Automatizing of visual attention*

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Perceptual automatizing was argued to occur as a consequence of repeated experience with a stimulus. Automatizing was hypothesized to entail a stereotyping in sampling of sensory information together with an attendant decrease in the rate of sampling of that information. An experiment was performed in which human Ss observed stimulus pictures for several trials, during which records were made of their visual fixations. It was found that fixation rate habituated and that this habituation was accompanied by a reduction in the uncertainty (entropy) of the spatial distributions of fixations. These results were interpreted as evidence for automatizing of visual fixation processes. Analysis of eye-movement distances suggested a possible mechanism for the reported loss of vividness of a stimulus which is perceived habitually.

People often refer to acts that have become so habitual that they are performed unconsciously, and it is not difficult to accept the proposition that motor skills, at least, can be in some sense automatized. But most skills that we learn are neither purely motor nor purely perceptual in nature, but some complicated mixture of both. When a person relates the common experience of driving a car over a familiar route automatically, it is not surprising to find that one of the things that he means is that he was unconscious not only of the movements of his arms and legs, but that he was also unconscious of the events going by his car's windows.

Most elaborations of the notion of perceptual automatizing seem to imply that it is a process typical of most perceptual systems and a process which is somehow responsible for the loss of consciousness when one performs some habitual perceptual act.¹ But, as previously used, the term "automatizing" denotes little more than a loss of consciousness. A better understanding of the mechanisms which may be involved may be gotten by analyzing the implications of automatizing in terms of the information flow in perceptual systems.

Arguing from a functional point of view, it would seem that automatizing of a perceptual process would occur in order to increase the efficiency of all ongoing perceptual activity. So, it is reasonable that automatizing should be evidenced by a decrease in the

activity of a perceptual system or by a decrease in the rate of information being processed by that system. It has been amply demonstrated that perceptual channels have limited capacity (Broadbent, 1958) so that any savings in the amount of information flow in a subsystem must result in a gain in the system's capability for processing other information simultaneously. That stimulus-specific perceptual processes decrease in activity as a result of experience is well known (e.g., Sharpless & Jasper, 1956), and this phenomenon is known physiologically as habituation. Automatizing can be viewed as an efficient decrease in the sensory information necessary to construct a repeated perceptual event, and on a phenomenological level, this can be seen as implying the reduction of awareness of things one acquires as a result of past experience with them.

One way in which a cognitive process may be made to operate more efficiently is simply by changing the code which is used to represent the elements of the process. A favorite trick is to arrange operational units hierarchically, so that a whole subprocess can be indexed by a single tag, much as one would use subroutines in programming computers. Such recoding strategies have been shown to be used by people in order to go beyond the limitations of the immediate memory span (Miller, 1956) and for organizing more permanent memories (Bower, 1970). Miller, Galanter, and Pribram (1960) have argued that even complicated servomechanisms in the brain are likewise indexed as well-packaged subroutines.

Another way to streamline the operation of a cognitive process would be to decrease the complexity of its operation by making it respond in a more stereotyped manner. Stereotypy of a perceptual process would mean a tendency to hear or see the same event in the same way as one did before. It

might at first seem that decreasing the variability of response of a perceptual mechanism would be maladaptive, but there is reason to believe that the brain works in this fashion by positing simplicity in the environment and by revising its predictions through a process of orienting to mismatches between neuronal models and sensory input (Sokolov, 1960). That is, insignificant variability of the environment is not incorporated into the response of a perceptual model, but rather is handled by a restructuring or upgrading of the model at the proper time. So stereotypy, or some tailoring of the perceptual mechanism to modal environmental events, can be an adaptive method of recoding sensory input. Perceptual automatizing, then, would be the outcome of efficient perceptual learning and would likely be evidenced by a stereotyping of response and by an attendant decrease in gross rate of operation of a perceptual mechanism.

