GLOBAL ATTRIBUTES IN VISUAL WORD RECOGNITION\textsuperscript{1}.

PART 1: LENGTH PERCEPTION OF LETTER STRINGS

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Abstract—Part of a general research programme on visual word recognition is concerned with stimulus attributes that may function as cues. The topic here was perception of word length as such.

Letter strings were tachistoscopically presented. Independent variables were stimulus length and eccentricity of presentation. Seven subjects reported how many letters they had seen. Correct scores decrease with increasing length. From the fovea outward correct scores decrease, but, surprisingly, they reach a plateau for \( |\phi| > 2^\circ \).

The length is systematically underestimated: the average reported length is approx 85\% of stimulus length. Evidence is supplied that perceived length is a linear function of string length in mm.

INTRODUCTION

Normal reading can be considered as the visual intake of language symbols such as letters and words. Only during the eye pauses is there an intake of information. After the processing by the visual system the language symbols have to be further processed by the brain. This includes the integration of the visual information and the reader's implicit knowledge of the language.

We are interested in the recognition processes and in this study we explore the properties of the visual information that operate in these processes. Restricting ourselves to single words, we try to specify the word properties relevant to recognition.

Word recognition

Around the turn of the century various investigators were already interested in how readers recognized the words and sentences of a text. One of their conclusions was that reading is not a concatenation of the recognized individual letters. Sometimes the word is recognized as a "whole", sometimes by a few conspicuous letters only. Pillsbury (1897) showed that readers often noticed omitted letters in words. He concluded that the length and form of the word tended to call up a word directly. The word form was taken to include both the outward shape and certain internal details, giving rise to a succession of shifted retinal images. The size of the functional (reading) field is much narrower than acuity boundaries would allow (Mackworth, 1965).

In normal reading the eyes jump about 2\(^\circ\) or eight letters, giving rise to a succession of shifted retinal images. The size of the functional (reading) field is larger than 2\(^\circ\) (Bouma, 1970, 1973), indicating that both foveal and parafoveal information can be used. In our experiments we imitate the retinal image of one eye pause by briefly presenting stimuli in the foveal and parafoveal fields.

In order to select relevant word properties, we use reduction of stimulus information. Thus, incorrect responses (confusions) are produced by the Ss. These confusions have certain attributes in common with the stimulus word and we assume that these have contributed to the final response word. We have chosen parafoveal presentation (\( |\phi| > 1^\circ \)) to stay close to the normal reading situation. Unlike foveal vision, parafoveal vision gives rise to specific interference effects between adjacent stimuli (Woodworth and Schlosberg, 1954). Because of this the functional field is much narrower than acuity boundaries would allow (Mackworth, 1965).

In visual tasks performance decreases with increasing eccentricity symmetrically round the fixation point. For isolated words, however, recognition is better in the right visual field (RVF) than in the left (LVF) (Mishkin and Forgays, 1952; Bouma, 1973). The decrease of recognition scores with increasing stimulus length is more pronounced in the LVF than in the RVF (Bouma, 1973).

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Word length

Nootbeoom and Bouma (1968) found that in reading from a relatively long distance the averaged responded word length was about 10% shorter than the stimulus length $l$ (for $l \geq 5$ letters). In exploratory word recognition experiments Bouma and van Rens (1970) found that a considerable part of the confusions had the correct length. As to the other confusions, the general tendency was to report words shorter than the stimulus. These experiments indicate that word length has a characteristic role to play in visual word recognition. Both correct and confused word responses rest upon more factors than word length alone. On the one hand there are other stimulus properties, on the other there are bias effects due to implicit knowledge about frequency of usage, distributitional constraints from orthographic rules, etc. In an effort to rule out these potential contributions we set out by using unpronounceable letter strings with which we investigate the attribute, i.e. word length, as such. We consider the perceived length of strings of identical letters and of strings of arbitrarily chosen letters. The contribution of perceived word length to word recognition will be studied in a subsequent paper (Schiepers, in preparation).

