Chapter Four

Age-Related Differences in Visual Information Processing: Qualitative or Quantitative?

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Numerous recent investigations have focused on age-related limitations in visual information processing. Two general types of limitations have been noted, one involving time, and the second involving space (Hoyer & Plude, 1980). With respect to time, the question is: Do older people carry out perceptual processes more slowly than younger people? With respect to space, the question is: Do older people accurately perceive information over a narrower spatial area than do younger people?

We have several goals in this chapter. Primarily, we are interested in whether age differences in visual information acquisition are quantitative or qualitative, and we present an experiment bearing on this question. Second, we demonstate how apparently temporal qualitative differences may be attributable to spatial limitations. Finally, we use our experiment to address some methodological issues; we note some shortcomings of previous methodologies, and offer a new technique to deal with these shortcomings. We begin by briefly reviewing the literature on temporal and spatial limitations in older adults.

Temporal Limitations

Temporal limitations have been investigated more extensively than spatial ones. Typical studies have used a visual backward-masking paradigm in which a brief target stimulus is followed by a mask that

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a visual marker designating one of the items to be reported. Before the experimental trials began, Ss practiced until they could report six out of eight items correctly when there was no delay between the array and marker. Nine young (18–31 years of age) and 10 (60–72 years of age) Ss participated in this experiment. The difference between old and young Ss was dramatic. The practice task was simple for the young Ss; they typically reported the first eight items correctly. The older Ss, however, found the practice task much more difficult. The task was impossible for 8 of the 10 old Ss. Even after 2 hours of practice these older Ss were unable to report more than four out of eight items correctly. The 2 older subjects who reached criterion did so immediately, like the 9 younger Ss. The performance of these 2 Ss in the actual experiment was not dramatically different from that of the young. These results suggest that most older Ss cannot process large blocks of items as single perceptual events.

PRESENT EXPERIMENT: THE QUANTITATIVE SLOWING HYPOTHESIS

We now report an experiment to investigate qualitative versus quantitative differences in acquisition of visual information. The paradigm used in this experiment was very similar to that reported by Cerella, Poon, and Fozard (1982). Briefly, old and young Ss performed a relatively simple visual memory task: On each of a series of trials, an S saw a target stimulus consisting of a row of four digits for exposure durations ranging from 25 to 641 ms, followed immediately by a mask consisting of random black splotches (visual noise) on a white background. Immediately after seeing the target-mask display, the S reported as many of the digits as possible. The principle data in this paradigm take the form of a *performance curve,* which is a function relating mean proportion of reported digits to exposure duration. We assume that the rate at which a performance curve rises reflects the rate at which information is acquired from the digit array.

Based on the past data described above, we expected that young Ss would perform better than older Ss on this task. Our principle goal was to test the (null) hypothesis that the expected old/young difference is *quantitative* against the (alternative) hypothesis that the difference is *qualitative.* The logic underlying both the conceptual and empirical comparison of these hypotheses is spelled out by Loftus (1985c) and, briefly, is this. Suppose that the old/young difference is quantitative. By quantitative, we mean that older Ss in this task acquire the same information, via the same perceptual processes, as do younger Ss, but at a rate that is slower by some factor, k. This hypothesis, which we a qualitative difference between visual processing for young and old people is inconclusive. Walsh (1976) found no interaction between age and target duration on critical SOA in his dichoptic backward-masking experiment. Till (1978) found a similar lack of interaction with respect to target energy: The peripheral processing difference between age groups was constant across target energy conditions. However, in a similar paradigm, Walsh et al. (1978) did find an interaction: The younger Ss improved more quickly with increasing energy level than did the older Ss. Kline and Szafran (1975) also found stimulus duration to interact with age in a monoptic backward-masking paradigm: young Ss improved more rapidly with increasing duration than older Ss.

Interpreting interactions. Relying on the presence or absence of a statistical interaction as evidence for quantitative or qualitative age-related differences if problematical (Anderson, 1961; Bogartz, 1976; Krantz & Tversky, 1971; Loftus, 1978, 1985a, 1985b). The major problem is that, unless the interaction is ordinal (crossover), it can be removed by applying a suitable monotonic transformation to the dependent variable. This, in turn, means that conclusions issuing from a nonordinal interaction cannot be extended to other dependent variables, or to underlying theoretical constructs, whose relationship to the dependent variable cannot be assumed stronger than monotonic. Loftus (1985b) points out a related problem, which is that conclusions based on statistical interactions are likely to be inconsistent, both within and across experiments. In the experiment we report below, we expand on this methodological issue, and suggest a somewhat different method for determining whether an obtained effect is quantitative or qualitative.

