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Schiepers, C.W.J.

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GLOBAL ATTRIBUTES IN VISUAL WORD RECOGNITION: CONTOUR PERCEPTION OF THREE-LETTER STRINGS*

C. W. J. SCHIEPERS

Instituut voor Perceptie Onderzoek, Den Dolech 2, Eindhoven, The Netherlands

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The experiments reported here were designed to investigate the extent to which subjects perceive the contour of three-letter strings composed of permutations of the letters (k, x) or (d, o, p). The strings were presented for 100 ms at various retinal eccentricities. 13 subjects were required to report the entire letter string. Both average contour scores and individual letter scores decrease with eccentricity. Position in the string appears to be of paramount importance, letters farthest from the fovea showing the best performance. The extensions of the letters seem to be salient cues for perceptual analysis. Shortening of the extensions causes reduced accuracy in contour recognition.

1. Introduction

As explained elsewhere (Schiepers 1976a,b) our work concentrates on the specification of attributes in the process of recognition of printed words. An attribute is conceived as a property of the stimulus configuration which may serve as a cue for recognition. For our purpose a distinction is drawn between attributes which are predominantly letter-bound (analytic) and those which are predominantly word-bound (global). A global attribute is related to what is called the general word shape, e.g. word contour, word length or spelling pattern. It is stressed that the

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whole word is essential, either directly, as in word length, or indirectly, as in the position of certain features. We have dealt with word length in previous papers (Schiepers 1976a,b). Here we shall confine the discussion to the contours of three-letter words.

The contour can be thought of as the immediate sensation conveyed by the outline or envelope of the word, and is assumed to be a faithful representation of the concatenation of the short, ascending and descending letter parts.

1.1. Recognition

Contemporary neurophysiological research assumes passive feature analysers in the human visual system. These analysers are triggered by suitable features in the retinal images (Hubel 1963). Evidence of these detectors of contrast, edge, line and length has been combined and they have been built up into complicated higher-order mechanisms, tuned to complex properties and units.

In psychological research on word recognition, the properties of letters and words have taken the place of the 'demons' intervening between the stimulus and the recognized word. More complex attributes such as edginess, curvature, obliqueness, straightness and intersection have been proposed (Gibson 1969). With regard to letter recognition, Gibson (1969) has specified certain features for capital letters, Bouma (1971) aimed at the same for lower-case letters. With regard to words, various models have been proposed in the literature. They all share the notion of attributes extracted from the stimulus configuration. These attributes operate, in conjunction or not with internal factors, as intermediaries between the stimulus and the final overt response (Neisser 1967; Morton 1969; Norman and Rumelhart 1970; Gibson 1971; Smith 1971, 1973; Rumelhart and Siple 1974).

1.2. Word contour

Normal print consists of capitals and lower-case letters. Its legibility is largely determined by the type face and the layout (Tinker 1963). It is well known that words consisting entirely of Latin capitals are harder to recognize than those comprising only lower-case letters, because of the uniform contour of the former. Experiments of Coltheart and Freeman (1974) found about 5% better identification for lower-case words eight
letters in length. The extra ease over upper-case words suggests a special role for the extensions. They are the conspicuous parts of the contour and therefore seem to form relevant 'grasping points' for the feature analysers.

In isolated letters extensions are integrated in the letter shape, their influence on letter recognition can be thought of as completely letter determined. In words, however, extensions protrude above and below the trunk and might operate rather independently from the body of the letter.

The experiments were directed to this question of independence, i.e. whether extensions can wander through the string, or whether they are tied to a certain location. In such a case the position of the letter in the word would be important.

Another characteristic is the recognizability of the extension, which is related to its size or height. This factor was studied in an additional experiment where the height of the extension of a letter 'k' was systematically varied and could even be absent.