Perception can be conceived of as a synthesis of sensory and memorial (structural) brain events, and it is assumed here that one's consciousness of the perception is related closely to the amount of sensory information flow, and less so to the amount of structural information activated. When first encountering a novel event, the brain is seemingly processing more sensory information than it does later. This is spoken of as a generalized orienting reaction (Sokolov, 1960). When the orienting reaction has been habituated, presumably mediated by the acquisition of structure, people report being less conscious of the events than when the events were novel.

In order to gather evidence for the proposition that there is some kind of automatizing which occurs in perceptual systems as a result of repeated exposure, an experiment was performed, with the aim of observing a perceptual process under conditions which usually produce habituation of simple physiological responses, to find out if there are changes in rate and stereotypy of operation. It was decided that fixation eye movements would be studied in this connection, both because of their suggested intimate involvement in visual processes² (Hebb, 1949; Festinger, Ono, Burnham, & Bamber, 1967) and because of their correspondence in time with visual perception.

Rate of information processing was interpreted to be rate of eye movements, because this correspondence is suggested in several studies showing relationships between rate of eye movement and concurrent visual activity. Breese (1899), investigating binocular rivalry, found

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Fig. 1. Habituation of visual fixations. (A) Mean number of fixations per trial for individual pictures. (B) Mean number of fixations and mean number of different sectors searched for all pictures.

that Ss could increase the amount of time one visual field was seen by actively paying attention to that field. This act of attention was accompanied by considerable eye movement when the relevant field was reported as seen and very few eye movements when the other field was seen. Tepas (1962) found that the "blank out" of the visual field in a ganzfeld was accompanied by an absence of saccadic eye movements and that the conclusion of the blank-out period was coincident with the resumption of these movements. The assumption that eye-movement rate reflects the amount of ongoing visual activity receives further verification if it is found that this measure habituates. Stereotypy was interpreted in terms of predictability of fixations. This technique involved obtaining spatial distributions of ocular fixations by the Shannon entropy function ($H = -\sum p_i \log_2 p_i$) of the distributions (Shannon, 1948).³

METHOD

Apparatus

A Mackworth stand camera (Mackworth, 1967) was used to record the locus of fixation during inspection of pictures. This technique involves reflecting a small spot of light off the cornea and optically superimposing this eyespot on a picture of the stimulus being viewed. The movement of the eyespot is roughly proportional to corneal movement for stimuli occupying about 20 deg of arc, and with careful alignment the apparatus

can give a record of where a S looks to an accuracy of about 1 deg. Stimulus pictures were 8 x 8 in. and were mounted on boards which could be loaded into a frame-and-shutter arrangement, mounted at eye level and 22.5 in. in front of the S's eye. This gave a display subtending 20 x 20 deg. Eye tracks were recorded on high-speed 16-mm film at a rate of 11 frames/sec with a Bolex H16 movie camera.

Stimulus Pictures

Six color photographs were selected as stimulus pictures for this experiment. The subject matter of the pictures was as follows: an aerial view of Amsterdam; two men seated in front of a canal; a 1938 Bentley automobile; a masked face; an iceberg; and a clockmaker. In the data analysis, each picture was broken up into 64 sectors, each 1-in. square, by an 8 x 8 grid superimposed on the projected image. The primary record for each trial was a sequence of picture sectors, one sector for each frame of film, showing where the eyespot was located in each frame. A change of sector defined a change of fixation.

Subjects

The Ss were 12 Stanford University male undergraduate volunteers, participating in the experiment for credit in an introductory course in psychology.

Procedure

The Ss were seated before the

apparatus and fitted with a biteboard and headrest to eliminate movements of the head. They were told that they were participating in an experiment dealing with pupillary responses and that they were to familiarize themselves with a group of pictures they would be shown for several trials so that they would be able to recognize them in a later part of the experiment. They were informed that while they were doing this, the E would be photographing some "baseline measurements" of their pupillary responses. The Ss were then presented a series of 30 trials of looking at the stimulus pictures (5 trials for each of the six pictures). The pictures were presented in an order determined by an arbitrary sequence, constructed with the constraints that no two trials of the same picture could be adjacent, and that the maximum distance between successive trials for the same picture was eight. The average interval between successive trials for the same picture in this sequence was 4.5. Assignment of pictures to sequence elements was counterbalanced over Ss in a Latin square design.

