Effect of perceptual grouping by similarity on eye movements in processing simple visual stimuli

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Abstract

In the present study we analyzed the impact of grouping by similarity on saccadic processing of simple sequential stimuli. We used four sets of stimuli: (1) points, (2) points, triangles, squares, and rhombs (two or more figures of the same shape were followed by two or more figures of a different shape), (3) the 2nd set of stimuli colored according to the shape, and (4) the 2nd set of stimuli with a colored background according to the shape. Stimuli were distributed in the same distance from each other and the size of stimuli was equant.

In measuring saccadic amplitudes and stability of gaze during fixations we observed increasing processing load in grouping stimuli. This is reflected in (a) increase of standard deviations of amplitude dispersion in the tasks with grouping effects (additionally the distribution of saccadic amplitudes is significantly higher in stimuli with grouping effects); (b) increase of small saccades in the grouping tasks, (c) a systematic increase of the amplitude of microsaccades within a fixation time.

These observations enable us to confirm two general assumptions: a. the grouping significantly influences saccadic processing of simple visual stimuli, b. the complexity of grouping is reflected in complexity of saccadic processing.

Keywords: eye movements, perceptual organization

Instead of selecting arbitrary elements or generating several possible combinations our perception prefers only certain groupings of stimuli. Even in case of simple and relatively meaningless and experientially not directly biased stimuli our perception groups together some elements. There are several well known principles that guide grouping in perceptual processing, e.g., proximity, similarity, connectedness, good continuation, figurality, thing-likeness and common region (e.g., Wertheimer, 1923, Palmer, 1992, Pinna, Brelstaff, & Spillmann, 2001).

In our study we are focusing on the principle of *grouping by similarity*. We are ruling out direct experiential effects and are also ruling out direct effects of meaning assignment. More specifically our current study analyzes saccadic eye movements in case of monotonous horizontally distributed and experimentally modified stimuli. Our aim was to explore possible effects of grouping on scanning simple meaningless horizontal stimuli and to describe their structural properties.

Our guiding assumptions we were able to confirm:

a. the grouping significantly influences saccadic processing of simple visual stimuli,

b. the complexity of grouping is reflected in complexity of saccadic processing.

Experiment and method

Participants

Five people (age 20-25) participated in experiments. All subjects had normal vision without correction. Participants were not informed regarding the aim of research and the research hypothesis.

Method

Eye movements were recorded with video-oculograph iViewX (240 Hz). Data analysis was conducted with program BeGaze and Microsoft Excel.

Stimuli were presented at a distance of 60 cm. Participants were instructed to scan stimuli horizontally from row to row and to move gaze like in case of reading.

Distribution of saccadic amplitudes and stability of gaze during fixations (henceforth: fixations) were compared and analyzed in case of every participant in all four experimental tasks. Saccadic amplitude is considered the absolute value (expressed in degrees) from the distance between gaze coordinates in pixels on screen before and after a saccade. Saccade amplitude can only aproximately be characterized as horizontal; moreover, an additional error is caused by participants' head movements. However, we assume that this approximate assumption is sufficient in horizontal gaze movement and in case of a separate saccade it does not exceed 0.2^0.

Extraction of saccades and fixations from raw gaze position data was made by BeGaze program. Eye movement velocity 25^0/s was chosen as saccadic threshold.

Manually excluded were all gaze movements during scanning the first and the last stimuli row, regression to new row, as well as blinking areas.If saccade amplitude was less than $0{,}3^0$ and the fixation before it was less than 120 msec, the saccade was also manually excluded.

Every stimulus was projected only once and participants were not able to see stimuli sets before the experiment.

Design and stimuli

Four experimental tasks were formulated with the aim of scanning monotonously and symmetrically distributed elements. The size of elements was approximately 0.5°. Elements were distributed horizontally 2° from each other and ordered in 9 rows. The distance between two neighboring vertical elements was 1.2^0.

These four sets of stimuli were used as follows:

•Primary visual stimulus consisted of regular black circle-shape points on a white background without any additional grouping factors. In the three other sets of stimuli points were replaced by triangles, squares, and rhombs (henceforth: N1).