Because words exhibit a high level of redundancy, we are obliged to reduce stimulus information in our experiments in order to trace the relevant attributes. Thus, error responses may occur, whose attributes, in common with the presented stimulus, probably functioned as cues for recognition. Correct recognition is probably partly determined by the same attributes. We therefore developed a paradigm in which first the perceptibility of the word contour is examined and second the part it plays in the actual recognition process is pursued. In order to minimize non-visual, linguistic influences, we used letter strings, mostly unpronounceable, as stimuli.

We report experiments on the perception proper of three-letter contours in lower-case. The strings were presented at various eccentricities. The perceptibility of the contours presented at the several eccentricities will be treated in the results section. Main tendencies of the incorrect responses will be analyzed as well as the role of the extensions.

2. Experiments

2.1. Method

2.1.1. Stimuli

The stimuli were three-letter strings composed of all the possible permutations of
the letters k and x, denoted by: (k, x), i.e. the contours: xxx, kxx, xkx, xxk, kkk, kxx, xkk, and kkk. They were typed on white paper with an IBM-72 typewriter. The type face was Courier with a height of 1.95 mm for short letters and about 0.75 mm for upward and downward extensions; the letter spacing was 2.55 mm. A pilot experiment was run to supply the general trend of the scores and to determine the suitable eccentricities for stimulus presentation.

The strings of (k, x) (i.e. 8 different combinations or contours) were prepared at eccentricities $\phi$: 0°, ±1°, ±2°, ±3° and ±4°. The eccentricity $\phi$ is defined as the distance from fixation to the centre of the stimulus (i.e. the middle letter) in degrees of visual angle, $\phi > 0^\circ$ corresponding to the right visual field and $\phi < 0^\circ$ to the left. Every contour was presented 10 times at each eccentricity.

Strings of (d, o, p) (i.e. 27 different contours) were only prepared at $\phi = \pm 3^\circ$. Each letter combination occurred six times to the left and six times to the right of fixation.

The stimulus letters were chosen because they possessed maximum resemblance with regard to the trunk of the letter. In other words, they should have strong orientation specific interference, i.e. they shared parallel line segments, congruent circular details, etc. (Andriessen and Bouma 1976). Because the letters themselves are harder to identify under these circumstances, more prominence is given to the contour properties of the string, i.e. contrasts between the presence and/or absence of extensions. In other words, our aim is to make a purer estimation of the role of contours in perception.

2.1.2. Presentation

The stimuli were presented in a two-channel tachistoscope. The luminance was about 150 cd/m²; the duration of exposure was 100 ms; the viewing distance was 57 cm at which 1 cm (four letters) corresponds to 1°; vision was binocular. A black plus sign was used as the fixation mark. In the case of foveal stimuli with $\phi = 0^\circ$ only, it was replaced by two red dashes, one above and one below the position where the central letter would appear. In one session stimuli of equal eccentricity (left and right of fixation) were presented in random order to aid the maintenance of fixation. A randomized block design was used for Ss and eccentricities. S initiated an exposure by pressing a button. An infrared video system was used to record S's right eye for the purpose of checking fixation. The experiments proper were preceded by one training session.

2.1.3. Subjects

The Ss were 13 students (including two females), of whom six had participated in earlier experiments. Their ages were 19–26 years; they all had adequate (corrected) vision (foveal acuity 1.25–2) and were right-handed. Only 11 Ss took part in the experiment with foveal stimuli ($\phi = 0^\circ$) and in the additional experiment.

2.1.4. Instructions

Ss were told that the stimuli were three-letter permutations and what the letters comprising the stimuli were. They were asked to report the whole string in left-to-right order after each presentation. They were unaware of the aim of the experiments.
2.1.5. Terminology

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \phi )</td>
<td>eccentricity of presentation</td>
</tr>
<tr>
<td>( u )</td>
<td>number of extensions, the index denoting stimulus ((u_s)) or response ((u_r))</td>
</tr>
<tr>
<td>( p )</td>
<td>proportion, the index denoting the response category</td>
</tr>
<tr>
<td>LVF</td>
<td>left visual field ((\phi &lt; 0^\circ))</td>
</tr>
<tr>
<td>RVF</td>
<td>right visual field ((\phi &gt; 0^\circ))</td>
</tr>
<tr>
<td>inward</td>
<td>location closest to the fovea</td>
</tr>
<tr>
<td>outward</td>
<td>location farthest from the fovea</td>
</tr>
</tbody>
</table>