Spatial Limitations

Spatial limits impose constraints on the quantity of information that can occupy the system at any given time. The target stimuli for the Walsh et al. experiments were single characters; thus the spatial capacity was probably not a limiting factor. It is possible that any qualitative differences between the age groups involve a difference in the degree to which multiple units of information must be handled one unit at a time (serial processing) versus simultaneously (parallel processing).

Parallel processing of visual information does occur under some circumstances in young adults (Shiffrin & Schneider, 1977). However, it appears that parallel processing is more difficult for older adults. In a preliminary investigation, Walsh and Thompson (Walsh, 1975) studied age differences using a partial report procedure similar to that described by Averbach and Coriell (1961). An array of eight letters (two rows of four items) was displayed for 50 ms and followed at various delays by impairs the S's identification of the target. Efficiency of visual processing is usually characterized by the critical time required to escape masking effects, estimated by the interval between stimulus onset and mask onset (stimulus onset asynchrony, or SOA) that produces some criterion performance level. The general finding is that older S require longer SOAs. This may be taken to mean that older S require more time, relative to young Ss, to perform an equivalent task; that is, their processing is less efficient.

The finding of longer SOAs for older Ss has been demonstrated in many studies. A series of masking experiments reported by Walsh and his associates used single-character target stimuli. These experiments showed a slowing for older adults in both peripheral and central perceptual processes (as defined by Turvey, 1973). Walsh (1976) used a backward masking paradigm to investigate age differences in central perceptual processes. S viewed target and mask dichotically; that is, they viewed a target stimulus in one eye followed by a pattern mask in the other eye. The older group required a 24% longer SOA in order to achieve the same criterion level of performance. In two similar experiments, Walsh, Williams, and Hertzog (1979) found 33% and 38% increases in central processing time for older relative to younger Ss.

Peripheral processes were investigated by Walsh, Till, and Williams (1978) in a monoptic backward-masking study. Two experiments showed that older Ss needed longer SOAs to process the targets adequately. Apparently, slowing of perceptual processes occurs throughout the system.

The quantitative/qualitative issue. An age-related slowing in both peripheral and central visual processing is thus well documented. However, the reasons for this effect are unclear. One possibility is that the effect is quantitative. By this interpretation, older people acquire the same information, via the same cognitive processes, as do younger people, but at a slower pace. A second possibility is that the effect is qualitative. By this interpretation, older people acquire different kinds of information or are using less efficient information-acquisition strategies compared to younger people, or both.

How are these two possibilities to be empirically distinguished? One standard approach is to interpret the absence of a statistical interaction between age and a given independent variable as evidence that the effect of the independent variable is quantitative; that is, a quantitative effect is assumed to exist when the age difference is constant across all levels of the independent variable. Conversely, the presence of an Age × Condition interaction is cited as evidence that the effect of the condition is qualitative.

By this test, the evidence supporting either a simple quantitative or term the *quantitative slowing hypothesis,* yields a simple, but very strong prediction: It will take k times as long for older, relative to younger, Ss to reach any arbitrary performance level. Mathematically, this prediction may be expressed as

$$\mathrm{PY}(t) = \mathrm{PO}(kt),$$

where $\mathrm{PY}(x)$ and $\mathrm{PO}(x)$ refer to performance levels for young and old subjects, respectively, following an array exposed for a duration of x.

This prediction is illustrated in Figure 1(a), with k arbitrarily set to 2. To test the prediction empirically, it is convenient to plot performance as a function of duration on a log scale, rather than a linear scale, as shown in Figure 1(b). The prediction then becomes

$$\mathrm{PY}[\ln(t)] = \mathrm{PO}[\ln(k) + \ln(t)].$$

That is, the performance curves for old and young subjects should be *horizontally parallel,* with the old-subject curve shifted to the right by a distance equal to $\ln(k)$. Thus, if the obtained performance curves *are* horizontally parallel, the quantitative slowing hypothesis is confirmed, and k can be estimated by the horizontal difference between the curves. If the curves are not horizontally parallel, then the quantitative slowing hypothesis is disconfirmed, and a qualitative difference is inferred.[1]

Method

Subjects. Subjects were 11 old adults (5 males and 6 females, 56 to 73 years of age, mean age 64.45 years) and 11 young adults (4 males and 7 females, 18 to 28 years of age, mean age 19.75 years). Of the old Ss, 4 were parents of the experimenters, 4 were University of Washington staff members, 1 was a senior faculty member, and 3 answered an advertisement in the campus daily paper. They were paid $10 for participating. The young Ss were university undergraduates receiving course credit for their participation. All Ss (including those with corrected vision) were roughly screened for visual acuity: They saw a practice slide and had to report the top row of digits. All Ss did so with ease.

