Investigations of Information Utilization during Fixations in Reading[1]

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During the reading of connected text, visual information is acquired during fixations. The question addressed in this paper is when during these fixation is visual information acquired? In order to deal with this question, it is necessary to clarify what we mean by the "acquisition" of information. Acquisition can be distinguished into two processes, registration and utilization. Registration refers to visual information becoming available to the brain. Utilization refers to the visual information being used to further the comprehension of the text being read.

At least four different patterns of utilization are possible. (1) Utilization immediately follows registration. This expresses the common assumption that the first 50 ms of each fixation is devoted to information acquisition and the remainder of the fixation period to other processing activities. (2) Utilization from different regions at different times. Some segments of a word or text may be utilized at different times than other segments. One possible pattern of this kind is the left-to-right scan (e.g. Geyer, 1970). This states that letters are utilized, in a left to right sequence, beginning at the left side of the field of clear vision and proceeding to the right. (3) Utilization occurs continuously throughout the fixation. (4) Utilization occurs at a specific point in time. Utilization could occur at a specific point in time, as in the first alternative, but not necessarily immediately after registration. Two possibilities exist: utilization could occur at, or after, the end of a fixation or utilization could occur during the fixation, with the specific time of its occurrence being variable. This paper presents evidence which narrows down these possibilities to the last alternative.

Blanchard, McConkie, Zola, & Wolverton (1984) provided evidence on two hypotheses: utilization follows registration and the left-to-right scan. The experiments reported here provide evidence on the left-to-right scan and continuous utilization hypotheses. These experiments all use a variation of Blanchard et al.'s (1984) technique.

Blanchard et al. (1984): Experimental Procedure and Findings

How can the time course of utilization be experimentally determined? Blanchard et al. (1984) manipulated the visual input available during fixations. If the visual pattern is different at different times during the fixation, then what the reader reports having seen can specify the time at which visual information was utilized. Fast control over the stimulus during the process of reading continuous text was achieved through eye movement contingent display control. In this technique, the subject reads text from a cathode ray tube (CRT) linked to a computer and an eyetracker. The CRT provides the ability to change the text presented in any way desired very quickly (approximately 4 ms). Eye movements are monitored while the subject is reading. The signal from the eyetracker is collected by a computer, which

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identifies, on line, whether the subject is fixating or making a saccade. The text displayed on the CRT can be changed contingent upon what the subject's eyes are doing. In the manipulation used by Blanchard et al. (1984), the text was changed by switching a single letter on the line.

Passages were written in which two words fit into the same place in the text, e.g. The underground caverns were meant to house hidden (tombs,bombs), but then the construction was stopped because of lack of funds. Changing a letter, from t to b, changes the meaning of the text. This critical letter was changed partway through each fixation that the subject made in the vicinity of the letter. The word containing the critical letter is the critical word. At the beginning of a fixation, one word was in the text (tombs). Partway through the fixation, the line of text was replaced by a mask of X's for 30 ms, and the text was then returned to the screen for the remainder of the fixation. However, after the mask, the critical letter was different than it had been in the early part of the fixation, thus changing the critical word to bombs. During the saccade, bombs was changed back to the original word, tombs, and the cycle began again. In this way, the same sequence of display changes was repeated for each fixation-saccade cycle. This sequence of changes caused different information to be present in the early and late parts of the fixation.

The purpose of the mask in this experiment was to eliminate apparent movement which was localized at the critical letter position when the letter changed. Localized apparent movement attracts attention to the location of the movement. The mask causes apparent movement at all letter positions equally, thus removing the effect caused by a localized change.

After reading each passage, the subject was given four test words, one after another, and indicated for each whether or not it had been in the text. Two of the test words were the critical, changing words, e.g. tombs and bombs in the above example. Which word or words were reported indicated whether the critical letter was utilized before the mask, after it, or throughout the fixation.

Given these experimental conditions, the hypothesis that utilization immediately follows registration predicts that only the first word present during the fixation should be reported. Blanchard et al.'s (1984) results do not conform to this prediction. Sometimes subjects reported reading the first word, sometimes both words, and sometimes only the second presented word. Each of these reports occurred with nearly equal frequency (29% for the first, 36% for the second, and 35% for both). Clearly, utilization does not inevitably occur at the beginning of the fixation -- sometimes it occurs later in the fixation.

The Left-to-Right Scan Hypothesis

Blanchard et al. (1984) conducted several tests on the left-to-right scan hypothesis, and found no evidence for it. Two additional experiments were specifically designed to test this hypothesis.

In Experiment 1, the same technique as Blanchard et al. was used, except now there were two critical letters in a critical word instead of just one. Texts were used in which four words contrasting by two letters all fit into the same position in the text, for example, Ruth's great aunt is definitely the most (mushy,musty,gushy,gusty) person she has ever met. During fixations

in reading, the two critical letters were changed (with an interpolated mask) so that one of the four possible words was present during the early part of each fixation (mushy) and a second word during the latter part of each fixation (gusty). The other two words were never presented. If a left-to-right scan were taking place, it would be expected that at least sometimes the first critical letter from the first word and the second critical letter from the second word would be utilized, causing the subject to report reading a word that was never present on the screen (musty in this example). The frequency of this phenomenon would depend on the speed of the scan and on where the scan begins (and, therefore, on where the fixation was with respect to the critical letter).

The results were much like Blanchard et al. (1984) in that the subjects sometimes reported the first present word, sometimes the second, and sometimes both. However, they did not report the musty-type non-presented words which would be expected from a left-to-right scan hypothesis with a frequency greater than that expected purely by error. Also, there was no pattern of the frequency of such reports varying with where the fixations were with respect to the position of the critical letters. Thus, no support was found for a left-to-right scan.