2.2. Results

There were no systematic differences between Ss for strings \((k, x)\). Therefore, the data have been averaged over all Ss. These averaged data were subjected to several analyses. First, the results with strings \((k, x)\) will be discussed. Second, we will check these results on strings \((d, o, p)\). The latter contours are investigated in greater detail with regard to their extensions.

2.2.1. Strings of permutations \((k, x)\)

Correct scores averaged over all 8 contours and all 13 Ss are presented in fig. 1 in relation to eccentricity. The scores decrease with increasing eccentricity but not continuously, flattening out in the parafovea. Even at \(\phi = \pm 4^\circ\), scores are very much above chance level, indicating that Ss in fact use the visual information. Fig. 1 does not show any significant left–right visual field differences except for \(\phi = \pm 3^\circ\) \((p < 0.05)\), where there is an RVF advantage.

![Fig. 1. Correct scores \(p\) averaged over all contours and Ss in relation to eccentricity \(\phi\). White bars: responses to \((k, x)\) \(N = 1040\) for each data point; black bars: responses to \((d, o, p)\) \(N = 2106\) for each data point. Bar length indicates the actual length of the three-letter stimulus.](image-url)
Certain contours, however, do show L–R field differences. Two methods are used to compare contours in different visual fields: (1) numbering the letters in left-to-right (l–r) order and (2) numbering them in outward-to-inward (o–i) order with respect to the fovea.

Significant differences \( (p < 0.05) \) are found:

(a) \( (l–r) \): Contour kxx has an RVF advantage for all 4 comparable eccentricities. For 3 out of 4 situations, contour xxk shows an LVF advantage, while contours xxx and xkx show RVF advantages;

(b) \( (o–i) \): Mackworth (1965) found a foveally oriented scanning in letter strings. The \( (o–i) \) correspondence, therefore, has to be tested independently. For 3 out of 4 comparable eccentricities contours kxx–xxk (LVF–RVF respectively) show LVF advantages. Of course, the findings for the symmetrical contours xxx and xkx for \( (l–r) \) also apply here.

It seems, therefore, that the \( (o–i) \) numbering is somewhat more appropriate.

### 2.2.1.1. Number of extensions

In a further attempt to derive information from the data, an analysis was made as to perceived extensions, i.e. the number of letters \( k \) responded, irrespective of their position. An analysis of this kind may reveal whether an extension is perceived at all, independent of its position. Pooling the data into four stimulus and four response classes yields confusion matrices with four rows for number of presented extensions and four columns for responded extensions. Thus for \( u_s = 1 \) or 2 (contours kxx, xkx, xxk or kkx, kxk, xkk) there were three times as many stimuli as for \( u_s = 0 \) or 3 (contours xxx or kkk). The fractions of correct responses, i.e. the scores in the diagonal cells, are depicted in fig. 2. For the various

![Fig. 2. Fractions f of correctly responded number of extensions (irrespective of their location) in responses to \((k, x)\) as a function of the eccentricity \(\phi\). Figures denote the number of extensions. Number of stimuli per data point \(N = 130\) for \(u_s = 0\) or 3 and 390 for \(u_s = 1\) or 2.](image-url)
Fig. 3. Proportions $p$ of correctly reported letters in a certain position (inward, middle or outward) in responses to three-letter permutations of $x$ and $k$. $p$ is given in relation to eccentricity $\phi$: (a) for letters $x$; (b) for letter $k$. Lines indicate the letters belonging to a certain string. $N = 520$ for each data point. Notice the striking picture for letter $k$ in the LVF.

situations, these fractions decrease with eccentricity and with the number of stimulus extensions ($u_s$). Strings with $u_s = 3$ (contour kkk) have low scores; strings without extensions ($u_s = 0$, contour xxx) show L–R field differences.