Stimuli. The stimuli were 72 12-digit arrays, prepared as black-on-white 35 mm slides. The 12 digits in each array were arranged in three rows of four digits per row. Each digit subtended 0.56° vertical × 0.28°

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[1] We should emphasize the difference between pairs of curves that are horizontally parallel and pairs of curves that are vertically parallel. Vertical parallelism is implied by lack of interaction in a standard analysis of variance. If two curves are vertically parallel, they are generally not horizontally parallel, and vice versa.

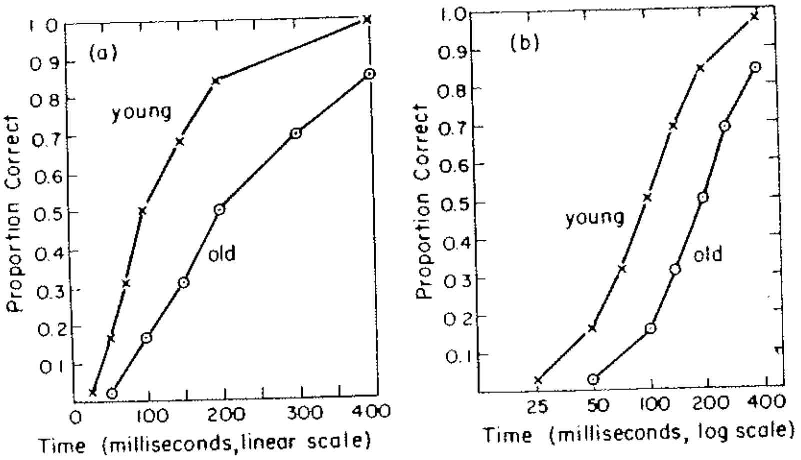

Figure 1. **Hypothetical performance curves predicted by the quantitative slowing hypothesis. In this example, old Ss take twice as long as young Ss to reach any given performance level. In the right panel, the curves are plotted on a log duration scale: The prediction is that the curves will be horizontally parallel.**

horizontal. Digits were separated by 0.37° vertical and 0.74° horizontal. The digits in each array were chosen randomly with the restriction that no digit could appear more than twice in any row. On each trial, the S attempted to report the four digits from one of the three rows.

As noted, the noise mask that followed each array consisted of black visual noise on a white background. When the mask was superimposed on the digit arrays, no digits could be read from the arrays.

There was a dim adapting field continuously present during the experimental session.

Apparatus. The apparatus is described in detail by Loftus, Gillispie, Tigre, and Nelson (1984). All slides were displayed by Kodak carousel projectors. Timing was controlled by a Gerbrands tachistoscopic shutter with rise and fall times of approximately 1 ms. Subjects responded with keys marked 0–9 on a response box. All display apparatus was enclosed in a soundproof box. All display and response-collection apparatus was under control of an Apple II Computer.

Design and procedure. Subjects were run individually. At the start of an experimental session, an S was read the instructions, and was allowed to dark-adapt for 5 min. After having the procedure explained, the S had a few trials of practice.

In the experiment proper, each S saw a total of 144 stimuli in the form of two consecutive passes through the 72 slides. We refer to each of the two 72-trial passes as a *set* of trials.

Aside from age, the only independent variable was exposure duration of the target array. Each array was shown for one of nine exposure durations, ranging from 25 ms to 641 ms, in equal log steps; each duration differed from the adjacent durations by a factor of 1.5. Exposure durations occurred randomly across the 144 trials with the restriction that, within each 72-trial set, eight arrays were displayed at each of the nine exposure durations.

Recall that each stimulus array was three rows by four columns. During each trial, the S had to report only one of the three rows. The S always knew in advance which row was to be reported. This was accomplished by blocking trials, by to-be-reported row, in 24-trial blocks. Prior to the start of each block, the S was informed which row was to be reported for that block. Additionally, a high, medium, or low tone prior to each trial reminded the S that the top, middle, or bottom row was to be reported on that trial.

On each trial, the following sequence of events occurred. First, a series of ten, 30-ms-on/30-ms-off, 1,000-hz beeps signaled the start of the trial. During this warning period, a dim fixation light was displayed at the point where the middle of the upcoming array would be. This was followed by a blank (adapting field only) delay of 500 ms, followed by a 200-ms, 2,000-hz, 1,000-hz, or 250-hz tone, reminding the S to report the top, middle, or bottom row of the upcoming array. There was then another 500-ms blank delay, followed by the digit array, followed by the mask which lasted 500 ms. Immediately after the display sequence, the S attempted to type in the four digits, in correct order, guessing if necessary. Pressing a return key completed the response. If the S typed in fewer, or more, than four digits, he or she was requested to respond again. Feedback followed the S's response in the form of four, 250-ms tones: Each tone was high (1,500 hz) if the corresponding digit had been correctly reported, and low (250 hz) if it had been incorrectly reported. Following feedback was a 500-ms pause prior to the start of the next trial. Ss were urged to guess as best they could, even when they were certain that they had not seen anything.