Part of the results has been reported in a preliminary report (Schiepers, 1974).

METHODS

Stimuli

Using an IBM-72 typewriter, the letter strings without spaces were typed on white paper. The letter face was Courier-10, in which the height of the short letters is 1.95 mm and of the extensions 0.75 mm. Letter width varies from 1.4 mm (j) to 2.5 mm (m, w). All letter spacings measured between centres were 2.55 mm. The letter strings consisted of concatenated letters x, d, e or arbitrarily chosen letters. The main stimuli had a length $l$ of 3, 4, 5, 6 or 7 letters. Stimuli of lengths 1, 2, 8, 9 or 10 were added to smooth possible end effects.

We define as nominal eccentricity $\phi_{nom}$ the distance from the fixation point to the middle of the nearest letter of a string in degrees of visual angle. Usually, the eccentricity $\phi$ is measured between fixation point and the middle of the stimulus. With a normal typewriter, however, it is difficult to realize such a constant eccentricity with varying length, for only length-steps of two letters would be possible. We therefore chose the simpler solution of keeping the nominal eccentricity equal. The graphs, however, show true or averaged eccentricities.

Strings of letters $x$ were prepared at eccentricities $\phi_{nom}$: $0^\circ$, $+0.75^\circ$, $+1.75^\circ$, $+2.75^\circ$, $+3.75^\circ$ where a negative sign refers to LVF and a positive to RVF. For each eccentricity the distribution of stimuli was for $l = 3, 4, 5, 6$ or 7 ($n = 25$, each) and for $l = 1, 2, 8, 9$ or 10 ($n = 5$, each). However, three times as many stimuli were prepared at $\phi_{nom} = +1.75^\circ$, for examining possible individual and field differences. There were also stimuli centred round the fixation point, for $l = 3, 4, 5, 6$ or 7 ($n = 25$, each) and for $l = 1, 2, 8, 9$ or 10 ($n = 8$, each) which we shall call "foveal stimuli." Of these, the central lengths were selected to make symmetrical round the fixation point. In those cases they appeared just as often with a longer left tail as with a longer right tail.

Strings of letters d and e were prepared only at eccentricities $\phi_{nom} = +1.75^\circ$. The distribution of stimuli over the various lengths was the same as for letters $x$.

Strings of arbitrarily chosen letters were also prepared at $\phi_{nom} = +1.75^\circ$. Slightly different numbers of stimuli were used.

For every session, the stimuli were randomized over length as well as randomly typed left ($\phi < 0^\circ$) and right ($\phi > 0^\circ$) of the fixation point.

Presentation

The stimuli were presented by a two-channel tachioscope. In the blank field of about 30 x 30 cm, illuminated with white light, luminance $= 150 \text{ cd/m}^2$, a fixation point was placed. This field was replaced during 100 msec by a similar one in which one letter string was present.

The limited exposure time takes care that $S$ cannot fixate on the stimulus during presentation. $S$ depressed a micro-switch to initiate a presentation. The viewing distance was 57 cm, at which 1 cm (4 letters) corresponded to an angle of 1°. Vision was binocular.

In one session only stimuli of one eccentricity were presented. A session took about 30 min and there were no more than two sessions a day. After four training sessions the experiments were started. The order of presentation of eccentricities was randomized among the subjects.

Subjects

After a short visual test on acuity and binocular vision, 10 students of the Eindhoven University of Technology were selected as $S$s. Two students were no longer available in a subsequent experiment and one dropped out because he did not maintain fixation and moved his eyes to the right before depressing the micro-switch. Therefore, only the data of the other seven $S$s have been used. Their ages were between 19 and 25; they all had adequate vision (foveal acuity $= 1.25$–2) and were right-handed. They were naive as to the aim of the experiments.