Most error responses to strings with either one or no extension contain just one extension more. The reverse is for stimulus strings with two or three extensions, in which case most errors contain one extension less than the stimulus. (See also table 2).

It seems, therefore, that an extension is detected fairly accurately, in spite of possible position errors.

2.2.1.2. Letter position. The other way of examining the data is to calculate the proportion of correctly reported letters $k$ and $x$ in a certain position. Figs. 3a and b represent these proportions in relation to eccentricity, averaged over all contours and Ss.

Here, too, comparison on the basis of left-to-right and outward-to-inward numbering applies. For letters $x$, the middle and outward letters have symmetrical (virtual) curves. The inward letters, however, show obvious asymmetry ($p < 0.05$ except for $\phi = \pm 1^\circ$). A similar asymmetry has already been found for letter recognition (Bouma 1973). For letters $k$, letters in all three positions show asymmetries at first sight. Indeed, nearly all cases show significant field differences with both types of comparison.
The results are especially striking in the LVF. Experimental evidence suggests the middle part of words and strings is the least readily perceptible one (Williams et al. 1970; Fudin and Kenny 1972; Eriksen and Eriksen 1974; Wolford and Hollingworth 1974). Contrary to these findings, final letters k in the LVF are even less perceptible than central ones.

2.2.2. Strings of permutations d, o, p

The correct scores averaged over all 27 contours and 13 Ss are given, too, in fig. 1 (black bars) for the purpose of comparison. The scores are about 6% lower than for (k, x), which might be ascribed to the larger number of alternatives.

The full 27 x 27 confusion matrix can be subdivided according to the number and the direction of the extensions. The result is as shown in table 1.

Table 1
Subdivision of the full confusion matrix for (d,o,p). A cross denotes an empty cell.

<table>
<thead>
<tr>
<th>RESPONSES</th>
<th>( u_r = 0 )</th>
<th>( u_r = 1,2 )</th>
<th>( u_r = 2,3 )</th>
<th>( u_r = 3 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( u_s = 0 )</td>
<td>ooo</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( u_s = 1,2 )</td>
<td>doo ddo pdo ppo ooo odd odd ooo opp</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( u_s = 2,3 )</td>
<td></td>
<td>rest</td>
<td></td>
<td></td>
</tr>
<tr>
<td>( u_s = 3 )</td>
<td>ddd</td>
<td></td>
<td></td>
<td>pp</td>
</tr>
</tbody>
</table>
were found to resemble those of \((k, x)\) at \(\phi = \pm 3^\circ\) fairly closely. No significant differences for \((d, o)\) and \((p, o)\) were found, either for stimulus conditions or for visual field.

2.2.2.1. Number of extensions. The submatrices \((d, o)\) and \((p, o)\) (explained in the preceding paragraph) were now compared with \((k, x)\) as regards the number of extensions. The data were again pooled, but this time the position of the extensions was not taken into account. The fractions thus obtained for correct and incorrect response classes are given in Table 2.

<table>
<thead>
<tr>
<th>(u_f)</th>
<th>LVF ((-3^\circ))</th>
<th>RVF ((+3^\circ))</th>
</tr>
</thead>
<tbody>
<tr>
<td>(u_s)</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>((d, o))</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>0.76</td>
<td>0.22</td>
</tr>
<tr>
<td>1</td>
<td>–</td>
<td>0.69</td>
</tr>
<tr>
<td>2</td>
<td>–</td>
<td>0.15</td>
</tr>
<tr>
<td>3</td>
<td>–</td>
<td>0.04</td>
</tr>
<tr>
<td>((o, p))</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>0.72</td>
<td>0.20</td>
</tr>
<tr>
<td>1</td>
<td>0.01</td>
<td>0.66</td>
</tr>
<tr>
<td>2</td>
<td>–</td>
<td>0.13</td>
</tr>
<tr>
<td>3</td>
<td>–</td>
<td>0.03</td>
</tr>
<tr>
<td>((k, x))</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>0.81</td>
<td>0.18</td>
</tr>
<tr>
<td>1</td>
<td>0.01</td>
<td>0.68</td>
</tr>
<tr>
<td>2</td>
<td>0.01</td>
<td>0.19</td>
</tr>
<tr>
<td>3</td>
<td>–</td>
<td>0.01</td>
</tr>
</tbody>
</table>