Results and Discussion

Performance curves. Average performance curves for old and young Ss will be shown below. First, however, Figure 2 provides a flavor for the individual curves. For sake of clarity, only three curves—those for the best, worst, and median Ss from both the old and young groups—are shown. These six curves are fairly typical of those from all 22 Ss.

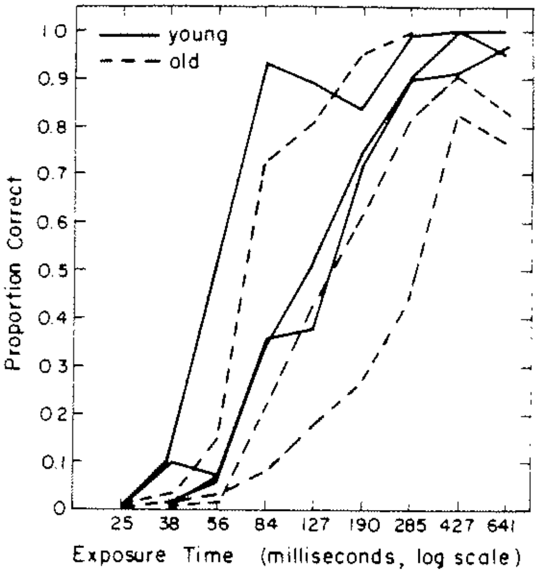

Figure 2. **Individual performance curves for three young Ss (solid lines) and three old Ss (dashed lines).**

Old Ss are represented by dashed lines, and young Ss are represented by solid lines. As expected, performance was generally better for young Ss, relative to old Ss. The observed across-S variability was also greater for old relative to young Ss.

Recall the prediction of the quantitative slowdown hypothesis: on the average, old-S performance curves should be horizontally parallel to young-S performance curves. The observed individual curves for old and young Ss were not grossly nonparallel (see Figure 2). An evaluation of the prediction must therefore depend on a statistical test.

Averaging artifacts. At this point, however, we face a problem. To make old/young horizontal comparisons, it is inappropriate to obtain, and compare, average curves across the young and across the old Ss. Figure 3 illustrates why this is so. Here, hypothetical performance curves are illustrated for two old Ss and two young Ss. The curves are as predicted by the quantitative slowing hypothesis; they are all horizonatally parallel to one another. As with the observed performance curves (Figure 2) there is more variability in the old Ss, relative to the young Ss. The dashed curves in Figure 3 show the averages of the young and old Ss. Note that conclusions based on the average curves only would be incorrect: Although all the individual curves are horizontally parallel, the average curves are not. The effect of increased

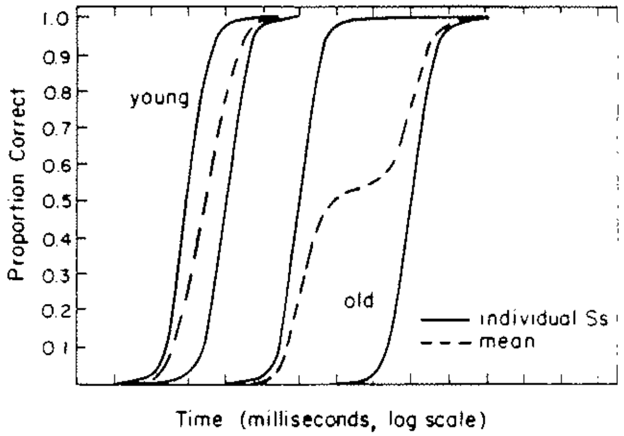

Figure 3. **Hypothetical performance curves for two young Ss (left) and two old Ss (on the right). The increased old-S variability produces a systematic bias when the curves are averaged.**

variability in the older Ss is to bias the average slope systematically; it is shallower. It is important to realize that the presence of this artifact does not depend on there being increased *population* variability for the older Ss; it is only necessary that there be more *sample* variability. The greater the difference in observed variability between young and old Ss, the more serious the artifact.

Cumulative normal fit to the psychometric function. We solve this problem as follows. We have found, using experienced Ss in this paradigm, that the curves shown in Figure 2 are fit reasonably well by a cumulative normal. A normal curve has only two parameters, μ, the mean, and σ, the standard deviation. Two cumulative normal curves are horizontally parallel if and only if they do not differ in σ. Our statistical strategy, therefore, was to fit each of the 22 individual performance curves by a cumulative normal, thereby estimating μ and σ for each S. A test of old/young horizontal parallelness can be accomplished by performing a t- test of the estimated sigmas for old and young Ss.