•Black elements on a white background – points, triangles, squares, and rhombs according to the principle where two or more figures of the same shape are followed by two or more figures of a different shape (henceforth: N2).

•Colored elements on white background, i.e., the second set of stimuli colored according to the shape (henceforth: N3).

•The second set of stimuli with a colored background according to the kind of shape (henceforth: N4).

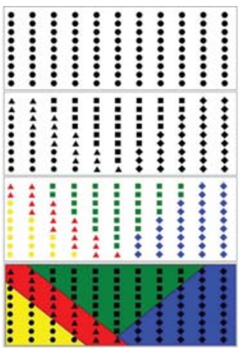
N1
N2
N3
N4

Fig. 1. Stimuli sets.

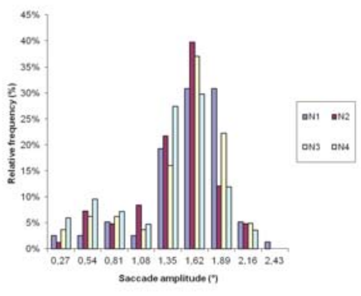

Fig. 2: Saccadic amplitudes in all tasks (1st participant).

Results

Precise sequential visual scanning of monotonous elements is a complicated task requiring focused attention from a participant. During the experiment an account regarding the place of current gaze direction is frequently lost. This is the reason why contrary to text reading nobody of the participants has indicated significant correcting saccades.

Similarly to reading, scanning is an individual process and the results cannot be compared between the participants. A common feature of amplitude distributions is positive asymmetry indicating more saccades with smaller amplitudes.

Perceptual complexity of the task is indicated by the duration of fixations exceeding the average usual duration of a fixation more than 100msec, e.g., during reading a text. Also the high number of saccades in executing each of tasks is an evidence for the processing load for a participant: instead of formal 70 saccades (7 rows containing 11 elements each) a high amount of saccades can be observed (relative mean 87,4) (Table 1)

Participant	N1	N2	N3	N4
1	78	83	81	84
2	76	57	71	75
3	95	97	96	84
4	73	80	71	99
5	106	116	88	138

Table 1: Total number of scades during the task

Distrbution of saccadic amplitudes in all tasks (1st participant) is shown in the 2nd figure. We were able to observe an increase of processing load if additional grouping effects were applied to the points. If grouping effects were applied in the manner of increasing complexity to the sets of stimuli from N1 to N4 (figural grouping effects applied to N2; figural + colored grouping effects applied to N3, and, finally, figural + background-colored grouping effects applied to N4), the following general results were observed:

(1) Average amplitudes of gaze movement have do not change significantly; however, standard deviations of amplitude dispersion increase in the tasks where stimuli with grouping effects are used. In the 2nd, 3rd, and 4th tasks the distribution of saccadic amplitudes is relatively higher than in the first task where no additional grouping information is used (cp. Table 2., 3.).

Participant	N1	N2	N3	N4
1	1.59	1.44	1.49	1.34
2	1.76	1.80	1.69	1.72
3	1.72	1.87	1.85	1.86
4	1.74	1.63	1.72	1.52
5	1.09	0.98	0.94	1.05

Table 2. Mean values of saccadic amplitudes ( )

Participant	N1	N2	N3	N4
1	0.41	0.42	0.45	0.48
2	0.42	0.57	0.62	0.67
3	0.66	0.70	0.69	0.75
4	0.72	0.67	0.62	0.60
5	0.48	0.45	0.42	0.50

Table 3. Standard deviation of saccadic amplitude ( )

(2) In the tasks of grouping elements there is a significant increase in number of small saccades (with amplitude not exceeding 0.8°; see Table 4). This characterizes the distribution of amplitudes for all participants. The increase of small saccades indicates additional distribution of gaze direction. This could be seen as an evidence for the increase of perceptual choices in scanning tasks containing elements with grouping effects.

(3) Third, in scanning elements with grouping effects gaze fixations of most participants are less stable. Within a fixation time there can be observed increase of eye movement drift and systematic increase of the amplitude of microsaccades.

Comparison of gaze direction dispersions during fixation shows that participants have increasing number of small amplitude saccades in case of grouping stimuli. According to our approach this indicates that fixations referring to >10px amplitude are less stable. Moreover, within fixations participants demonstrate more short-term correcting saccades in different directions (cp. Table 5).