The fractions correct are in fair agreement with those for \((k, x)\), except that contours \(ddd\) and \(ppp\) \((u_s = 3)\) have higher scores than \(kkk\). A similar agreement applies to the fractions incorrect. Contours without extensions again give good results, particularly in the RVF: high correct scores and hardly occurring as error response.

These results indicate that the perceptual processes operating in response to strings \((k, x)\) and \((d, o, p)\) are the same and that upward and downward extensions are not normally confounded. In other words, the results suggest that the direction of an extension is accurately perceived.
2.2.2.2. Letter position. The proportions of correctly reported letters in a certain position, averaged over all 27 contours and 13 Ss, are shown in fig. 4. The results for k and x have been included for the purpose of comparison.

Fig. 4. Proportions p of letters correctly reported in their position at string eccentricities 1.3°: (a) for letters o; (b) for letters d and p. Each data point: N = 546. Results of letters k and x were included for the purpose of comparison. The lines denote letters of a connected string.

Accuracy on letters o is somewhat lower than on x. The letters d, k and p show results which generally coincide for the outward and middle positions, but whereas o and p show the expected asymmetry for the inward position, inward d does not. We will return to this finding later on. The remarkable picture of inward k in the LVF (fig. 3b) is not found for letters d and p.

2.2.3. Response bias
So far we have investigated visual factors concealed in the data. As stated earlier, the differences between Ss were not great. It is nevertheless not yet clear whether they share the same preference in naming certain contours or not. Bias, presumably, has the same effect in both visual half fields, while visual factors do not. Dissimilar scores in both half-fields therefore argue against bias influences. On the other hand, if the LVF and RVF scores are roughly the same, the exact share accounted for by response bias remains open to question.

Table 3 shows correct and incorrect scores for contours (k, x) pooled in each half-field. Correct scores indicate that no contour benefited specially. The incorrect scores in particular indicate that visual factors predominate.
Table 3
Fractions of correctly and incorrectly responded contours. The data have been pooled for all eccentricities in a certain visual field. N denotes the total number of responses.

<table>
<thead>
<tr>
<th>Responses</th>
<th>Contours</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>xxx</td>
<td>kxx</td>
</tr>
<tr>
<td>Correct</td>
<td>LVF</td>
<td>0.15</td>
</tr>
<tr>
<td></td>
<td>RVF</td>
<td>0.17</td>
</tr>
<tr>
<td>Incorrect</td>
<td>LVF</td>
<td>0.02</td>
</tr>
<tr>
<td></td>
<td>RVF</td>
<td>0.05</td>
</tr>
</tbody>
</table>

For comparison of the various confusion matrices, we correlated results at corresponding eccentricities. Table 4 shows coefficients of correlation between the diagonals and between sums of incorrect responses in columns. High correlation for outward-to-inward numbering also argues against bias effects. Especially in the case of incorrect responses to \((k, x)\), preference is given to visual factors.

In the case of responses to \((d, o, p)\), the results do not show convincingly which factor dominates. Close inspection does not reveal salient frequently occurring incorrect contours. Indeed, individual Ss show irregularities and favour certain contours, but on average the effect is negligible. A negative response bias applies to contour \(dpd\), which occurred as error response 1.4% in the LVF and 2.2% in the RVF, while the chance level is 3.7%.

