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# 12
# Effects of Visual Degradation on Eye-Fixation Durations, Perceptual Processing, and Long-Term Visual Memory

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We have all had the experience of processing visual stimuli that are *degraded* in one form or another. Examples of such situations include trying to decipher a photocopy of a photocopy, looking at slides or movies while the room lights are still on, and searching for an object in the dark. It seems more difficult to process these degraded stimuli relative to their undegraded or *clean* counterparts. Why is this? In this chapter, we will address two questions regarding the effects of visual degradation on cognitive processing: How does degradation affect initial perceptual process? and How does degradation affect the memory representation that presumably results from perceptual and subsequent processes?

## Prologue: Visual Degradation and Eye Fixations

This research began about 6 years ago with a simple question: Does degrading a picture by lowering its contrast affect eye fixation durations on the picture? Loftus (1985, Experiment 5) reported an experiment to address this question. Observers viewed a series of complex, naturalistic color pictures at 1.5 sec apiece with the intent of subsequently being able to recognize them. Eye fixations were recorded during viewing.

Each picture was shown at one of four contrasts. Contrast control was achieved by manipulating stimulus luminance against a uniform adapting field. Because the pictures contained different shadings and different colors, it is not possible to quantitatively characterize the degree of contrast reduction. Roughly speaking, however, contrast in a typical area in a typical picture varied from about 60% in the highest contrast condition to about 20% in the lowest contrast condition.

Figure 12.1 shows the results of this experiment. Here fixation duration is plotted against contrast level, with different curves for the first, second, and third fixations on the picture. It is clear that decreasing contrast leads

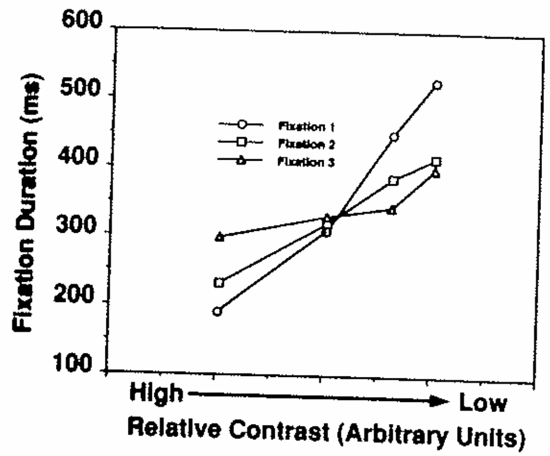


FIGURE 12.1. Fixation duration as a function of stimulus contrast. Different curves represent the first three fixations on the picture.

to increased fixation duration. This effect is most pronounced in the first fixation on the picture.[1]

The explanation that Loftus provided for this finding as is follows: It is reasonable to suppose that a fixation lasts until some criterion amount of information has been acquired from the fixation's location. With lower contrast, perceptual processing slows, which, in turn, causes information to be acquired more slowly. Accordingly, with lower contrast, longer fixations are needed to acquire the same information. This hypothesis led to the first of the two questions that we will be addressing in this chapter: Does stimulus contrast initial perceptual processing?

## General Issues

In this section we will describe research designed to investigate the effects of degradation (generally achieved by manipulating stimulus contrast) on perception and memory.

[1]The location of the first fixation was controlled by a prestimulus fixation point, and was thus invariant across the contrast conditions. Locations of subsequent fixations, which were not controlled, may depend on contrast condition. Accordingly, the curve corresponding to the initial fixation is the only one guaranteed to be free of confounding, and should be taken the most seriously.



### Questions

As noted earlier, we address two major questions. First, does degradation affect initial perceptual processes? In particular, does degradation cause a slowing of visual information acquisition from visual stimuli? Second, does degradation affect the long term-memory representation? In particular, is there some long-term degradational effect apart from that mediated by variation in initial perceptual processes?

### Methodology

All experiments use similar methodology: An experiment consisted of a series of trials. On each trial, some visual stimulus was presented. In general, stimulus duration and degree of degradation were jointly manipulated in a factorial design. Memory for the pictures was assessed using some form of memory test. The test could be either immediate (in which case it presumably reflected the output of initial perceptual processes) or it could be a long-term recognition test (in which case it was presumably based on a long-term memory representation).

The major data in this paradigm assume the form of a curve relating performance to stimulus duration. This curve, referred to as a performance curve, reflects the degree of processing over time, beginning at stimulus onset. As we will see, comparison of performance curves for different degradation levels allows evaluation of specific hypotheses about the degradation effect.

## Effects of Degradation on Initial Perceptual Processes: Investigations of the Slowdown Hypothesis

In this section we describe a simple hypotheses called the *slowdown hypothesis*, which is that degradation slows the rate of perceptual processing by some constant factor. Within certain boundary conditions, the slowdown hypothesis has successfully characterized effects on visual memory of stimulus luminance (Loftus, 1985), stimulus priming (Reinitz, Wright, & Loftus, 1989), attentional locus (Reinitz, 1990), and observer age (Loftus, Truax, & Nelson, 1986).

### Two Experiments to Investigate Two Stimulus Types

We will demonstrate that the slowdown hypothesis holds for two quite different stimulus types: one very simple, and the other very complex.

The stimuli in the first experiment were simple, consisting of four black digits on a white background. On each trial, the digits were presented at one of four contrasts[2] ranging from 0.207 to 0.053. There were six stimulus durations within each contrast level for a total of 24 conditions. The observer's task, following each stimulus presentation, was to report as many of the four digits as possible in their correct positions.

Before presenting the results of this experiment we describe the predictions of the slowdown hypothesis, which is illustrated in Figure 12.2. Suppose that we have two conditions, a clean and a degraded condition, and that perceptual processing is slowed by some factor $s$ in the degraded condition relative to the clean condition. It would then require $s$ times as much time to acquire a given amount of information and, accordingly, achieve any given performance level in the degraded relative to the clean condition[3]. This is illustrated in Figure 12.2a for $s = 2$. We refer to this prediction as the *equal-ratio-divergence prediction*.