Accordingly, we corrected each S's nine probabilities for the guessing level of 0.1, and then transformed each corrected probability to a z-score. We then computed the best-fitting straight line through the data points relating z to log duration. From this fit, we obtained three pieces of data for each S. The first datum was the slope of the regression function, which reflects the estimate of σ (and to which we shall hereafter refer as a slope).[2] The second datum was the X-intercept of the regression function, which represents the estimate of μ. The X-intercept may be viewed as the critical time required to achieve a 50% performance level (i.e., to recall two out of the four digits), and is comparable to the critical times to escape masking (e.g., as reported by Walsh and his colleagues). We shall hereafter refer to the X-intercept as the "critical time." The third datum was the Pearson r^2. Table 1 shows these data for the 11 old and 11 young Ss.[3] Figure 4 shows the mean performance curves for young and old Ss. These average curves were obtained by averaging the corrected-for-guessing z-score curves and transforming back to probabilities. Note that under the assumption that the z-transformed curves are linear this technique is not subject to the averaging artifact described above.

As indicated earlier, comparison of the slopes for old versus young Ss constitutes the statistical test of the quantitative slowing hypothesis. The mean slopes are 0.51 and 0.58 for old and young Ss, respectively. Although small, the difference is significant, $t(20) = 2.20$ $p < .05$, indicating that the old-S performance curves shown in Figure 2 are, on the average, slightly shallower than the young-S performance curves. The quantitative slowing hypothesis is thus disconfirmed. Apparently the difference between young and old people in this task is at least qualitative.

The mean critical times are 176 and 105 ms for old and young Ss, respectively. This difference is significant, $t(20) = 3.58$, $p < .05$. Recall the suggestion of Figure 2 that the older Ss appear to be more variable than the younger Ss. The observed increased variability is reflected in the across-S critical-time standard deviations of 1.49 and 1.28, respectively, for old and young Ss. However, this young/old variability difference is not significant, $F(10,10) = 2.68$.

Basis of qualitative differences. What is the nature of the qualitative difference between old and young Ss? We will address this question in several ways. Recall first that Ss had to report a row of four lights. The pattern of responding across the four digits, i.e., the serial position curves, provide evidence for the kinds of processes that are used. For example, if information from different spatial locations were acquired

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[2] An actual estimate of σ could be obtained by raising 1.5 to the (1/slope) power.

[3] Because the regression analyses were carried out on a log time scale, all descriptive statistics (means and standard deviations), as well as inferential statistical tests, were computed on log transforms of critical time values. For ease of discourse, mean critical times are expressed in time (ms) when they are presented in tables or in the text. Standard deviations of critical times are expressed as ratios (e.g., a mean of 100 and a standard deviation of 2.0 indicates that ± 1 standard deviation ranges from 100 2.0 – 50 to 100 × 2.0 = 200).

Table 1. Summary Data for All 22 Subjects

Old Ss	Age	Slope	Critical Time	r^2
S1	64	.358	228.1	.94
S2	73	.440	278.7	.96
S3	73	.509	175.9	.91
S4	59	.419	308.0	.90
S5	65	.382	225.9	.94
S6	56	.568	232.8	.84
S7	61	.609	88.2	.89
S8	66	.547	106.7	.92
S9	72	.542	144.0	.91
S10	64	.623	124.0	.97
S11	56	.617	170.7	.92
Means	64.45	.510	175.9	.92
SDs		.096	1.49	
Young				
S1	28	.534	119.1	.90
S2	19	.588	86.5	.95
S3	19	.535	68.7	.88
S4	19	.623	135.6	.93
S5	18	.587	80.6	.92
S6	18	.533	120.3	.94
S7	18	.672	139.8	.96
S8	19	.549	139.8	.97
S9	18	.599	121.5	.97
S10	21	.597	88.2	.86
S11	22	.565	98.5	.88
Means	19.91	.580	105.6	.92
SDs		.043	1.28	

Note: Critical times are in ms, and mean critical times are geometric means.

entirely in parallel, and if there were no short-term memory limitations, then performance would not depend on serial position. Conversely, to the degree that performance *does* depend on serial position, we can conclude either that the digits are originally acquired serially or that there are short-term memory limitations, or both. Thus we ask: Do old and young Ss differ in their response pattern across the four digits?