It therefore seems safe to conclude that the present design of the experiments was efficacious for safeguarding the data against overwhelming biases. Obviously, visual factors largely determined the results.

Table 4
Correlation coefficients of the diagonals (correct) and sums of all incorrect responses in columns (incorrect) of confusion matrices at corresponding eccentricities in the two visual half-fields, \(o\rightarrow i\) numbering outward-to-inward, and \(l\rightarrow r\) numbering in normal fashion, left-to-right.

<table>
<thead>
<tr>
<th>(\phi)</th>
<th>((k, x))</th>
<th>((d, o, p))</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(\pm 1^\circ)</td>
<td>(\pm 2^\circ)</td>
</tr>
<tr>
<td>Correct</td>
<td>(l\rightarrow r)</td>
<td>0.11</td>
</tr>
<tr>
<td></td>
<td>(o\rightarrow i)</td>
<td>0.06</td>
</tr>
<tr>
<td>Incorrect</td>
<td>(l\rightarrow r)</td>
<td>0.48</td>
</tr>
<tr>
<td></td>
<td>(o\rightarrow i)</td>
<td>0.71</td>
</tr>
</tbody>
</table>
2.3. An experiment to illustrate the contribution of an extension

In the preceding sections it has emerged that the extensions play a special role in the perceptual processes. The upward or downward direction is perceived accurately as such and the number of extensions perceived is generally correct. One of the properties of an extension is its height relative to the trunk or body of the string. We wished to elaborate more clearly the relationship between the height of an extension and the contour perceptibility. Manipulating the height of an extension changes the contour of the string, which may hamper recognition. If the trunk of the string is held intact and only the extensions are affected, recognition performance directly reflects the differential contributions of the contour.

We therefore conducted an experiment using the same set-up as for strings (k, x), with the extra condition that the letter k could have any of three shapes: (1) normal, (2) without the upper 0.25 × 0.04 mm serif and (3) with the entire extension missing. Three stimulus blocks of (k, x), each with a different k, were prepared at eccentricities $\phi = \pm 3^\circ$. In each block, every string was presented six times both in the LVF and the RVF in random order. The blocks were presented in (almost) counterbalanced order on one and the same day to each of 11 Ss. The apparatus and instructions remained unchanged. Ss were informed of the fact that the legibility of the print in the individual blocks might have been changed. The reason for this was not explained to them.

Correct scores averaged over all contours and all Ss for the three conditions are shown in fig. 5. Mutilation of the extension has a clear-cut effect on performance.

![Fig. 5](image_url)

Fig. 5. Correct scores p averaged over all eight contours of letters k and x, and 11 Ss at eccentricities of $\pm 3^\circ$, white bars: normal k; hatched bars: k minus the upper serif; black bars: k minus the entire extension. N = 528 for each data point.
The proportions of correctly reported letters in a certain position at eccentricities of ±3°.
(a) Letters x surrounded by letter k in three conditions: x normal, • minus the upper serif and o minus the entire extension. (b) Letters k for three conditions: k normal, • minus the upper serif and K minus the entire extension. N = 264 for each data point.

For conditions (1) normal and (2) without upper serif, the confusion matrices showed the same main tendencies. As previously, the proportions of correctly reported letters in a certain position were calculated. The results are reproduced in figs. 6a and b. Again, a gradual change-over can be observed for the three conditions.

The letters x also 'suffer' from the mutilation of k. This indicates a reduction in the perceptual contrast between x and k. Omission of the serif induces lower accuracy for letters k (fig. 6b). The letters close to the fovea suffer more markedly from this mutilation.

Removal of the entire extension drastically reduces recognition scores; the proportions correct for letters k drop to chance level. With this condition, the proportions correct for letters x are affected to a greater extent than before but they still do not reach chance level, indicating that enough visual information remains to permit discriminating between x and k without extension.