Participant	N1	N2	N3	N4
1	8	12	12	17
2	4	5	4	7
3	3	10	6	8
4	11	15	8	12
5	37	42	41	36

Table 4. The amount of small amplitude saccades (< 0.8°), %.

Participant		N1	N2	N3	N4
1	X	35	38	37	41
	Y	38	27	34	37
2	X	51	58	48	56
	Y	58	45	45	47
3	X	64	72	68	61
	Y	49	61	57	49
4	X	73	74	74	73
	Y	75	71	77	76
5	X	63	65	71	73
	Y	58	64	52	66

Table 5. Ratio of microsaccades refering to >10px amplitude. Dispersion means gaze intervals during a fixation.

Conclusions

If applying additional grouping factors – similarity in shape, color, and background – to the monotonous rows of elements a significant change in perception can be observed. This change is reflected in the experimentally detectable changes of parameters of gaze movement which are in turn expressed in more frequent confusing the rows, distribution of saccadic amplitudes and decreased stability of gaze direction within the fixation times.

Our general conclusions are twofold: first, the grouping by similarity significantly influences saccadic processing load of simple visual stimuli, and, second, the complexity of grouping corresponds to the complexity of saccadic processing.

Our study is consistent with other work in the field:

(1) It allows us to hypothesize that *grouping by similarity* is a strong and robust process and is efficient even in non-configurational stimuli which was the case in scanning tasks in our experiments. (For a consistent evidence that *grouping by proximity* is efficient in non-configurational stimuli see Kubovy, Holcombe, & Wagemans, 1998).

(2) Our research also supports Houtkamp & Roelfsema, 2010 (cp. also Roelfsema & Houtkamp, 2011) results in case of local grouping where delay in visual processing can be observed. According to Houtkamp & Roelfsema there are two different processes in perceptual grouping: *incremental, slow grouping* and *base, fast grouping*. Our research supports the characteristics of the incremental processing. Although we have not explored temporal dynamics, we assume that the results of the present study and those by Houtkamp & Roelfsema (2010) are consistent. A research desiderate is to explore more carefully the relations between *parallel* and *serial* processing and to investigate whether indeed in case of local stimuli grouping is serial as proposed by Houtkamp & Roelfsema.

(3) Results provided by our study at least partially support the conception of trans-saccadic information processing by Carlson-Radvansky & Irwin, 1995. As explained in the second and third results we can observe an increase of small saccades in the tasks of grouping elements and a systematic increase of the amplitude of micro-saccades within a fixation time. This could be seen as an evidence for some trans-saccadic information invariance (eye movement drift and increase of micro-saccades within a fixation time might indicate that additional structural information increases processing load before moving to the next fixation referring to another structural invariant (e.g., from points to triangles); also decreased stability of gaze direction within the fixation times can be seen as evidence that there is perhaps still some structural information processed within the fixation time).

(4) Current results are consistent with the TLA model of visual perception (Pinna & Skilters, 2010) and support the autonomous processing of the first level (grouping) without directly involving higher level structures (i.e., shape and meaning assignment).

Our study has certain limitations and future research desiderata:

According to our experimental design, we have not taken into account time constraints in processing.

Further, we have not looked at the grouping effects in case of minimally semantic or experientially familiar stimuli (according to our research design and motivation we have ruled out possible effects of meaning assignment and experience).

Another interesting issue to be explored in future studies (but at least to some extent overlapping with the N4 set of stimuli in our study): how does grouping by similarity interact with grouping by common region (Palmer, 1992) in the analysis of saccadic movements? Additionally analysis of interaction between different grouping principles (e.g., similarity vs. proximity) would be a topic for a future research in using saccadic analysis.

Finally, a question regarding the role of attention as to be explored more in detail but we are inclined to assume that grouping (and shape assignment and segmentation in general), on the one hand, and attention, on the other hand, are mutually constraining (cp. also Driver et al., 2001).

In the current study we were able to observe increase of processing load in sequential scanning of local stimuli; a future desiderate concerns some more global configurational effects of grouping.

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