Instructions

Subjects were asked to report after each presentation, the number of letters they had seen. In cases of doubt two responses were allowed, e.g. 4 or 5. In those cases each response category received a score of 0.5.

RESULTS

Strings of letters $x$

Averaged scores $v$ over seven $S$s of correctly reported lengths in relation to eccentricity are given in Fig. 1, for $l = 1, 2, 3, 4, 5$ or 7. We can divide the stimuli into two groups, $l = 1$ or 2 with almost maximal performance and $l \geq 3$ for which the scores decrease from the fixation point outwards and become roughly constant for $|\phi| \geq 2^\circ$. Correct scores decrease with increasing length $l$.

It is somewhat surprising that the scores do not continually decrease with eccentricity, as is often the case in visual tasks (acuity, contrast). Also there is no left-right (L–R) difference, contrary to word perception. As to incorrect responses, the general tendency was towards reporting shorter lengths than the stimulus, the more so as stimulus length increased. As an example Fig. 2 gives the distributions of response length $m$ at $\phi_{nom} = +1.75^\circ$, averaged over the seven $S$s. The distributions do not show significant L–R differences. To describe this underestimation in a simple way, we introduce a new parameter:

$$\text{Relative perceived length } \lambda = \frac{m}{l}$$

Mean of responded lengths

Mean of experimented lengths

Stimulus length

Values of $\lambda$ in relation to eccentricity are depicted in Fig. 3. Except in the central area, the relative perceived length is nearly a constant.
The relative perceived length $\lambda$ is not dependent on stimulus length for $l \geq 3$ and not dependent on eccentricity of presentation for $|\phi_{\text{nom}}| > 1^\circ$.

Computation of the standard deviation of $m/l$, i.e. reported length divided by stimulus length, of the various length distributions does not show significant differences for $l \geq 5$ ($F$-test; $P < 0.05$). This might be an indication that the length distributions can be conceived as samples from the same population. The average standard deviation $s(m/l) = 0.13$.

It is concluded that in the parafovea the perceived length of letter strings is a linear function of the stimulus length:

$$m = \lambda l$$

with

$$\lambda = 0.85 \pm 0.01$$

($l \geq 3$, $|\phi_{\text{nom}}| > 1^\circ$, 95% conf. interval).

In the foveal area $\lambda$ is somewhat higher for the shorter lengths ($l \leq 5$). Just next to the fovea, at $\phi_{\text{nom}} = \pm 0.75^\circ$, $\lambda$-values show a distinct dip. Because this dip was unexpected, we have carefully looked into the data at this eccentricity and found the $\lambda$-value reliable: (1) the variance of the response distribution was comparatively low; (2) for six of the seven Ss the dip was clearly present; and (3) the randomization had been such that the session-number in which stimuli of this eccentricity were presented, indeed was evenly distributed over the Ss, excluding a practice effect. Moreover, earlier pilot experiments with three quite different Ss had also shown a clear-cut dip at this eccentricity.

Figure 4 represents $\lambda$-values of each S as a function of stimulus length. Although the reliability of the data is limited (only 45 responses per data point) the principal conclusions about $\lambda$ can be maintained. Ss differ in the value of $\lambda$. The main deviation concerns $l = 3$ and Ss JK and WR. JK has decreasing $\lambda$-values with increasing stimulus length while WR shows the reverse trend. Ss do not show significant L-R differences. The one S who did not show a dip at $\phi_{\text{nom}} = \pm 0.75^\circ$ was the only female, MA.
After the experiment was run, each S was once more presented with the stimuli of the first session. Again, the results were a constant $\lambda$ for $l > 3$ and no L–R differences. Four Ss showed a consistent performance but three Ss showed lower $\lambda$-values (of about 0.75). (This concerned about 15% of the stimuli in the main experiment).