To evaluate this prediction, it is convenient to plot performance as a function of duration on a log scale, as in Figure 12.2b, rather than on a linear scale as in Figure 12.2a[4]. The reason for this is that equal ratios on a linear scale translate into equal distances on a corresponding logarithmic scale. Therefore, the equal-ratio-divergence prediction becomes: clean and degraded performance curves should be horizontally parallel when plotted on a log-duration scale. If this prediction is confirmed, the horizontal distance (in log units) may be measured and exponentiated to acquire an estimate of $s$, the slowdown factor.

Figure 12.3 shows the results–performance curves on a log-duration axis for two observers[5]. The equal-ratio-divergence prediction is confirmed: for both observers the curves are approximately horizontally parallel[6].

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[2] Contrast was defined to be the ratio of maximum minus minimum luminance to maximum plus minimum luminance.

[3] There is an implicit model here, that is described more fully by Loftus and Hogden (1988). The model states that there is a one-to-one correspondence between "amount of perceptual processing" and "amount of information," and similarly, there is a monotonic relationship between "amount of information" and observed memory performance.

[4] There is always some awkwardness in labeling a log scale. In some cases (e.g., in Figure 12.2b) we wish to emphasize the logarithmic units. In such instances, the axis units are linearly spaced natural log units, and the axis is labeled "ln ms." In other cases (e.g., Figure 12.3) we wish to emphasize the original scale units. In these instances, the axis units are logarithmically spaced original units and the axis is labeled "ms, ln scale."

[5] In Figure 12.3, as in all data figures, the error bars represent standard errors.

[6] In describing these data, Loftus and Ruthruff (1992) take a somewhat different tack. It turns out that the performance curves on original linear time axes can be described essentially perfectly by the exponential equation

$$P = 1.0 - e^{-(d-L)/c}$$



Figure 12.4 summarizes the contrast effect. Here we have plotted the reciprocal of the slowdown factor (scaled as a proportion of the highest contrast slowdown, which is defined to be 1.0) as a function of contrast for the two Figure 12.3 observers, plus on additional observer (KG)[7]. The best-fitting linear functions are drawn through the data points for each observer.

The interpretation of these functions is as follows: The slowdown factor may be interpreted as the relative duration required to achieve any given performance level. For example, suppose that in the highest contrast condition a duration of 1 (arbitrary time unit) is required to reach some particular performance level. In a contrast condition characterized by a slowdown factor of $s$, $s$ time units would be required to achieve the same performance level.

Now consider an analogue of Bloch's law in which there is a perfect trade-off between contrast $c$ and the duration $s$ required to achieve the performance level. The form of this law would be

$$c \times s = k_1$$

or,

$$1/s = c/k_1 = k_2$$

where $k_1$ and $k_2 = 1/k_1$ are constants. The implication of this Bloch's-like law is thus that the reciprocal of the slowdown rate is linearly related to contrast with a zero intercept[8]. The Figure 12.4 linear fits are quite good, although the intercepts are not quite zero. Loftus and Ruthruff (1992) discuss the implications of this finding.

We have thus demonstrated the validity of the slowdown hypothesis when simple digit strings are used as stimuli. We next demonstrate its applicability to complex naturalistic pictures of the sort used in the eye-movement experiment described above. Such pictures were shown to subjects in one of two contrast conditions that we term *clean* and *degraded*. Again, contrast cannot be defined precisely with naturalistic pictures, but generally, a typical area in a typical picture ranged from approximately 60% contrast in the clean condition to approximately 40%

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where $P$ is performance, $d$ is stimulus duration, and $L$ and $c$ are free parameters. The parameter $L$ represents the duration at which performance departs from chance, and the parameter $c$ is the exponential time constant (both $L$ and $c$ are in units of ms). For all observers in this experiment, contrast affected *both* $c$ and $L$, but in approximately the same ratio, which is what leads to the horizontally parallel curves of Figure 12.3.

[7] KG's curve was arrived at in a somewhat complicated manner, and is described in detail by Loftus and Ruthruff (1992).

[8] Note that $k_1$ and $k_2$ are determined by the choice of time units and the particular criterion performance level. Accordingly, they are quite arbitrary.

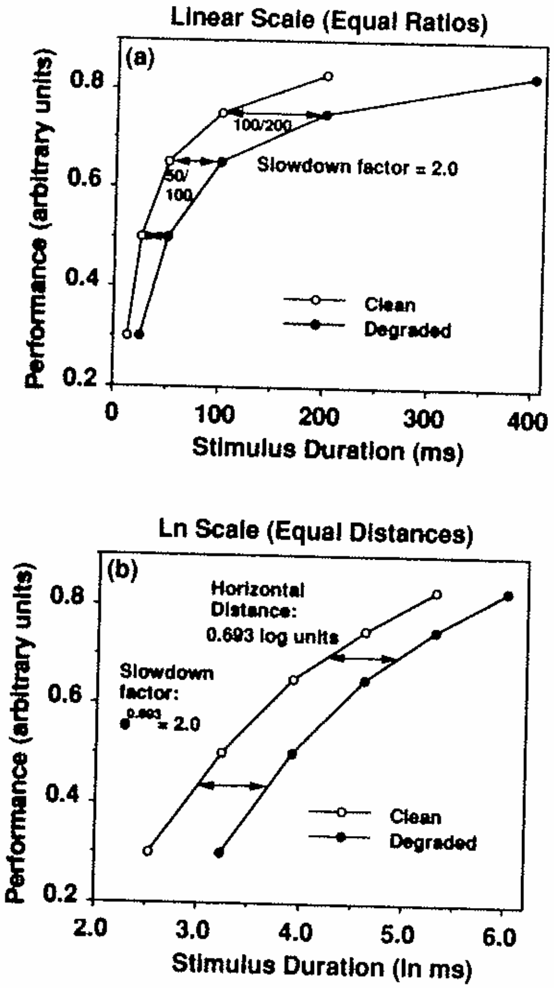


FIGURE 12.2. Illustration of the equal-ratio-divergence hypothesis for a slowdown factor of 2.0.

contrast in the degraded condition. There were six stimulus durations within each contrast condition for a total of 12 study conditions.