Answering this question is not entirely straightforward because, when comparing old and young Ss with respect to serial-position effects (or any other variable), we would like to keep performance level constant. To achieve this goal, we selected, for each S, the four adjacent exposure durations that produced two performance levels below 50%, and two performance levels above 50%. We computed probability correct as a function of serial position, for old and young Ss, for these durations

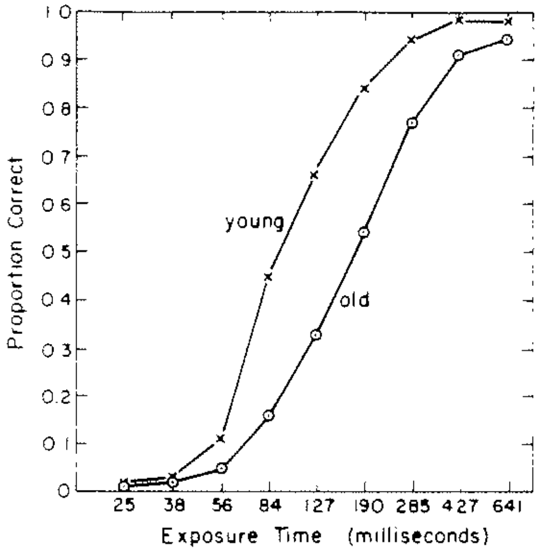

Figure 4. **Mean performance curves for old and young Ss. Averaging was done on the *z*- transforms of the individual curves, and the resulting mean curves were transformed back to proportions.**

only. This analysis technique is somewhat unusual, in that it entails a comparison of data from systematically different exposure durations for old and young Ss—exposure durations are typically longer for older Ss. However, we assert that old/young serial-position differences can be best examined when performance, rather than exposure duration, is kept constant. Versions of this technique have been used by others for the same reason. Biederman and Tsao (1979) and Salthouse (chapter 8 of this volume) achieved equivalence across Chinese and American Ss, and across old and young Ss, respectively, by judicious subject selection. Likewise, Schoenfield and Wenger (1975) equated old/young performance in a perceptual task by differentially dark-adapting the Ss of different ages.

Table 2 shows the result of our serial-position analysis. The overall difference between old and young Ss is, of course, small; it was made to be that way. In general, performance drops over serial position. This effect was statistically significant, $F(3, 60) = 30.0$, $p < .05$, Mse = 0.007. Of primary interest is the strong crossover interaction between age and serial position, an effect that was also significant, $F(3, 60) = 6.29$, $p < .05$, Mse = 0.007. We may thus conclude that performance declines over serial position, but faster for old Ss than for young Ss. As suggested earlier, this result is consistent with a variety of possible

Table 2. Proportion Correct for Each Serial Position for Young and Old Subjects

	Serial Position				
	1	2	3	4	Means
Young	.64	.63	.57	.53	.56
Old	.70	.65	.50	.40	.59
Means	.67	.64	.53	.47	

Table 3. Slopes and Critical Values for Old and Young Ss, for Serial Positions 1 and 2 Only, and Serial Positions 3 and 4 Only (standard deviations in parentheses)

	Serial Positions 1–2	Serial Positions 3–4
Slopes		
Old	0.559 (0.075)	0.462 (0.111)
Young	0.574 (0.051)	0.592 (0.040)
Critical Values (ms)		
Old	138 (1.41)	247 (1.80)
Young	91 (1.35)	117 (1.30)

old/young qualitative differences. We briefly sketch four: the first and second seem reasonably likely; the third and fourth seem less likely, but not entirely implausible. The present data do not allow us to distinguish among these various possibilities.

First, extraction of information from different spatial positions may be more of a parallel process for young, relative to old, Ss. Second, extracted digits may be serially placed into a short-term memory whose capacity is lower for old relative to young Ss. For example, it may be that four digits never overload short-term memory for younger Ss, but sometimes overload short-term memory for older Ss (see Sperling, 1986; Sperling & Speelman, 1970). Third, events intervening between seeing the display and reporting it may produce retroactive interference that affects the most recently stored information more severely for old than for young Ss. Fourth, Ss may make errors in striking the response keys; the causes of such motor errors may be such that later keys struck are more prone to error for older relative to younger Ss.

Is whatever causes the Age × Serial Position interaction sufficient to explain the qualitative differences between old and young Ss? To address this question, we recomputed performance curves, considering data from Serial Positions 1 and 2 only, and from Serial Positions 3 and 4 only. The results of this analysis are shown in Table 3.

For Serial Positions 3 and 4, the mean slopes for old and young Ss are 0.462 and 0.592, respectively. This difference is statistically significant, $t(20) = 3.67$, $p < .05$. Clearly, the old/young difference for Serial Positions 3 and 4 is qualitative.

For Serial Positions 1 and 2, however, the mean slopes for old and young subjects are 0.559 and 0.574, respectively. This difference is not statistically significant, $t(20) = 0.55$. Although we must exercise the usual prudence about accepting null hypotheses, we note that the observed slope difference is quite small—less than 5%. We tentatively conclude that, when only the first two serial positions are considered, the quantitative slowing hypothesis is confirmed: Old/young differences are quantitative, not qualitative.