After each session Ss were asked to describe the strategies they had followed in their judgements. They all reported that in larger strings most letters were indistinguishable from each other. They saw a "gray stripe" of which they estimated the length. Up to 4 or 5 letters they thought that they were able to distinguish all letters separately, both in foveal and in parafoveal vision.

**Other letter strings**

Strings consisting of letters d and e showed results comparable to those with letters x. The general tendency again is systematic underestimation, without left right field differences.

For both letters at $\phi_{nom} = \pm 1.75^\circ$ we obtained:

$$\lambda_d = \lambda_e = 0.78 \pm 0.01 (l \geq 3, 95\% \text{ conf. interval}).$$

Surprisingly there is no difference between letters d and e within quite narrow limits. The experiments with d and e were carried out with four Ss on the same day and with the other three within a few days. The $\lambda$-values are somewhat lower than for letters x, which might be due to criterion differences developing over time.

The responses for strings of arbitrarily chosen letters have length distributions that resemble those of identical letters. Results for $3 \leq l \leq 7$ are given in Fig. 5; LVF and RVF scores have been averaged, there being no significant differences. The other lengths $l < 3$ and $l > 7$ gave similar results. At $\phi_{nom} = \pm 1.75^\circ$ we obtained for the relative perceived length: $\lambda = 0.87 \pm 0.02 (l \geq 3, 95\% \text{ conf. interval}).$ It
would seem, therefore, that the extensions of the letters do not have a noticeable influence on length perception.

**Different letter face and spacing**

In order to investigate the underlying (judging) mechanism of length perception, we made a direct comparison between two letter faces: Courier-10 and Bold-Face. In these letter faces the letters have the same height but the spacing is different. Courier-10 has a constant letter spacing of 2.55 mm, while Bold-Face has a so-called "graphical spacing". This means that its spacing width is variable, being 2, 3, 4 or 5 units per letter, where each unit is 0.706 mm. Because of the great variety of individual letter widths the letters are not properly linked up in a Courier string. In a Bold-Face string, however, the graphical spacing provides an equable concatenation of letters. Figure 6 shows a few examples.

In an exploratory experiment strings of arbitrarily chosen letters were presented in Courier-10 as well as in Bold-Face at an eccentricity $\phi_{nom} = \pm 2.75^\circ$. Presentation and instructions remained the same as earlier. Four members of our Institute served as Ss.

The plot of the averaged responded length $m$ is depicted in Fig. 7 as a function of string length in mm. We corrected for the fact that the width of a letter is slightly smaller than a spacing unit. This correction amounted to 0.5 mm for Courier-10 and 0.1 mm for Bold-Face.

It appears in particular from the Bold-Face data that the perceived length of letter strings is linearly related to physical length (in mm). Moreover, data of the two faces coincide for lengths smaller than 15 mm. If we plot the Bold-Face data as a function of string length in numbers of letters, three different lengths in mm are brought in a vertical line, thus increasing the variance. Therefore it seems that Ss used a physical string length as a base for their length perception.

**DISCUSSION**

So far we have examined the length perception of diverse letter strings. From a visual point of view it is remarkable that the correct scores do not continue to decrease with increasing eccentricity. As is normal in visual tasks, correct scores are symmetrical round the fixation point. From a psychological point of view both results are remarkable. Constant correct scores for larger eccentricities as well as the absence of a left-right visual field difference, contrary to what is found in word perception.

We shall now discuss the results on length perception and consider their implications for ideas about visual interference and word recognition.

**Length perception**

From experiments on magnitude estimation of line length, it can be concluded that a psychophysical function obtains:

$$\psi = k \cdot L^n$$

in which $\psi$ = judged length, and $L$ = stimulus length.