There is, however, a left-right difference which has not occurred elsewhere in our data. Because most of the k's without extension are below chance level, this might indicate a negative response bias. However, visual factors can be held responsible here too. These recognition curves of the k's without extension, appear to be mirror images of those for k's with extension (fig. 6b). Therefore it seems that when letters k without extension are in a location which allows better recognition, S more readily responds to it as an x instead of a k, because of the more apparent absence
of the extension. Since this strategy leads to less k responses, S might compensate for this, owing to the reduced perceptual contrast, in error responses to x. This might explain the lower recognizability of the x's in fig. 6a.

A short interview revealed that Ss had not noticed any differences between strings with normal k and those with k missing the upper serif. With regard to strings without extensions, all Ss considered it extremely difficult to discriminate. In fact, two Ss refused to give responses other than xxx. One S remarked that he saw the Greek letter κ in the string without extensions. To him we dedicate the name we have given to this dramatic drop-off in performance: the kappa effect.

On the basis of these results it is concluded that manipulation of the extension (particularly the height) directly influences performance, even if the S himself is not aware of any difference.

3. Discussion

In the present experiments:
- a substantial influence of the extensions on recognition has been established (figs. 5 and 6);
- the direction of an extension is perceived accurately (tables 1 and 2);
- the number of extensions perceived is generally correct (fig. 2).

By and large, findings in the literature are corroborated:
- an overall decrease of contour perception with increasing eccentricity (Lefton and Haber 1974);
- the best performance on outward letters and a worsening towards the fovea (foveally oriented interference, Mackworth 1965); the worst performance on middle letters (Wolford and Hollingworth 1974);
- left-right visual field asymmetries for inward letters, with an advantage for the RVF (Bouma 1973).

3.1. Visual interference

The notion of outward-to-inward numbering for comparison between visual half-fields (the correspondence rule) is based on the presumed existence of the foveally oriented interference. Figs. 3 and 4, showing higher proportions correct for outward letters than for others, indeed provide evidence for this notion. However, although the correspondence rule is satisfied by individual letters, it has to be checked with whole strings. Unfortunately no generally accepted way of expressing the similarity of
entire confusion matrices exists and we therefore aimed at testing the correspondence rule for contours by correlating (1) correct scores (diagonals) and (2) sums of all incorrect scores per contour, between data at corresponding eccentricities. Both types of numbering (1) left-to-right and (2) outward-to-inward were compared throughout. The results have already been given in table 4. For correct scores for \((k, x)\) the correlation coefficients do not provide arguments for any correspondence. Because many attributes can trigger a correct response, this might indicate that different attributes are the determiners for recognition at different eccentricities. On the other hand, incorrect responses have parts differing from and parts matching the stimulus. It is hypothesized that precisely these matching parts constitute the relevant attributes leading to the final overt response. The data in table 4 for incorrect responses to \((k, x)\) favour a description in terms of an outward-to-inward numbering. For \((d, o, p)\) responses, however, the agreement is not found.

3.2. Extensions

Clear-cut influence by the number of extensions on overall performance is exhibited in fig. 2 and table 2. Contours without extensions were found to be excellent ones. Because stimuli \(u_r = 1\) or \(2\) were more often exposed (particularly for \((k, x)\)), the presentation frequency may have benefited these as responses.

Correct scores for contours ddd and ppp are higher than for contour kkk, probably because of the presence of more alternatives among \((d, o, p)\) which would reduce the influence of frequency of presentation. The almost total absence of \(u_r = 3\) error responses was therefore interpreted as an avoidance of the extreme response class and not as a case of selective interference between extensions.

The experiment with mutilated letters \(k\) argues strongly in favour of perceived extensions determining the contour and not other letter properties. The trunk of the string was kept intact, while the variation was limited to the form of the extension. This manipulation affected contour recognition. Removal of the extension produces a dramatic decline in performance, demonstrating that its function is not at all superfluous.