To assess immediate memory, subjects provided a *rating* after each stimulus presentation. This rating reflected the subject's subjective probability that he or she would subsequently recognize the picture in a long-term recognition test. The rating scale ranged from 1 ("definitely *would not* recognize the picture") to 4 ("definitely *would* recognize the picture").



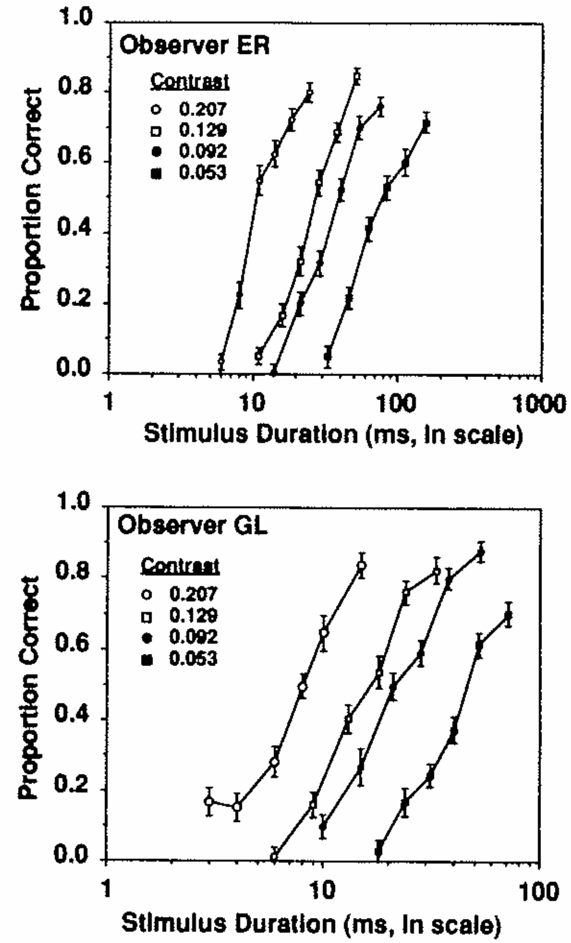


FIGURE 12,3. Results of the digit experiment: for each of two observers, the curves represent proportion of correctly recalled digits as functions of exposure duration. In each panel, separate curves represent the four contrast levels.

Figure 12.5 presents mean rating as a function of stimulus duration (again on a log scale). The curves are horizontally parallel, separated by 0.3 log units, which corresponds to a slowdown factor of 1.35.

## Conclusions About the Slowdown Hypothesis

We have seen that for two quite different stimulus types the slowdown hypothesis was confirmed essentially perfectly: the duration required to

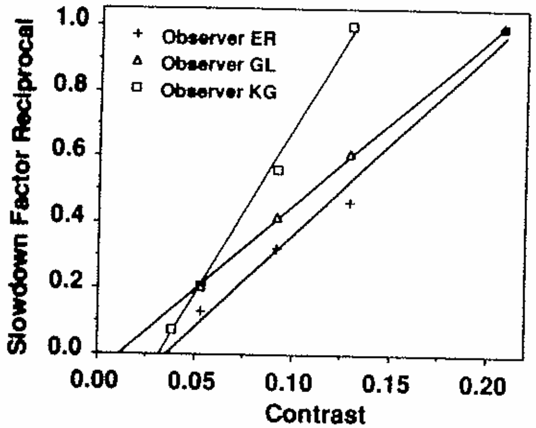


FIGURE 12.4. Results of the digit experiment: reciprocal of the slowdown factor (scaled as a proportion of the highest contrast slowdown, defined to be 1.0) as functions of stimulus contrast. Separate curves represent three separate observers.

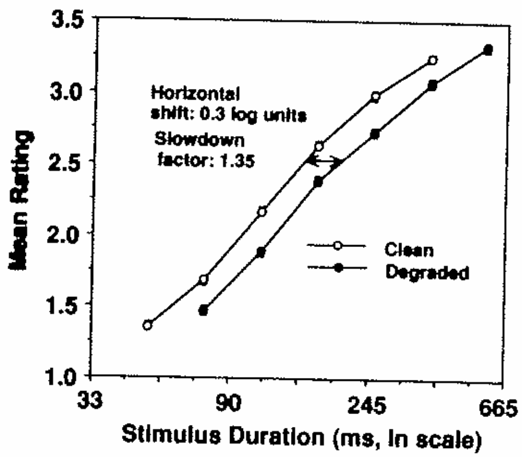


FIGURE 12.5. Results of rating experiment: mean rating as functions of stimulus duration. Separate curves represent clean and degraded pictures.

achieve any given performance level was greater by a constant factor for degraded stimuli relative to clean stimuli.

It should be noted that, as discussed by others (e.g., Loftus, Johnson & Shimamura, 1985; Reinitz et al., 1989), because our conclusions issue



from horizontal comparisons, they are invariant in two important ways. First, they are invariant over any dependent variable that is monotonically related to the one actually used, e.g., they would apply to log proportion correct (cf. Schweickert, 1985) as well as to proportion correct. Second, they are invariant over any theoretical construct, e.g., "amount of information" assumed to be monotonically related to performance. Both forms of horizontal invariance occur because any two durations that produce equal performance in one scale will also produce equal performance in any monotonically transformed scale.

The stimulus complexity inherent in naturalistic pictures rendered it impossible to quantitatively characterize the contrast effect for these stimuli. With digits, however, contrast was precisely defined, and here the contrast effect was quite lawful. There was almost a perfect trade-off, analogous to Bloch's law, between stimulus duration and stimulus contrast.

## Effect of Degradation on the Long-Term Memory Representation: Investigations of the Single-Dimension Hypothesis

So far we have seen a simple effect of degradation on initial perceptual processes. Normally, however, we are concerned with more than just perception of a visual stimulus. In particular, we can think of perception as being the first in a series of processing stages that ultimately result in a picture's long-term memory representation. To what degree does visual degradation affect this whole process?