In Experiment 2, the same basic procedure as in Experiment 1 was used, except that now every letter in the critical word was changed after the mask was removed during fixations. Passages were written in which a pair of critical words differing at every letter position fit into the same position in the text, for example: Sandy spent a long time preparing the (melon,cakes) for dessert and completely forgot about the hors d'oeuvres. In this case, if a left-to-right scan takes place, there should be some instances where some letters from first presented word and some letters from the second presented word are utilized together. The subject would perceive a non-word as a result.

The results of changing an entire word during a fixation resemble the original results of Blanchard et al.'s (1984) single letter switch, in that sometimes a single word was reported and sometimes both critical words were reported. However, the relative frequency of reporting both critical words presented during the fixation doubled with respect to the single letter change experiment. This may be due either to the greater possibility of localized movement being perceived despite the mask or to the greater disruption to the perceptual processes prior to utilization. With respect to the scan hypothesis, however, subjects did not report seeing non-words.

It is possible that instead of seeing a nonword, the perceptual system may allow some kind of error recovery, where perhaps both critical words are consciously perceived. In this case, instances where only one critical word is reported would be expected in cases where the scan traversed all the letters of the critical word competely before or after the mask replaced the text. These instances would have to be cases where the scan started very close to or far away from the critical word. This translates to the prediction that the probability of reporting one or both critical words should vary as a function of fixation location. This was not the case, however.

The results of these experiments rule out the left-to-right scan, with the possible exception of very rapid scans, faster than 10 ms per letter.

The Memory Process Explanation

The next possible pattern is continuous utilization throughout the fixation. This would seem to be ruled out by Blanchard et al.'s (1984) basic results, in which subjects reported reading only one critical word, indicating that utilization did not occur for the entire duration of the fixation. However, there is a way in which continuous utilization could be made compatible with these results. The reports of reading a single word could be explained through the action of memory processes rather than through perceptual processes. Under this alternative hypothesis, both critical words present during a fixation are always perceived (utilized), but one of the critical words is more susceptible to forgetting than the other. Cases where the subject reports reading only a single word are caused by forgetting processes operating after utilization.

Two experiments were conducted to test the memory process hypothesis. In Experiment 3, the display changes and texts were similar to those used by Blanchard et al. (1984): a single letter was changed during fixations. However, subjects in Experiment 3 were instructed to press a button while they were reading if they observed a word change. These were all non-naive subjects: they were aware of what a letter change looked like. The memory process explanation requires that there should be no correlation between the indications of seeing a letter change and whether subjects report one or both critical words. The results are not consistent with this explanation. When subjects did indicate seeing a letter change, they reported both words on the recognition test 92% of the time, and when they did not indicate a change, they reported a single word 80% of the time. Performance on the recognition test appears to accurately reflect what subjects are detecting during their on-going reading. Therefore, the results do not support the memory process hypothesis.

In Experiment 4, the single letter change technique was again used to test the memory process explanation. On half of the passages in this experiment, the text was removed from the screen completely during a saccade taking the eyes away from the critical word. When this happened, subjects were instructed to verbally report the last few words that they remembered reading, and to report any letter changes they had detected. This "turn-off-the-text" technique is an alternative method to the recognition test. It greatly reduces non-immediate effects such as memory processes by obtaining reports very soon after the critical word was fixated. On half the texts, this turn-off-the-text procedure was used, but on the remainder, subjects proceeded through the text without interruption and then performed the recognition test. This allows comparison of the two testing methods and assessment of the influence of non-immediate effects on subjects' reports.

There was essentially no difference between the recognition test and the immediate verbal reports, in that the percentage of reports of one critical word and of both critical words are nearly the same. This is in direct contradiction to the memory process explanation, which predicts that subjects should always be able to report both critical words present, because they do not have an opportunity to forget one of the words. At the very least, the probability of reporting both critical words should increase with the immediate verbal reports, but this is not the case. It seems safe to conclude that the pattern of reporting which was observed in the recognition tests of this and previous studies largely reflects processes that are occurring during

perception, or, at least, during the very early stages of processing. These results do not support the memory process explanation, and so are not consistent with the hypothesis that utilization occurs continuously throughout the fixation. The results are consistent with the position that utilization occurs during a specific, delimited point in time during the fixation.

Conclusion

These experiments have clearly narrowed down the possible patterns of utilization described above. Utilization does not typically occur immediately after registration, letters are not utilized in a left-to-right scan, and utilization does not occur continuously throughout the fixation.

This leads to the last possibility, that utilization occurs at a delimited point in time during the fixation. There are two possible versions of this hypothesis. In one, the pattern of sometimes reporting a single word is attributed entirely to the pattern masking characteristics of the interpolated mask. The mask is viewed as a backward mask for the first presented word and a forward mask for the second presented word. One or both critical words will be reported, depending on the effectiveness of the mask for each critical word during an individual fixation. This involves a kind of indirect competition between the two words present during a fixation. Visual information is available from both words when utilization takes place, although either one or both words may be perceived. For this to occur, utilization must take place at the end of the fixation or after it is terminated, in order for information from both words to be available.

The other possibility is that reports of reading a single critical word directly indicate when utilization occurs during a fixation. That is, the fact that the subject reports the word present early in the fixation or the word present later in the fixation corresponds to the actual point during the fixation at which utilization occurred. If this is so, then the time of utilization would appear to vary, occurring sometimes early and sometimes later in the fixation. This was proposed by Blanchard et al. (1984). It can be further speculated that the variable time of utilization is influenced by the current need of concurrent language processes. When on-going language comprehension is ready to accept new input, then utilization will occur. This activity will not be in direct correspondence with the saccade-fixation cycle, so the time of utilization will vary independently of the making of a new fixation. Further research examining these two possibilities is being conducted using the letter change during fixations technique.

References

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