![Fig. 7. Mean of reported lengths $m$ in number of letters, in relation to stimulus length in mm for two letter faces. Averaged scores of four Ss and eccentricities $\phi_{nom} = \pm 2.75^\circ$.](image)
The exponent is usually about 1, whereas the value of \( k \) is not discussed (Stevens and Galanter, 1957; Stevens and Guirao, 1963; Teghtsoonian, 1965; Baird, 1970). Although we used a different experimental method and paradigm (eccentric presentation, short exposure time and reporting number of letters) we also obtained a simple linear relation between averaged reported length \( m \) and stimulus length \( l \):

\[
m = \lambda l
\]

where \( \lambda \) is a constant of about 0.85 in the parafovea for \( l \geq 3 \). The difference in performance between \( l = 1 \) or 2 and the other stimuli may be caused by different perceptual strategies of the Ss. One or two letters can be recognized as separate units, whereas larger numbers of letters are rather perceived as "a gray stripe" whose length is estimated. We would argue that these different perceptual strategies are responsible for the higher \( \lambda \)-values of \( l = 1, 2 \). In fovea vision there are also more details visible than in parafoveal vision. Hence more letters can be recognized separately. Because of this, the higher foveal \( \lambda \)-values for stimulus lengths \( l = 3, 4 \) or 5 also seem due to increased detailed perception.

The dip in the values of the relative perceived length \( \lambda \) at \( |\phi| \approx 1 \) just next to the fovea (Fig. 3) remains unclear. A suggestion would be that it is related to the transition of detailed foveal vision toward parafoveal vision, where length is judged on the base of stripe estimation rather than letter counting.

Comparison of length perception of different letter faces supplies additional arguments that length can be perceived as such. Averaged responded length is linearly related to string length in mm. This might be interpreted as if S used an internal length standard, perhaps extracted from the height/width impression of a stimulus.

**Visual interference**

In eccentric vision an adverse interaction operates between adjacent letters, called (visual) interference. Evidence of this is that fewer details of embedded stimuli can be distinguished, as compared to isolated stimuli (Woodworth and Schlosberg, 1954). Although acuity is sufficient to distinguish the individual letters, certainly for small eccentricities, this interference effect is assumed to disturb the correct perception of letters or letter parts. Could this possibly be an explanation for the underestimation tendency? For two reasons we do not think this an attractive hypothesis.

Firstly, in word recognition experiments there exists a left–right difference, to the advantage of the right field, which difference increases with word length. A left–right difference in which word length exerts a similar influence has also been found for the most inward letters (nearest to the fovea) of non-word letter strings (Bouma, 1973). Our experiments did not show any L–R differences. Secondly as Fig. 7 shows, for parafoveal strings physical length seems to be the relevant parameter rather than the number of letters.

How can these results be interpreted in relation to word recognition where also an underestimation of word length has been reported? (Meister and Van Rens, 1970; Baird, 1970). Exploratory experiments on parafoveal word recognition by Bouma and Van Rens (1970) furnish length distributions of word confusions which (a) show an underestimation tendency for \( l \geq 4 \) and (b) do not depend both on eccentricity of presentation and on stimulus length.

This will be the subject of the subsequent paper.

**CONCLUSIONS**

(a) There exists a general tendency to underestimate the length \( l \) (number of letters) of letter strings. In parafoveal vision, the averaged perceived length \( m \) can adequately be described by the linear function:

\[
m = \lambda l, \quad \lambda \approx 0.85
\]

(b) The relative perceived length \( \lambda \) is (i) independent of stimulus length for \( l \geq 3 \), and (ii) independent of eccentricity of presentation for \( |\phi| > 2 \).

At \( |\phi| \approx 1 \) there is a distinct dip in \( \lambda \)-values for \( l \geq 3 \).

(c) Performance is better, however, for: (i) stimulus lengths \( l \leq 2 \) in parafoveal vision, and (ii) stimulus lengths \( l \leq 5 \) in foveal vision.

This seems mainly due to more details being distinguished.

(d) At constant letter height, length perception is linearly related to string length in mm.

(e) The length distributions of the responses do not show left–right differences, contrary to word recognition, which is better in the right visual field.

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**REFERENCES**