### The Single-Dimension Hypothesis

We couch this question in the form of what we will call the *single-dimension hypothesis*, which is that duration and degradation affect the same dimension of the memory representation.

#### IMPLICATIONS OF THE SINGLE-DIMENSION HYPOTHESIS

According to the single-dimension hypothesis, stimulus duration and stimulus degradation both affect initial perceptual processing *only*. Perceptual processing combines duration and degradation into an early memory representation. This representation, termed $\mathbf{R_E}$, is some function **P**, of duration and degradation. The important idea is that $\mathbf{R_E}$ is assumed to be a *single number on a unidimensional scale*. The early representation, $\mathbf{R_E}$ is the input to conceptual processing (cf. Intraub, 1984; Loftus, Hanna, & Lester, 1988; Potter, 1976). The result of conceptual processing is **C** ($\mathbf{R_E}$), a long-term memory representation.[9]

Notice that if the single-dimension hypothesis is correct, information about a stimulus's degradational state is lost at an early processing stage. For example, if $\mathbf{R_E}$ were a particular number, like 30, the system would have lost the information about whether this number resulted from a short, clean stimulus of from a longer, degraded stimulus. Informally the hypothesis is that degradation and duration operate in "equal currency." Thus, the hypothesis's implication is that degradation's only effect is to slow perceptual processes. Information about a stimulus's degradational state is not included anywhere in the memory representation.

### Other Instantiations of the Single-Dimension Hypothesis

The single-dimension hypothesis has been suggested (under various names) by other researchers. Three examples serve to illustrate.

Sternberg (1967) suggested two hypotheses for the effect of test-stimulus degradation on short-term memory scanning. By the first hypothesis—a form of the single-dimension hypothesis—a degraded test stimulus is "cleaned up" during an initial processing stage; accordingly, the test-stimulus representation that is used in the scanning/comparison stage is identical to the representation that accrues from a clean test stimulus (clean and degraded scanning rates are thus the same as well). By the second hypothesis, a degraded test stimulus simply engenders a degraded memory representation that then slows down scanning rate. Sternberg found evidence for the single-dimension hypothesis for practiced observers, but not for unpracticed observers.

McClelland (1979) analyzed data reported by Pachella and Fisher (1969) on the effects of stimulus luminance on speed-accuracy tradeoff curves. Pachella and Fisher reported that lowering luminance produced a rightward shift of the curve without affecting its shape. McClelland showed how, within the context of his cascade model, such a shift could be accounted for by assuming luminance to affect the rate of a "light-analysis process" whose operation is early and fast relative to other (e.g., decision) processes. However, this effect (essentially) occurs only during this fast, initial process. Once luminance has had its effect, the operations of subsequent processes are unchanged.

Sperling (1986) proposed that perceptual ("signal") information acquired from a visual stimulus traverses a limited-capacity serial channel enroute to short-term memory. In Sperling's theory, degrading a picture

[9] It should be noted that the dimension along which $R_E$ falls need not be the *only* dimension of the early memory representation. Accordingly, conceptual processing, represented by the function C, may operate on more than $R_E$. It is only $R_E$, however, that is affected by duration and degradation.



decreases the amount of signal relative to the amount of noise that occupies the channel. Accordingly, the signal transfer rate is slowed; it takes longer for a given amount of degraded signal information compared to clean signal information to accumulate in short-term memory. The contents of short-term memory (and all subsequent memory repositories), however, contain only accumulated signal information; information is not recorded about the original signal-to-noise ratio in the serial channel. This constitutes a version of the single-dimension hypothesis (and of the slowdown hypothesis as well).

### Remark

Validity of the single-dimension hypothesis does not require validity of the slowdown hypothesis. Rather, the slowdown hypothesis implies a particular (multiplicative) form of the perceptual function **P** that combines duration and degradation.

## An Initial Test of the Single-Dimension Hypothesis

The first experiment to test the single-dimension hypothesis is actually the very same complex-picture/ratings experiment that we have just described. Our above description of the ratings experiment was incompletely. As we described, pictures were indeed shown, one by one, and a "recognition-probability rating" was obtained after each presentation. However, this series of presentations also constituted the study phase of a study-phase/test-phase, old/new recognition memory procedure.

To connect the single-dimension hypothesis with data, we make the weak assumptions that (a) rating performance is some monotonic function, $\mathbf{M_{Rt}}$ of the early memory representation, and that (b) recognition performance is a separate monotonic function, $\mathbf{M_{Rg}}$ of the long-term memory representation. With these assumptions, we can then make the fundamental prediction: *two duration/degradation conditions that are equal in terms of rating should also be equal in terms of recognition.* Briefly, the reason for this prediction is as follows: If there are two duration/degradation conditions that produce equal ratings, then these conditions must have produced equal early representations, $\mathbf{R_E}$. This, in turn, means that the long-term memory representation for these two conditions must be the same and therefore they must produce equal recognition performance (for elaboration see Bamber, 1979).

We tested this prediction using what Bamber (1979) refers to as a *state-trace graph.* The results are shown in Figure 12.6 wherein recognition performance is plotted as a function of rating performance, with one data point for each of the 12 study conditions. The open circles represent the six clean conditions and the closed circles represent the six degraded conditions. Note that, except for the top right-hand data points, the open

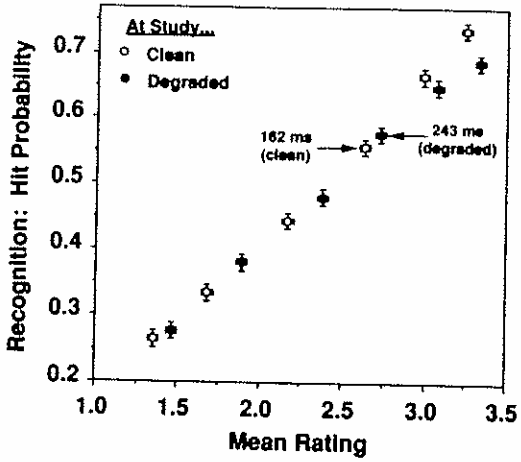


FIGURE 12.6. State-trace plot. Recognition performance as functions of rating performance. Different symbols represent clean and degraded study conditions.

and closed circles fall essentially all along the same line. We assert that this finding constitutes confirmation of the single-dimension hypothesis.

