, even if not clearly visible. It is proposed that exposure to totally novel stimuli may indicate markedly less absolute visual acuity than may be determined by the use of familiar stimuli such as those in the Snellen test.

D. Theoretical Integration

Earlier in the present paper explanations of some of the results obtained made reference both to an active processing model for visual information processing and to a multichannel model of the visual system. An examination of the relationship of aspects of these models to one another may provide for conceptual integration of the two classes of model.

A considerable body of evidence has accumulated which indicates that the operation of the visual system as a whole may be a combined function of the operation of a variety of discrete channels. These channels may include mechanisms differentially sensitive to discrete classes of hue and spatial frequency (Sekuler, 1974) to temporal and spatial aspects of stimuli (Kulikowski and Tolhurst, 1973; King-Smith and Kulikowski, 1975), and to movement (Tolhurst, Sharp and Hart, 1973).

Multichannel theories which explain the integration of temporal and spatial information in terms of inter and intra-channel inhibition have been formulated (Breitmeyer and Ganz, 1976). These theories are not fully developed, however, since at present we are unable to estimate even the number of channels which might exist in the visual system, much less how each channel may operate in relation to others. Further limitations are that much of the spatial frequency data available has been collected using stimuli which vary only across the horizontal plane, and interpretation has often included (with circumspection) an assumption of homogeneity of receptive fields within the visual system (Sekular, 1974).

Despite these limitations, however, there does appear to be sufficient data in the literature to indicate that the visual system is organized along the lines of a multichannel processor. A general version of the multiple channel model is likely to be of considerable utility in helping to describe many aspects of visual system operation.

In addition to making explanatory use of a multichannel model, reference has been made in the present paper to an active processing model of visual information processing (Di Lollo, 1979). This model has evolved through analysis of spacio-temporal interactions in vision investigated in the literature on visual masking and persistence. The active processing model treats performance in visual masking tasks as indicative of the time required to execute early visual processing at a feature acquisition level, and treats duration of visual persistence as an outcome of similar ongoing activity in early stages of visual information processing (Di Lollo, 1979). This model is also of considerable utility in helping to explain aspects of visual system operation but has generally been treated as an alternative to a multichannel interpretation rather than as a complement.

Treatment of these two models as alternative rather than complementary conceptualizations of the visual system has perhaps been a product of assignation of different neural loci to their interpretation of visual system operation (receptive fields in the multichannel model, visual cortex feature detectors in the active processing model). There is a general tendency in psychology to seek confirmation of models in physiological correlates. Certainly it is valuable to find physiological structures whose components appear to function according to a model and it may be helpful to relate those structures to the function one wishes to describe. However, at present, there is simply too little physiological data available on neural specificity to lock psychophysical models to specific nervous system loci (Sekuler, 1974).

A levels of processing approach (e.g., Turvey, 1977) permits construction of models based on logical analysis of operations which must be performed. For example, we are fairly certain that a visual stimulus must be effectively detected before it can be effectively identified. Both operations may include a multitude of overlapping parallel activities in discrete channels but the priority of the operations is not logically reversible. If described in terms of levels of processing, multichannel models and activity processing models of visual information processing may be viewed as complementary rather than as conflicting constructs. Conceptualizing the multichannel model as a breakdown of the active processing model into subcomponents permits integration of these theoretical approaches.

In the present study three tasks designed to examine duration of persistence in segregation of events and in integration of contours, and effective interval of backward visual masking, respectively, were employed to investigate post maturational developmental changes in early visual information processing. Performance in all three tasks provided monotonic functions which indicate that increases in time required to process visual information accompany increases in age. The magnitude of the backward masking function and its particular sensitivity to age-related changes confirm masking as a multicomponent phenomenon which may represent an index of total visual system efficiency. The differential age-related functions for persistence in temporal segregation of events and in integration of contours seem to support the concept that channels exist in the visual system which are differentially sensitive to temporal and spacial classes of information. At one and the same time the data also suggest that these differential channels "age" at different rates.

A major implication of the above results is that further research into age-related changes may have considerable theoretical utility. For example, investigation into spacial frequency effects might benefit from examination of differences in developmental changes among hypothetically discrete visual channels. The possibility that discrete functional mechanisms may change differentially over age brings forward the use of developmental functions to confirm and/or detail differences in the operation, complexity and vulnerability of these mechanisms. With regard to the visual system in particular, thorough and analytic investigation of developmental differences may serve to isolate discrete components in human information processing.