The E was seated in the room near the S throughout the experiment. Each trial began with a ready signal from E, following which the picture was exposed for approximately 5 sec, with about 30 sec between trials. There were short rest pauses after the 10th and the 20th pictures in the sequence.

RESULTS

Fixation Rate

Figure 1 shows mean fixation rates for the five trials of the experiment. In order to equalize unavoidable differences in film sequence length, only the first 50 frames (all the film sequences were at least 50 frames long) of each trial were used in this and in all following analyses. Excursions of the gaze outside of the picture were disregarded, and the terminal point of the prior eye movement was taken to be the point of reentry onto the picture. (When protocols were reduced below 50 frames by these excursions, statistics for them were normalized to 50 frames.) Figure 1a shows the fixation rate for each of the six pictures, and Fig. 1b is the group average. There is a clear habituation effect, even during this relatively short series of trials. Average fixation rate declines from greater than 13 fixations/trial (2.63 fixations/sec) to 9.5 fixations/trial (1.91 fixations/sec). An analysis of variance showed the effect of habituation to be highly significant [$F(4,44) = 10.76$, $p < .001$], and there were significant differences

Fig. 2. Habituation and between-trial spontaneous recovery of fixation rate. Mean number of fixations is shown for the first and second halves of each trial.

among the six pictures [$F(5,55) = 3.42$, $p < .025$]. The Picture by Trial interaction failed to reach significance [$F(20,220) = 1.07$, $p > .05$], indicating that there were no major differences in the rates of habituation among the six pictures. Figure 1b also shows a monotonic decrease in the group mean number of different sectors searched per trial, which appears to parallel the fixation rate.

Figure 2 plots the mean number of fixations in the first and the last half of each trial. It can be seen that there is considerable habituation within each trial which partially recovers between successive presentations of a picture. The difference between first and second half for all trials was highly significant ($t = 4.09$, $df = 5$, $p < .005$). In their review of habituation phenomena, Thompson and Spencer (1966) list spontaneous recovery following interruption as one of the characteristics of habituation. These data give further support for regarding the observed temporal changes in fixation rate as an habituation phenomenon and thus reflecting a decrease of activity in the visual system.

Stereotypy of Fixation

Distributions of the number of fixations in each sector and of the total time spent fixating each sector were obtained for each S and each trial. Shannon uncertainty [$H = -\sum p(i) \log_2 p(i)$], a measure of predictability or peakedness of these distributions, was computed, and group averages were taken for the five trials. Any change in average uncertainties reflects a change in the degree to which fixations become predictable or stereotyped with repeated exposure to a stimulus pattern. A decrease in uncertainty indicates an increase in predictability.

One problem presents itself in

analyzing these statistics. It is desired to obtain estimates of population uncertainty—the uncertainty associated with the population probability distributions of sectors fixated. To do this, it is necessary to use the observed relative frequencies of fixation as estimates of the population distributions. It has been shown that in using $\hat{n}_i/\hat{N}$ as an estimate for $p(i)$ (the population parameter for the probability of cell i of a multinomial distribution), the usual formula for uncertainty is a downwardly biased estimate of the population uncertainty for small $\hat{N}$ (Miller & Madow, 1954). Since fixation rate (and, therefore, N of the distribution) decreases over trials, it might be expected that there would be a decrease in estimates of H independent of any real differences in uncertainty of the underlying population distributions. In order to compensate for this bias, a correction factor suggested by Miller and Madow (1954) was added to each raw entropy value,⁴ yielding an approximation to an unbiased estimate that is accurate to the order of $1/N^3$. (It may be pointed out that no selective bias exists in the entropies for the fixation-time distributions, because the N s of these distributions were constant at 50 frames.) The corrected entropy data were then averaged to obtain the results shown in Fig. 3. There is a strong decrease in the uncertainty of both fixation-frequency and fixation-time distributions. These decreases were highly significant [$F(4,20) = 4.58$, $p < .01$ for frequency; $F(4,20) = 6.74$, $p < .005$ for time], indicating an increase in the predictability of fixations after repeated exposure to a stimulus array.