3.3. Letters

The differences between letters \(d, k\) and \(p\) (figs. 3 and 4), can be
ascribed to a contrast effect, which places an extension at the very verge of a string in an outstanding position. A particular property of certain ascending and descending letters in the Latin alphabet is their asymmetry, in the form of an extension either to the left or to the right (perhaps the 'slender' letters t, i, l, f and j form a separate group). Because of the foveally oriented interference, a letter with a left-side extension may be favoured in the LVF above the RVF. In the RVF, a k can easily be confounded with an x and a p with an o, while the extension itself either is perceived as belonging to another location or disappears. The opposite can be claimed for the letter d. Such an explanation would account for the generally lower scores of outward letters k and p in contours in the RVF. It is also a neat explanation for the rank ordering of inward letters in fig. 4b. As can be noticed in figs. 3b and 4b, the place of an extension is of supreme importance in determining the relationship between letter location and eccentricity.

Perhaps the fact that d is an exceptional case among the ascenders (extension at the right) acts as an extra cue. The choice of letters d and p might then help to explain the failure to satisfy the correspondence rule for (d, o, p). It happens that d and p have their extensions on different sides and may derive some benefit from different visual fields.

3.4. Linguistic factors

Kolers (1970) remarks that the beginning, middle and end of a word do not contribute equally to recognition. The beginning of a word conveys more information largely, it is thought, because of constraints built in the language. He advances the argument that linguistic factors cause this benefit of the beginning over the end. The argument was derived from position errors in naming the letters of pseudo-words. About the same number of errors were made on every letter in different word lengths. "... Thus, the visual system does not have some special difficulty in identifying the letters in various parts of word. The advantage to recognition of the beginning is owing to linguistic, not visual, factors." (p. 99–100).

In the RVF we did not find this superiority of the beginning of a string (figs. 3 and 4). If linguistic factors favour the beginning, i.e. they introduce left–right visual field differences, contour perception proper should be the same at corresponding eccentricities. We tried to minimize linguistic influences by using mostly unpronounceable letter strings and
by presenting all possible three-letter permutations. The experiments reported here nevertheless suggest that visual factors are responsible for different contour perceptibility, depending on retinal eccentricity, visual half-field and individual contour. In other words, we have succeeded in establishing that visual attributes contribute substantially to causing field differences.

Although we tried to avoid pronounceable strings, two existing Dutch words occurred with (d, o, p), namely *dop* and *pop*, and most other strings with a central o were pronounceable. After some training, subjects responded with letter sequences, but occasionally some subjects responded with the Dutch word. Results for these contours were not markedly different from those for the others. The conclusion, therefore, seems warranted that there was no interaction with higher cognitive (word) levels.

Dick (1974) states that the read out from the icon into short term memory involves a conversion process which proceeds in a left-to-right scan. This well-established empirical bias for letters is not a neutral one, but a functional one, most likely the result of experience. We adhere to foveally oriented interference as the explanation for the fact that outward letters score highest. Nevertheless, our results also show high accuracy at the beginning of the string. This conforms to intuition about the influence of left-to-right order of report. In the LVF interference and scan have the same direction, whereas in the RVF they have opposite directions, implying a conflict. This accords with Bouma’s suggestion (1973) that the interference has different ranges in the two half-fields. Thus, from a visual point of view there would not be any differences of contour perception in the half-fields; the best performance would be on outward letters. The spatial-to-temporal conversion, necessary for overt responses, would proceed in a left-to-right scan which favours the beginning of a string over its end. The different contributions of interference and scanning effects would be dependent on the task. Recognition of short strings (which can always be quickly read out of iconic memory and which cannot overload short term memory) would not normally be disturbed by scanning effects. In the case of (d, o, p), more feature information is needed in order to distinguish between the additional alternatives, and the results are therefore more subject to scanning effects than in the case of (k, x).

In another study we have attempted to derive rules, based on individual letter scores, which can largely account for the present data. A
multidimensional analysis of the confusion matrices has also been carried out with a view to acquiring insight into the rules describing the complex interactions between the letters (Schiepers 1976c).

References