Bamber (1979) provides a formal of why this is so. To see why it is so informally, consider the two data points indicated in Figure 12.6 that correspond to the 162-ms clean condition and the 243-ms degraded condition. Note that these two data points are almost, but not quite, on top of one another.

Suppose they *were* on top of one another. In this case we would have found two degradation/duration conditions, equal in terms of rating performance, that were also equal in terms of recognition performance. This, as described earlier, is exactly the prediction of the single-dimension hypothesis.

Now suppose that we had run the "perfect experiment" in which we had tested performance at all possible stimulus durations (between, say, 0 and 500 ms) rather than just the six durations within each degradation condition that we actually used. If this were true, the state-trace graph would consist of two continuous functions: one of open circles (all squished together) and the other of closed circles (similarly squished). These two functions would be identical (fall on top of one another) if and only if any two duration/degradation conditions that were equal in terms of rating were also equal in terms of recognition, as predicted by the single-dimension hypothesis.

Returning to our actual, "imperfect" experiment, the curves corresponding to the open and the closed data points in Figure 12.6 constitute *estimates* of these perfect-experiment functions. These estimated functions lie largely on top of one another, thereby confirming the single-dimension hypothesis.

There is a notable departure from this confirmation: the two functions start to diverge in the top right-hand corner of the Figure 12.6 state-trace plot. These points correspond to the longest exposure durations, where more than one eye fixation may have occurred. If more than one eye fixation occurred, the curves would not be strictly comparable, because any eye fixation after the first (whose location was controlled by a fixation point) may be in systematically different locations for the clean versus degraded conditions. Essentially what we have shown is that the single-dimension hypothesis is confirmed as long as stimulus duration is sufficiently short that only one fixation on the picture is probably occurring.



## Objects and Actions

The next test of the single-dimension hypothesis took a somewhat different tack.[10] Instead of having two dependent variables (as we had ratings and recognition in the previous experiment) we had two types of stimuli, termed *objects* and *actions*, which, although perceptually similar, differed greatly in their distinguishability from one another. Objects were pictures of single objects (e.g., a chair, a lamp, etc.), whereas actions depicted a baseball pitcher in different phases in his windup and pitch. These two types of stimuli were used in an old/new recognition experiment.

Both types of pictures were simple black line drawings on a white background. However, the objects were very dissimilar to one another, whereas the actions were very similar to one another. Preliminary pilot work indicated that recognition performance was substantially higher for the objects than it was for the actions.

During the study phase of this experiment, half of each stimulus type were shown *clean* whereas the other half were *degraded* by superimposing dim, random noise over them. Within each of the four conditions defined by a factorial combination of object/action and degraded/clean, there were five stimulus durations. These durations differed for the four conditions so as to produce approximately equal performance ranges. The durations were quite different for objects and actions: the longest clean and degraded object durations were 800 and 2,000 ms, whereas the longest clean and degraded action durations were 15 and 21 sec.

Recall that the single-dimension hypothesis states that degradation has its effect only once, on initial perceptual processes. This means that,

[10]This experiment was conceived, run, and analyzed by Takehiko Nishimoto.

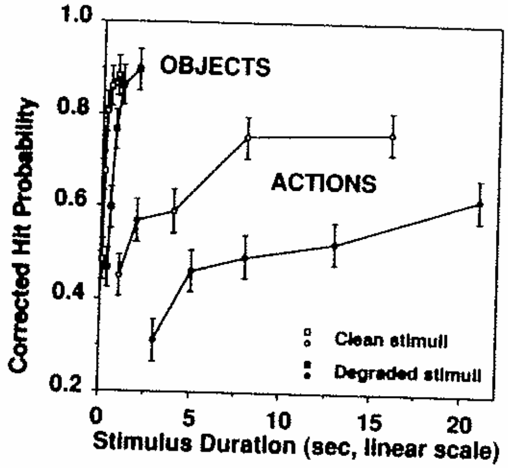


FIGURE 12.7. Results of the action/object experiment. Hit probability (corrected for false-alarm probability) as functions of stimulus duration. Separate curves represent objects (right curves) and actions (left curves) and clean and degraded study conditions (open and closed symbols).

assuming the slowdown hypotheses to be correct, the slowdown factor should be the same for objects and actions, and the memory representations of the pictures should be the same up to the time of recognition. At this point, some monotonic function $M_A$ should operate on the long-term memory representation to produce recognition performance for actions, whereas a separate monotonic function, $M_O$ should operate on the memory representation of objects to produce object performance.

Figure 12.7 shows the results. Here, hit probability (corrected for false-alarm probability) is shown as a function of stimulus duration on a linear scale. Several (qualitatively unsurprising) effects are evident: longer stimulus durations lead to higher performance, clean pictures are recognized better than degraded pictures, and objects are recognized better than actions. Figure 12.7 dramatically indicates the vast processing-rate difference between objects and actions: it takes an order of magnitude more time to achieve a given recognition-performance level for the actions relative to the objects. In addition, the asymptote for object performance appears close to 1.0, whereas the action-performance asymptote appears to be considerably below 1.0. In short, recognition memory performance is dramatically different for the two stimulus types.