Another type of predictability, sequential predictability of fixations, was examined to see if similar changes could be found in the conditional probability distributions of fixation frequency. For each trial, 64 conditional distributions were constructed, giving the frequency of transitions from each of the 64 grid cells. Because of the small N s associated with these distributions for individual Ss, group distributions were summed over all Ss, and corrected entropy values were calculated. Most of these distributions were still too thin for reasonable estimates of uncertainty, so a selection was made of only those conditional distributions for each picture which contained five or more observations on each trial. Thirty-six such distributions were found, comprised of seven from p1, three from p2, nine from p3, five from p4, six from p5, and six from p6. The average number of observations in these distributions were as follows:

Fig. 3. Mean uncertainty of spatial distributions of fixations. Values given are corrected for sampling bias.

Trial 1, 11.93; Trial 2, 10.71; Trial 3, 10.71; Trial 4, 12.63; Trial 5, 9.63. Figure 4 shows average entropy values for these sequential distributions. The difference across trials was highly significant [$F(4,20) = 7.42$, $p < .001$]. If one can assume that there exist at least first-order sequential dependencies in eye movements—not at all a strong assumption considering spatial proximity relations of the visual field—it may be concluded that with perceptual experience, eye-movement patterns become more determinate. That is, there is more predictability in the sequence of eye movements, with certain modal eye-movement sequences becoming characteristic of a person's visual attack on a stimulus.

Analyses of both marginal and sequential distributions of fixations show a decrease in the uncertainty of these distributions. These results are taken to indicate an increase in the redundancy of visual information sampling with increased experience of a stimulus pattern and thus a

Fig. 4. Mean uncertainty of selected group sequential distributions. Values are corrected for sampling bias.

Fig. 5. Mean transition distance between successive fixations. (A) All fixations. (B) Transition distance following brief ($t < 300$ msec), intermediate ($300 < t \leq 600$ msec), and long ($t > 600$ msec) fixations.

stereotypical restriction of visual search.

Transition Distance

A measure of the length of each eye movement was computed as the distance between two fixations, a change in fixation being defined as a change of picture sector. Figure 5a shows average distance of sector transitions for the five trials. There was a slight decrease in this measure during habituation, with most of the change occurring between Trials 1 and 2. A one-way analysis of variance was not statistically significant, but the difference between Trial 1 and the average of the other four trials was significant ($t = 2.71$, $df = 5$, $p < .05$).

Since there is an increase in average fixation time over trials (average number of fixations decreases), transition distance was computed separately for different fixation times, in order to see if these data could aid

in the interpretation of changes in fixation times. Figure 5b shows transition distance for brief (less than 300 msec), intermediate (between 300 and 600 msec), and long fixations (greater than 600 msec). There is a strong and consistent difference between transition distances related to duration of fixation, averaging 0.80 deg for the difference between brief fixations and longer ones. Brief fixations are followed by relatively shorter eye movements than intermediate and long fixations. An analysis of variance for these data is given in Table 1. The effect of fixation time is highly significant ($p < .005$), but neither the effect of habituation trials nor the interaction is significant. The difference between intermediate and long fixations is fairly consistent over trials, but an a posteriori test between the two groups failed to reach significance ($t = .98$, $df = 5$, $p > .10$).