Given this conclusion, consider the critical times for Serial Positions 1 and 2 only. Of primary importance is that the old/young difference is still quite substantial. This difference may best be characterized by noting that the mean ratio of old to young critical times is 138/91 = 1.52. Because old and young slopes are approximately equal, this ratio is approximately constant across all performance levels. The ratio can be interpreted as the degree of slowdown in information acquisition rate for old Ss relative to young Ss. That is, we may conclude that our young Ss acquire information 1.52 times faster than our older Ss.

Practice effects. We have concluded that, considering data from Serial Positions 1 and 2 only, there is no qualitative difference between old and young Ss. If all serial positions are considered, however, there *are* qualitative differences. We have already listed several possible mechanisms to explain these differences.

We now consider the possibility that whatever does underlie the qualitative differences may be attenuated with practice. Recall that each experimental session consisted of two sets of 72 trials per set. Table 4, which is organized like Table 3, shows data for Sets 1 and 2 separately. The most noteworthy result is that, whereas old and young slopes differ significantly for Set 1, $t(20) = 2.54$, $p < .05$, they do not differ significantly for Set 2, $t(20) = 1.38$. Again, we must be cautious about accepting the null hypothesis for Set 2. However, it does appear that the slope difference for old and young Ss decreases with practice.

Table 5 provides data for both serial position and practice effects. Consider young Ss first. It is evident that slopes are unaffected either by practice or by serial position. This indicates that young Ss are qualitatively invariant over both these variables. Examination of critical values, however, indicates that both variables do produce quantitative differences: Young Ss are faster by an average factor of 1.23 on Set 2 versus Set 1, and are faster by an average factor of 1.29 on Serial Positions 1–2 versus Serial Positions 3–4.

1973) the major question is: How much target processing time (critical time) is necessary to escape the effect of a noise mask? Walsh and his colleagues have defined "escaping the effect of a noise mask" to be the achievement of some arbitrary criterion performance level. In the present experiment we found, like Walsh and his colleagues, that this critical time is greater for older than for younger people.

Our paradigm may be viewed as an extension of that used by Walsh and his colleagues in that critical times are compared across *all* performance levels; this is what a horizontal comparison of performance curves (Figure 1) amounts to. We did this to test whether the expected old/young difference was qualitative or quantitative. The prediction of the quantitative slowing hypothesis was that the percent additional time required by older people (or, equivalently, the ratio of old-to-young critical times) would be independent of performance level. Note that comparison of critical times for only a single criterion performance level does not allow a test of this hypothesis.

Our experimental paradigm is very similar to that used by Cerella et al. (1982). Indeed, the major difference between our work and theirs is in the data analysis technique. Cerella et al. assumed a specific, two-stage serial scanning model, and fitted their obtained performance curves with the assumption that that model was correct. In contrast, our data analysis technique and the ensuing conclusions do not depend on any specific assumptions about the exact process of information acquisition. Thus, our conclusions may be viewed as a confirmation of Cerella et al.'s conclusions under a weaker, that is, more general, set of assumptions.

Qualitative and Quantitative Differences

Older Ss in our experiment did, indeed, require longer criterion times than did younger Ss in order to achieve any given level of performance. As indicated by the old/young difference in the psychometric function slopes, however, the ratio of old-to-young critical times was not constant across performance level, thereby disconfirming the quantitative slowing hypothesis. The difference between old and young Ss in this paradigm is at least partly qualitative.

The old/young slope difference that implied qualitative differences was small, and more detailed analyses showed that the qualitative difference is, in several respects, not very robust. First, the difference declines with practice. Second, an analysis of serial position showed that the decline in performance across serial position was substantially greater for old Ss, relative to young Ss, indicating that at least one component of the qualitative difference involved the processes by which information is acquired or integrated across spatial position. This con-

Table 4. Slopes and Critical Values for Old and Young Ss, for Set 1 Only and Set 2 Only (standard deviations in parentheses)

	Set 1	Set 2
Slopes		
Old	0.496 (0.108)	0.524 (0.108)
Young	0.588 (0.053)	0.573 (0.047)
Critical Values (ms)		
Old	189 (1.61)	166 (1.49)
Young	116 (1.28)	97 (1.31)

Table 5. Slopes and Critical Values for Old and Young Ss, for Serial Positions 1–2/Serial Positions 3–4 × Set 1Set 2 (standard deviations in parentheses)