Figure 12.8 (left panel) shows the Figure 12.7 data replotted on a log-duration scale. Now a good deal of lawfulness becomes apparent. First, for both objects and actions, the curves are approximately horizontally



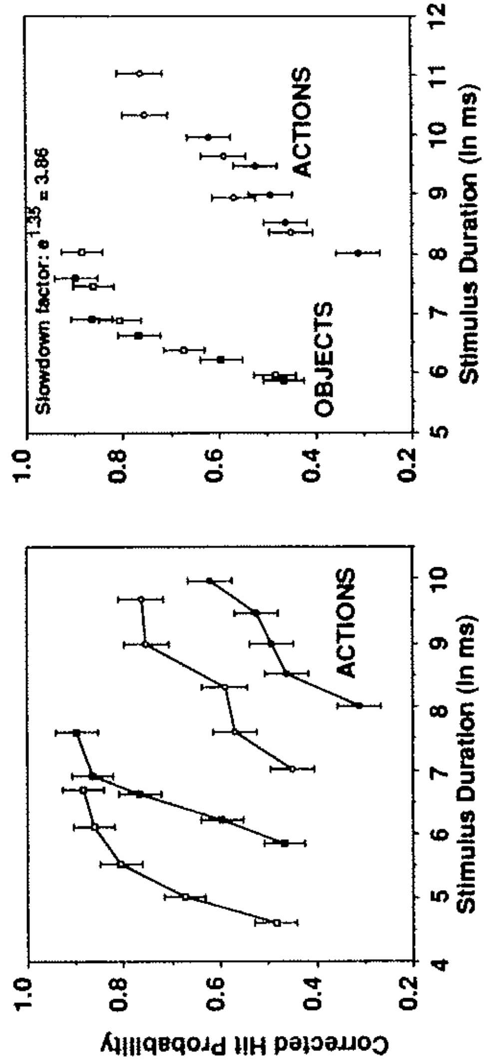


FIGURE 12.8. Results of the action/object experiment 4. Right panel: Figure 12.11 data on a log-duration abscissa. Left panel: The two clean curves have been shifted right by equal amounts (1.35 log units) relative to the two degraded curves.

parallel, indicating confirmation of the slowdown hypothesis. Second, the degree of horizontal separation is approximately the same for the two type of stimuli. The right-hand panel of Figure 12.8 shows clean-object and clean-action performance curves both shifted right by 1.35 log units relative to their degraded counterparts. Both object and action curves now line up essentially perfectly, which indicates that the slowdown factor (approximately $e^{1.35} = 3.86$) is the same for both types of stimuli.

These results allow two noteworthy conclusions. First, the slowdown hypothesis continues to be true for a very long time (up to 21 seconds!) following stimulus onset for these simple stimuli. This time, of course, vastly exceeds the duration of a single eye fixation. We conclude that for these stimuli, perceptual processing is slowed by a constant factor not only within a single eye fixation but, remarkably, across a series of perhaps 40 to 80 eye fixations.

Confirmation of the slowdown hypothesis allows a test of the single-dimension hypothesis. In particular, because the slowdown rate was approximately the same for both stimulus types, the single-dimension hypothesis is confirmed. Our second conclusion, therefore, is that for these stimuli, degradation affects cognitive processing only once by its slowing-down effect on initial perceptual processes.

We noted that in the rating/recognition experiment, the single-dimension hypothesis broke down at durations beyond about 300 ms. Yet with these action/object stimuli, the single-state hypothesis (and the slowdown hypothesis as well) is confirmed for much longer times. We conjecture that processing of these simple line drawings is more temporally homogeneous than is processing of complex scenes.

## Degrading Stimuli at Study and Test

Recall the the single-dimension hypothesis implies that no information about a stimulus's degradational state is stored as part of the memory representation. Although degrading a stimulus can, by this hypothesis, affect the memory representation, it can do so only by influencing initial perceptual processing; degradation leaves no trace of itself later on. As we have seen, this hypothesis has thus far been confirmed in two experiments.

But the hypothesis carries with it a surprising prediction. Suppose that we were to do an experiment in which we presented stimuli degraded or clean at study and then presented them similarly degraded or clean, in an old/new recognition test. The single-dimension hypothesis implies that there is no advantage of a stimulus being in the same degradational state at study and test. This is contrary to the prediction of any kind of encoding-specificity hypothesis (e.g., Tulving, 1974, 1983). It is also contrary to findings by Dallett, Wilcox, 'Andrea (1968), who showed normal or degraded pictures at study and/or test, and reported a recognition-test



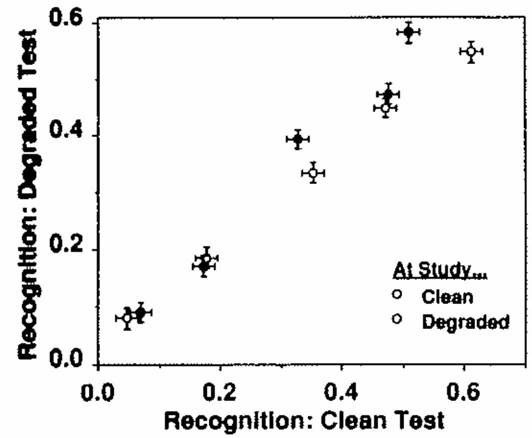


FIGURE 12.9. State-trace plot. Degraded-at-test recognition performance as functions of clean-at-test recognition performance. Different symbols represent clean and degraded study conditions.

advantage to being in the same state at study and test. This finding makes sense; a test picture presented in the same degradational state at test as it had been in at study should engender a closer memory match than a picture presented in dissimilar study and test states.

Accordingly, the single-state hypothesis's prediction is a counterintuitive one. We tested the prediction by repeating the rating/recognition experiment. As in the rating/recogntion experiment, half the stimuli were degraded at study and the other half were clean. However, in the present experiment, degradational state was also manipulated at the time of test: half the test stimuli were degraded and the other half were clean. This leads to a 2 × 2 design in which pictures were either clean or degraded at study and also were either clean or degraded at test. Within each of these four cells, pictures were shown at one of five study durations.

The prediction of the single-dimension hypothesis is based on logic analogous to that used in the rating/recognition experiment. Again, there are two dependant variables: clean recognition performance and degraded recognition performance. The prediction is that any two study-duration/study-degradation conditions that produce the same degraded recognition performance should also produce the same clean recognition performance.

Figure 12.9 shows the state-trace plot for these data. Here, degraded recognition performance is plotted as a function of clean recognition performance. There is some noisiness in the data that precludes us from drawing strong conclusions from them. It appears, however, that the clean and degraded study curves fall approximately on top of one another, thereby providing weak support for the single-dimension hypothesis.