Before interpreting these differences, it is necessary to rule out a possible artifact due to corrective eye movements. In examining eye tracks, it is often observed that long saccades sometimes are followed by brief correction saccades, usually interpreted as corrections of fixation when a saccade overshoots the fixation target. It might thus be expected that brief fixations would have a smaller average transition length, simply because included in these brief fixations are terminal points from long saccades which are then corrected, always by a short saccade. Short changes of fixation do not have such corrective movements, because aiming accuracy is a function of the distance separating two points of fixation. Fixations were therefore divided into those which follow short (1 sector) or long (greater than 1 sector) transitions⁵ and brief- (less than 300 msec) or long- (greater than 300 msec) duration fixations. The results, averaged over trials, are displayed in Fig. 6, and an analysis of variance for these data is given in Table 2. Both fixation time and previous transition distance produced significant effects on transition distance, as did their interaction. An a posteriori test revealed a significant

Fig. 6. Mean transition distance conditionalized on fixation time and previous transition distance. TS—short previous transition (= 1 sector); TL—long previous transition (> 1 sector); FS—short fixation (≤ 300 msec); FL—long fixation (> 300 msec).

difference between short transition/long fixations and short transition/brief fixations ($t = 2.99$, $df = 5$, $p < .05$, one-tailed), indicating a relationship between fixation time and subsequent transition distance independent of artifact due to corrective saccades. The difference between the two long fixation groups was not significant, suggesting that the significant F for previous transition distance was largely due to long transition/short fixations (i.e., corrections of fixation).

DISCUSSION AND CONCLUSION

The experiment reported here suggests considerable reduction in the rate of information processing in the visual system (indicated by a 25% decrease in eye-movement frequency) after a few exposures to a novel stimulus. This is a habituation phenomenon and is not in itself a particularly surprising result. What is significant is that what gets looked at becomes more predictable, and this increase in predictability is also true for the order in which things are searched. This stereotypy of search is

Table 1
Analysis of Variance of Transition Distance for Brief, Intermediate, and Long Fixation Times

Source	SS	df	MS	F	
Fixation Time (F)	2.091	2	1.046	11.50	$p < .005$
Trials (T)	.208	4	.053	.93	n.s.
Pictures (P)	4.674	5	.935		
P x T	1.117	20	.056		
P x F	.905	10	.091		
T x F	.383	8	.048	1.00	n.s.
P x T x F	1.900	40	.048		
Total	11.278	89			

Table 2
Analysis of Variance of Transition Distance Conditionalized Upon Fixation Time and Previous Transition Distance

Source	SS	df	MS	F	
Fixation Time (F)	.508	1	.508	15.87	$p < .025$
Previous Distance (D)	.149	1	.149	6.77	$p < .05$
Pictures (P)	1.105	5	.221		
P x F	.162	5	.032		
P x D	.111	5	.022		
F x D	.050	1	.050	12.50	$p < .025$
P x F x D	.020	5	.004		
Total	2.105	23			

taken to be one of the many kinds of stereotypy which could occur in a repeatedly activated perceptual process. In this case, it is as if part of one's perceptual representation of an object was a skeletal search structure for moving one's eyes over it. This was suggested in a famous hypothesis about visual perception by Hebb (1949), which states that motor commands for moving one's eyes over an object serve to integrate the wholistic perception of the object.

The significance of the finding that long fixations tend to be followed by long eye movements may be seen in terms of a speculative hypothesis about momentary shifts of attention. It is suggested that the difference in average transition distance reflects a difference in central attentional state which is signified by long or short fixations. One might think of the visual system as one channel in a large time-shared computer. When the information to be input from the channel is relatively low, the central processor can switch into or out of the channel at an extremely rapid rate without missing the information it wants. Assume that there are two central states, corresponding to "attention" or "inattention" to the visual channel. Commands for a new fixation can occur from either of these states, but the parameters of control of eye movements will be different for each state. Probably the commands from an "inattentive" state will be coarser and result in relatively longer movements. One can assume both on a priori grounds and on the basis of studies of vigilance (e.g., Haider, Spong, & Lindsley, 1964) that a visual habituation process results in decreasing central demands on the visual channel. It has previously been seen that average fixation time increases during habituation. If one can further assume that long fixations reflect periods of central inattention to the visual channel, the difference in average transition length between brief and long fixation is explained. Further supporting data have been reported by Mackworth and Bruner (1970), who found that more difficult discriminations are accompanied by short eye movements and that children (for whom visual search is presumed to involve greater information flow) have relatively more short eye movements than do adults.