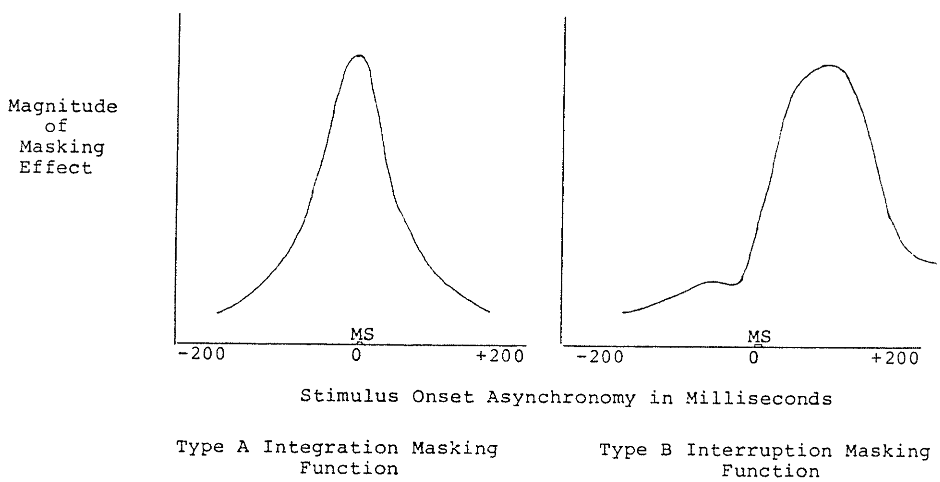

Figure 1. Magnitude of Effect Function for Integration and Interruption Masking (from Kahneman, 1968).

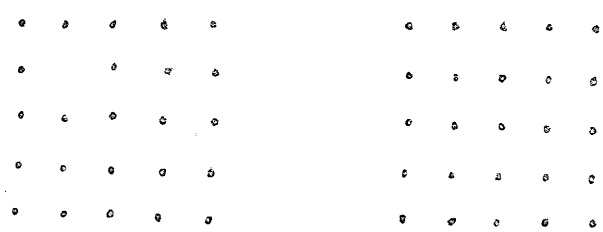

Figure 2. Negative Image of Display Configuration in the Matrix Integration Task.

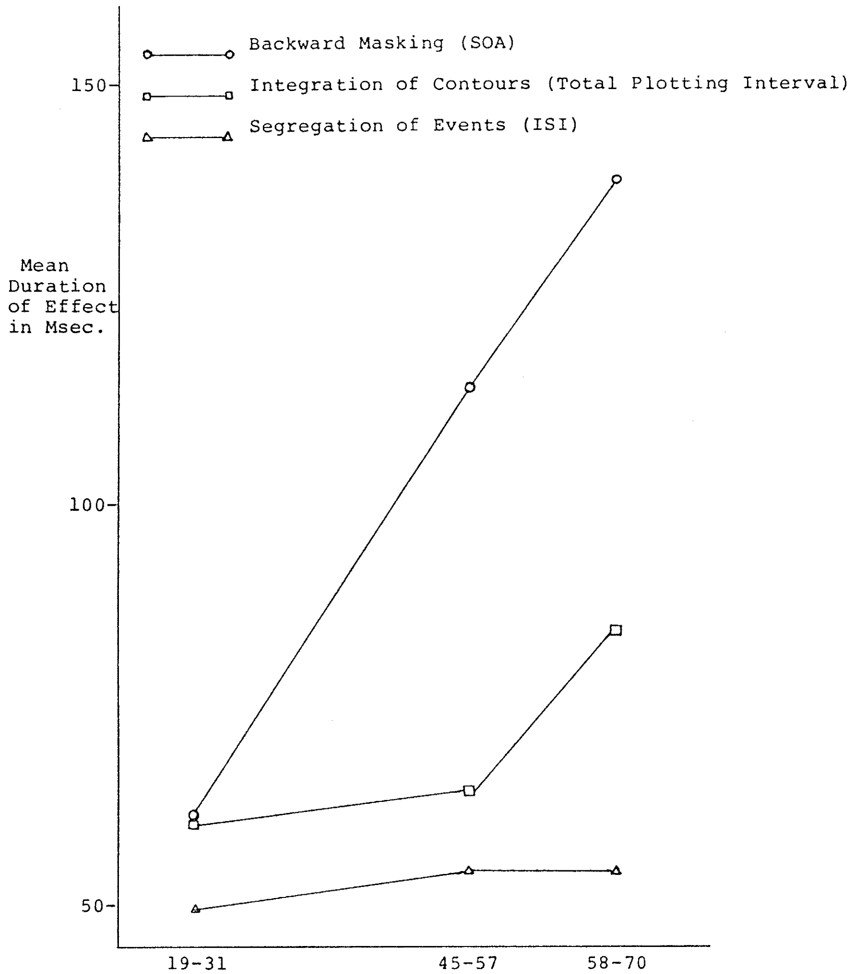

Figure 3. Mean Duration of Effect in Segregation, Integration, and Backward Masking Tasks as a Function of Chronological Age.

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APPENDIX A

Appendix A

The computer system used for this research is equipped with three digital to analog converters (X, Y, and Z) to drive the display oscilloscope. The Z axis defines the intensity of each dot from dimmest (invisible) to brightest (almost flaring) in 1024 steps.