		Serial Position	
		1–2	3–4
Slopes			
Set 1	Old	0.555 (0.100)	0.443 (0.121)
	Young	0.589 (0.066)	0.594 (0.045)
Set 2	Old	0.563 (0.090)	0.480 (0.137)
	Young	0.560 (0.054)	0.591 (0.048)
Critical Values (ms)			
Set 1	Old	150 (1.45)	273 (2.02)
	Young	103 (1.34)	127 (1.29)
Set 2	Old	127 (1.48)	221 (1.84)
	Young	80 (1.41)	109 (1.35)

The situation is somewhat different for old Ss. For Serial Positions 1–2 only, old Ss do not differ qualitatively from young Ss, as indicated by the similar slopes. For Serial Positions 3–4, however, old Ss are qualitatively different both from young Ss *and* from themselves at Serial Positions 1–2. The slope deficit (and by assumption the qualitative differences) does attenuate with practice.

GENERAL DISCUSSION

Assessing Age Differences in Critical Processing Time

At this point, it is useful to compare explicitly the present experimental paradigm with that used in past work. In both the present paradigm and those typically used by Walsh and his colleagues (see also Turvey, clusion was further confirmed by the finding that, when the first two serial positions alone are considered, the hypothesis of a strictly quantitative old/young difference cannot be rejected. In this situation the conclusion can be made (at least tentatively) that old Ss acquire the same visual information as young Ss, via the same cognitive processes, but at a rate that is about 1.5 times slower.

Application of Sperling's signal-to-noise theory. Loftus (1985c) showed that in certain circumstances reducing the luminance of visual stimuli caused the same kind of reduction in information acquisition rate as did aging in the present study. For relatively short exposure durations (under 300 ms), the reduction was quantitative, in the sense that the slopes of the psychometric functions were the same for high-luminance and low-luminance stimuli. For longer-duration stimuli, the reduction was qualitative, in the sense that the slopes were shallower for low-luminance stimuli.

Sperling (1986) proposed a signal-to-noise theory to explain these results. In Sperling's theory, decreasing luminance has the effect of adding noise to a limited-capacity serial-input channel. This causes less signal per unit time to be transmitted, which is equivalent to quantitative slowing. With increasing amounts of input information, however, the increased noise occupies space in a limited-capacity short-term memory. This effective reduction in short-term memory capacity amounts to a qualitative difference. Sperling suggested that his theory applied to any situation in which a visual stimulus is degraded by noise somewhere in the cognitive system prior to the serial input channel.

This theory suggests a tentative explanation of the present results, which would require three (testable) assumptions. First, aging must be assumed to involve addition of noise to visual stimuli at a relatively peripheral level of the visual system. Second, short-term memory capacity must be assumed to be smaller with older adults. Third, acquisition of information must be assumed to occur, at least partially, in a left-to-right order.

Given these assumptions, and Sperling's theory, consider the sequence of events in the present experimental paradigm. Acquisition of information would initially proceed with digits in the first and second serial positions. At this point, the aging deficit would occur only because of addition of noise prior to the serial input channel; such addition would cause quantitative slowing. Acquisition of additional digits, however, would tax short-term memory capacity more for older relative to younger Ss, thereby causing the qualitative difference that would result both in the shallower psychometric slopes for the older people, and in the Age × Serial Position interaction.

Levels of processing. We make a final comment on the quantitative/qualitative distinction that is prompted by P.B. Baltes (personal communication, 1984): A quantitative age difference at one level of cognitive processing may lead irrevocably to a qualitative difference at a higher level of processing. The major circumstance under which this will happen is that in which there is some time deadline for the completion of one process such that a subsequent process is executable only if the deadline is met. If young Ss are quantitatively faster than old Ss, then the young Ss will be more likely to meet the deadline and be able to carry out the subsequent process than the old Ss, thereby leading to a qualitative difference.

Deficits in older adults are found in many cognitive tasks that require considerably more complex strategies than the ones required in the present paradigm. It is possible, however, that in such experiments, observed qualitative differences have their roots in the sort of deficit that we have seen in initial acquisition of visual information. If this were true, then removal of the information-acquisition deficit would eliminate the qualitative differences that occur later in the cognitive system.

These considerations suggest a control in any experimental paradigm designed to investigate aging differences in which initial acquisition of visual information plays a significant role (e.g., in a Sternberg memory-scanning paradigm). The Ss in the experiment should be "handicapped" according to their rate of initial information acquisition. This could be done, for example, by differentially lowering the luminance of the stimuli (Loftus, 1985c) until the performance curves were the same for all Ss (or at least in such a way that mean old and young performance curves were the same). Such a procedure (which has occasionally been implemented; see Schoenfield & Wenger, 1975) would allow a much purer comparison of old and young Ss in more complex tasks, in the sense that eliminating initial sensory deficits would provide an isolation and examination of cognitive or strategic differences.

[illegible]? [illegible]

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