More evidence is needed on this issue, but if the above hypothesis about momentary shifts in visual attention is correct, it offers a more detailed explanation for the phenomenal impression of a loss of vividness of a visual stimulus under conditions which produce automatizing. It is not unreasonable to

suppose that the brain can be in a state of inattention to all visual input, and that during this state there are no gross changes of fixation. States of attention and inattention could alternate very rapidly, perhaps several times a second, so that one may not be aware of a complete lack of visual activity, but rather the impression might be of some more subtle decrease in the vividness of one's visual perceptions. Since the relative amount of long fixations increases during habituation, so presumably does the amount of time spent in an inattentive state, and this would seem to be a type of perceptual efficiency which was argued earlier in this paper to be the functional significance of automatizing.

The above are speculations that are not firmly supported by the data, but merely suggested by them. It is reasonable to expect such time sharing of central channels to occur, both on the basis of everyday observation and on the demonstrable limitations of channel capacity in the human brain (Broadbent, 1958). Mowbray (1954), in an experimental investigation of channel conflict, specifically addressed himself to this issue. He presented verbal messages simultaneously in visual and auditory modalities and found that the number of times both messages were perceived was not greater than chance. His conclusion was that simultaneous processing of information from auditory and visual channels does not occur. There are not many other relevant studies of crossmodal competition for a channel, and further experimentation might elucidate some of the boundaries of this problem. Additionally, it would be helpful to find physiological evidence for temporal changes in attention to different sensory modalities and their correlations. For example, a study of momentary EEG changes in visual cortex related to duration of eye movements would be useful in this context and highly relevant to questions posed in this paper.

It would be desirable to extend the present investigation of visual stereotypy. The experiment reported here investigated only the very early trials of the habituation process, and although there were significant increases in predictability of search, these increases were small. It would be fruitful to investigate the process at asymptote in order to see how strong is the limiting stereotypy for a well-known stimulus. There are some methodological difficulties in doing this, since it would be necessary to present a S with a perceptual task that was sufficiently demanding to keep his attention on the visual display over a

long series of trials and at the same time not be so highly structured as to force the issue. Also, unlike most situations outside the laboratory, the experiment reported here makes minimal task demands, and it would be desirable to know the effects of perceptual utility of the stimulus on automatizing. While there is now some empirical support for the phenomenological concept of automatizing of perceptual processes, more evidence is needed. Ideally, it would be desirable to find evidence of experientially induced stereotypy in the patterning of the aggregate of neuronal activity associated with some subsystem in the brain, but a convincing demonstration of this seems a long way off.

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NOTES

1. In the psychoanalytic tradition, Hartmann (1958) spoke of automatizing as an ego function which serves to increase perceptual efficiency by a conservation of "attention cathexis." Ford (1929) studied the problem in the context of structuralist investigations of the effects of distracting

stimuli, viewing "attention" and "automatization" as two end states of a continuum which varies with perceptual experience. A similar term ("automatism") is used in clinical neurology to denote states which occur during temporal lobe seizures, in which people perform complicated but inappropriate actions with no subsequent memory for them. Recently, deautomatizing has been suggested as an explanation for the heightened perceptual intensity reported as characterizing mystical experiences (Deikman, 1966).

2. Aside from the obvious connection of spatially tuning the receptor.

3. The entropy function can be regarded as an inverse or complementary measure of predictability. It reaches maximum for a uniform distribution. This is the case where there is minimal predictability, when all events are equally likely, and H then has the value of $\log_2 n$, where n is the number of events. H is at a minimum (namely 0) when

the distribution is maximally predictable, that is, when one alternative has a probability of occurrence equal to 1.

$$H' = H + (\log_2 e) \left\{ (k - 1)/2N - 1/12N^2 + [1/12N^2 \sum (1/p(i))] \right\},$$

where k is the number of cells in the distribution.

5. Sectors were 1 in. apart, which corresponds to approximately 2.5 deg of visual angle.

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