## Noisiness Banished: Replication with New Stimuli

The results that we have just described were somewhat surprising; confirmation of the single-dimension hypothesis is inconsistent with any model implying an advantage to being in the same degradational state at study and test. Unfortunately, as noted, the data were somewhat noisy. Accordingly, we set out to replicate them for the simple purpose of increasing experimental power. The only change we made for this replication was to assemble an entirely new set of slides. This was accomplished by photographing scenes (farmland, beaches, yards, streets, and house groupings) around the Seattle area. Given this apparently minor change we had expected the replication results to be at least qualitatively the same as the original results. This did not happen.

The major replication results are shown in Figure 12.10, wherein ratings, clean-at-test recognition performance, and degraded-at-test recognition performance are shown as functions of log duration. Surprisingly, for the first time, the slowdown hypothesis is disconfirmed: the clean and degraded curves diverge even on a logarithmic scale. This effect, seen most plainly in the rating data (top panel), implies that degrading a picture at study is doing more than simply slowing down perceptual processing. Informally, we can say that degradation in this experiment has a qualitative rather than a quantitative effect.

As noted earlier, confirmation of the slowdown hypothesis is not necessary to test the single-dimension hypothesis. However, it can be seen that the separation between clean-at-study and degraded-at-study curves is much less when the test stimuli are degraded (Figure 12.10 bottom panel) than when test stimuli are clean (Figure 12.10, middle panel).

This result can be seen more clearly in Figure 12.11, a state-trace plot. The clean-at-study function is clearly separated from the degraded-at-study function. When two duration/study-degradation conditions show the same clean-test performance, the degraded-at-study conditions enjoy a benefit on a degraded relative to a clean test and vice versa. A convenient way to construe the relationship of these functions is that the degraded-at-study function is above the clean-at-study function (i.e., it is "better" from the perspective of the vertical, or degraded-test axis). However, the clean-at-study function is to the right of the degraded-at-study function, i.e., it is better from the perspective of the horizontal, or clean-test axis.

In short, the data shown in Figure 12.11 indicate that there is a recognition-performance advantage to being in the same degradational state in study and test. This confirms any sort of encoding-specificity

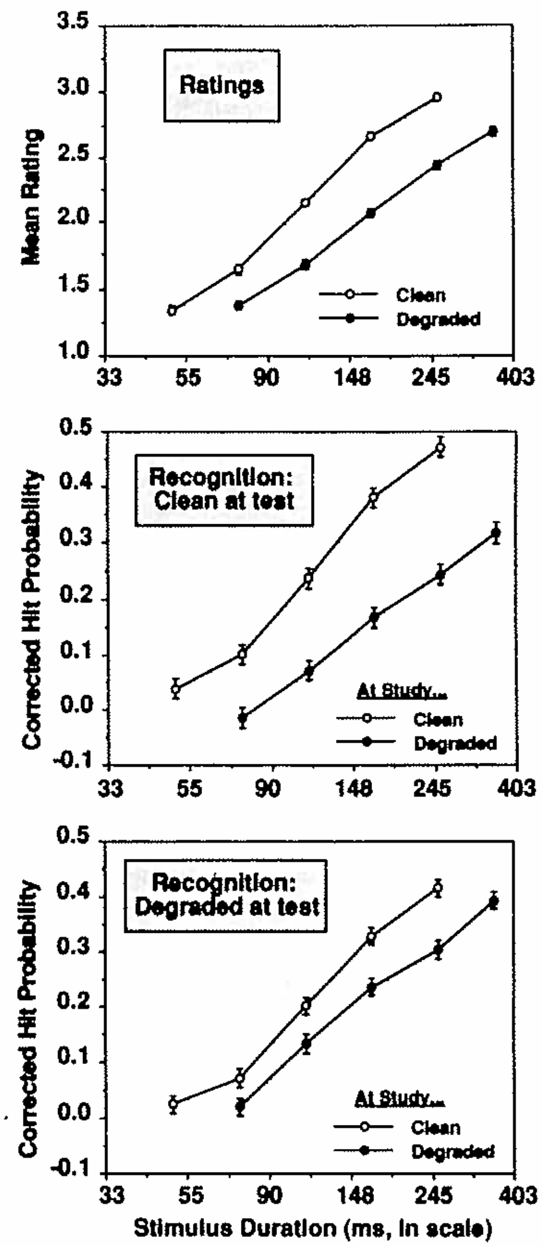


FIGURE 12.10. Replication results. Top panel: rating as functions of stimulus duration. Middle and bottom panels: hit probability (corrected for false-alarm probability) as functions of stimulus duration for pictures shown clean at test (middle panel) and degraded at test (bottom panel). In each panel, separate curves represent clean and degraded study conditions.

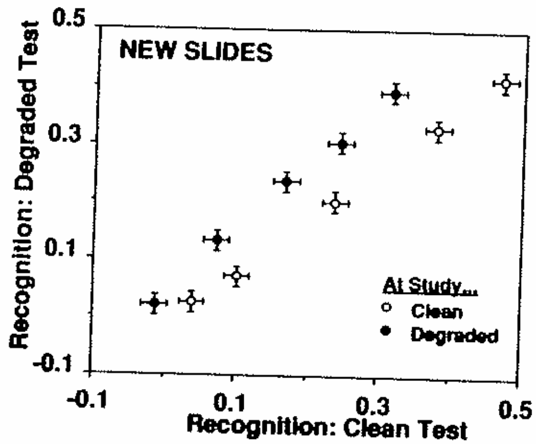


FIGURE 12.11. Replication results: state-trace plot. Degraded-at-test recognition performance is plotted as functions of clean-at-test recognition performance. Different symbols represent clean and degraded study conditions.

hypothesis, and also constitutes a replication of the Dallett et al. (1968) data.