The intensity level of the oscilloscope is set so that a standard patch of 15 rows of 15 dots each, covering an area 6 mm square, plotted at a fixed Z value registered a reading of .42 lm/m^2 on the lux scale of a Tektronix J16 digital photometer. The value of .42 lux was chosen because it provides a comfortable level of visibility for all displays in the study.

The display configuration in the segregation task poses special problems because a time/intensity reciprocity condition exists for light stimuli less than approximately 100 msec. in duration (Bloch's Law) such that a light pulse of, for example, 20 msec. would demonstrate half the subjective brightness of a 40 msec. pulse at the same intensity (Boynton, 1972). Since the maximum duration of the "light on" portion of the test stimulus is 40 msec. (two 20 msec. bursts with an interval between) and the "light on" duration of the comparison stimulus is 40 msec. plus duration of the interval, intensity of the test stimulus must be adjusted to ensure equal brightness between stimuli. As well, the brightness level of flickering stimuli tends to be a function of the mean luminance over time (Talbot's Law); therefore, adjustments must be made to compensate for the "light off" portion of the test stimulus.

A line brightness comparison task was administered to 4 subjects of various ages to provide intensity adjustment parameters for the segregation task computer program. In part one of the compensation task a comparison line of fixed intensity and 128 msec. duration appeared simultaneously alongside a test line of duration between 32 and 220 msec. when the subject pressed a button to initiate the display. The initial intensity of the test line was randomly set within $\pm$ 17% of the comparison line. Buttons were provided to permit the subject to increase or decrease the intensity of the test line. Subjects were instructed to adjust intensity and re-initiate the display until the two lines appeared to be equally bright. Values were obtained for intensity settings on test lines ranging between 32 and 220 msec. in duration in 4 msec. steps. In part one of the task, intensity settings permitting compensation for time/intensity reciprocity effects were derived.

In part two of the task the comparison line was a continuously presented line of duration between 40 and 200 msec. and with intensity derived from part one. The test line consisted of two 20 msec. bursts with an interval between bursts such that total onset to offset time was equal to that of the comparison line. Procedure was identical to that in part one. Part two of the task provided intensity settings to compensate for luminance averaging effects in flickering stimuli.

The values derived in part one were applied to intensity settings for comparison stimuli in the segregation of events program and the values derived in part two were similarly applied to the test stimuli. Thus, comparison and test stimuli in the segregation of events task are of equal duration, eliminating extraneous cues related to total duration differences, and are of equal brightness, eliminating extraneous cues due to brightness differences. The results of previous studies of this nature may have been confounded because such cues were not controlled.

APPENDIX B

Appendix B: Tables

TABLE 1

Means and Standard Deviations of Group Performance as a Function of Task

	Age Group							
	19-31		45-57		58-70		71-83	
Task	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
Segregation Task	50	6	55	14	55	6	72	14
Integration Task	61	10	65	12	85	20	-	-
Backward Masking Task	62	17	112	34	140	43	-	-

TABLE 2

Differences Between Age Group Performance Means (in milliseconds) in the Segregation Task

		Differences			
Groups	Means	19-31	45-57	58-70	71-83
19-31	50.3	-	4.8	5.0	21.6*
45-57	55.1	-	-	.2	16.8*
58-70	55.3	-	-	-	16.16*
71-83	71.9	-	-	-	-

*$p < .01$

TABLE 3

Differences Between Age Group Performance Means (in milliseconds) in the Integration Task

		Differences		
Group	Means	19-31	45-57	58-70
19-31	60.5	-	4.9	24.5*
45-57	65.4	-	-	19.6*
58-70	85.0	-	-	-

*p < .01

TABLE 4

Differences Between Age Group Performance Means (in milliseconds) in the Backward Masking Task

		Differences		
Group	Means	19-31	45-57	58-70
19-31	62.3	-	49.3*	77.5*
45.57	111.6	-	-	28.2**
58.70	139.8	-	-	-

*$p < .01$

**$p < .09$

TABLE 5

Univariate Statistics and Standardized Discriminant Function Coefficients for all Tasks among the First Three Age Groups

Task	Univariate *F* ratio and probability (2,33)	Multivariate standardized discriminant function coefficients (Omnibus Test) $F(6,62)=6.21, p<.0001$	Univariate *F* ratio and probability for linear trend (1,33)	Multivariate standardized discriminant function coefficients (trend analysis, linear trend) $F(3,31)=12.91, p<.0001$
Segregation task	*$F=1.15$, $p<.3296$	-.1936	$F=2.08$, $p<.1590$	-.1724
Integration task	$F=9.39$, $p<.0006$	.4981	$F=14.25$, $p<.0007$	.4455
Backward Masking task	$F=16.56$, $p<.0001$	.8357	$F=33.10$, $p<.0001$	.8669

*The segregation task demonstrates statistically significant age-related change when the fourth age group is included, [$F(3,44) = 9.37$, $p < .0001$].