## What is Different about Original and New Stimuli?

There is, of course, a discrepancy between the replication results and all previous results. In particular, the slowdown hypothesis and the single-dimension hypothesis were both disconfirmed in the replication. This failure to replicate is most dramatic when the last two experiments are compared, which were identical except for the stimuli used. Using the original stimuli we concluded that degradational information is not stored as part of the memory representation whereas using new stimuli we concluded that degradational information *is* stored as part of the memory representation. There is a great deal of power in all experiments; thus the key to the difference must lie in the difference between the two stimulus sets.

We observed informally that the new slides seem darker and have more contrast than the original slides, which seemed to make the degrading manipulation (imposition of the adapting field) more noticeable for the new stimuli. This led to the hypothesis that degradational information is stored as part of a picture's memory representation to the degree that the picture's degradational state is noticed and actively encoded at the time of study.

To test the validity of our informal observation (and, accordingly, of the resultant "noticeability hypothesis"), we showed groups of subjects all the original stimuli and all the new stimuli. For each stimulus set, half the stimuli were clean and half were degraded. The subjects' task was to report whether each stimulus was clean or degraded.



The results of this experiment were quite clear: whereas the ability to detect degradation was quite high for both stimulus sets, it was about 12% higher for the replication stimuli relative to the original stimuli.[11]

This finding is consistent with the following explanation of the difference between the original and the replication slides. First, the results represent an upper limit on a subjects' ability to detect degradation. When the subjects are not instructed to detect degradation (as was the case in all previous experiments) it is likely that they actually notice the degradation a much smaller percentage of the time. In particular, it is possible that they almost never detect degradation in the original stimuli, whereas they may occasionally detect degradation in the new stimuli. If degradation detection always engendered explicit storage of this degradational information as part of the memory representation, this would account for the discrepancy between the two stimulus sets.

# Conclusions

The original questions addressed in this chapter were, To what extent does visual degradation affect initial perceptual processes? and To what extent does visual degradation affect the ultimate memory representation?

## Degradation Effects on Perceptual Processes

We have demonstrated that visual degradation almost always has a profound effect on initial perceptual process. In one form or another, this result is shown in all the experiments that we have reported. In most cases, the effect is quite specific, and conforms to the slowdown hypothesis: a given degree of degradation can be characterized as slowing initial perceptual processing by some constant factor.

In the one experiment where degradation could be defined quantitatively (the digit-recall experiment) the relation between contrast and slowdown was quite lawful; there was almost a perfect tradeoff between contrast and duration required to achieve any given performance level. Another noteworthy effect was shown in the object/action experiment, wherein the slowdown effect continued to operate for a very long time following stimulus onset.

[11] The hit probability is higher and the false-alarm probability is lower for the new relative to the original stimuli. Accordingly, our conclusion is unaffected by our correction-for-guessing procedure.

## Degradation Effects in Long-Term Memory

In many situations, the degradational effect on perceptual processes appears to be degradation's *only* effect on picture processing. In three of the experiments, we confirmed the single-dimension hypothesis, which states, essentially, that degradational information is not stored as part of the memory representation; the information about the degradational state of the stimulus is lost during initial perceptual processing.

However, in the penultimate (replication) experiment we discovered that it is possible for degradational information to be stored as part of the memory representation. And finally, the results of our last (degradation-detection) experiment suggest that this may happen when the storage of such information is a conscious, deliberate process.

## Degradation and Eye Fixations

We began this chapter by recalling an old finding: eye-fixation durations are increased when the fixated stimuli are degraded relative to when they are clean. Given the newer results that we have described here, we are now in a position to be a bit more specific about the nature of this effect. We note two possibilities, each of which provides testable predications about future eye-movement experiments.

### The Slowdown Effect and Fixation Duration

We have seen that acqusition of perceptual information is slowed for degraded relative to clean stimuli. One simple hypothesis (noted at the outset of this chapter) is that eye fixations are "designed" to acquire some criterion amount of information. Such a hypothesis makes a very specific prediction: if one measured the slowdown rate (as we described above) and simultaneously measured eye fixations, then eye-fixation duration would be increase with degradation by a factor equal to the slowdown rate.

### The Unidimensional Effect and Fixation Pattern

We have seen that in some instances, degradational information does not appear to be stored as part of the memory representation, whereas in other instances it does. The latter situation must entail qualitatively different information-acquisition processes for different degradational levels, whereas the former situation may entail qualitatively identical (albeit quantitatively slower) processing. Given the supposition that qualitatively same or different encoding processes might be reflected in corresponding same or different eye-fixation patterns, we would expect to see different eye fixation patterns associated with different degradational levels when degradational information is stored in memory, but similar



patterns at different degradational levels when degradational information is not stored in memory.

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# 13
# An Exploration of the Effects of Scene Context on Object Identification

Susan J. Boyce and Alexander Pollatsek

A major question in visual cognition is whether the identification of objects is merely the result of a bottom-up perceptual analysis or whether it is highly dependent on real-world knowledge stored in memory as an aid to perceptual processes. An important part of this question is whether the context of the real-world "scene" in which the object is placed influences the identification of the object, and if so, how. However, there is significant disagreement among researchers in the area as to what has been discovered. This is due in part to different theoretical orientations and in part to disagreement as to what paradigm or paradigms are adequate for studying object identification. As a result, we will briefly review some of the literature in order to place our research in sufficient context.

## Does Scene Context Influence Object Identification?

The statement that an object that is viewed in a "natural" context is easier to process than an object that is viewed in an "unnatural" context is probably uncontroversial. What is at issue is whether a natural context is facilitating the actual identification of an object or some later stage of processing, such as integrating an identified object into a mental model of the scene being viewed. Central to this theoretical issue is the question of how to empirically assess object recognition in scene perception, or in other words, what paradigms are legitimate for studying object recognition.

We would like to distinguish between two aspects of a paradigm: (a) what the subject's basic task is and (b) the dependent variable used to assess object identification. Although the former to some extent determines what the latter will be, we think it is useful to distinguish between them. In this section, we will concentrate on the former aspect and, for the most part, delay our critical discussion of dependent variables until the end. Our general position is that no paradigm will be perfect. Thus,