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Boris M. Velichkovsky
Pavel M. Balaban
Vadim L. Ushakov *Editors*

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Editors
Boris M. Velichkovsky
National Research Center
"Kurchatov Institute"
Moscow, Russia

Pavel M. Balaban
Institute of Higher Nervous Activity RAS
Moscow, Russia

Vadim L. Ushakov
Institute for Advanced Brain Studies
Lomonosov Moscow State University
Moscow, Russia

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Contents

Eye Movements in Visual Semantic Search: Scanning Patterns and Cognitive Processing Across Three Cultures

Maria Rabeson(✉), Irina Blinnikova, and Anna Izmalkova

Lomonosov Moscow State University, Moscow, Russia
maria.rabeson@gmail.com

Abstract. The study compares performance and eye-movement indicators in students from Russia, Japan, and China when searching for English words among randomly organized letters. The assumption was that social and linguistic experience affects visual scanning strategies and cognitive processing of verbal material. The study involved 64 respondents, demonstrating similar levels of English proficiency. Eye movements were recorded with SMI Gaze & Eye-tracking System (SMIRED 250 Hz). Russian respondents were the most successful at performing the task. Presumably, their success is determined by the experience in analyzing letter strings during sequential cognitive processing. Significant differences between the groups were established for both fixation duration and saccadic amplitude that describe the characteristics of cognitive processing (Velichkovsky et al., 2005). The Russian sample was characterized by high fixation durations (m = 239.5 ms) and low saccade amplitudes (m = 4.1°), demonstrating the focal pattern of attention distribution. The opposite trend toward ambient and gliding type of processing was recorded in the Japanese sample. In addition, the parameters of intersaccadic angles and saccade directions were analyzed. Return saccades were most characteristic of the Japanese group with direction changes in the range of 90–135°. Russian students demonstrated saccades of a sequential pattern in the range of 0–45°. Chinese students considered letter sets only once showing the smallest number of return saccades (the range of 135–180°). Based on the results of this study, the basic characteristics of visual semantic search can be associated with the first language experience that defines the patterns and the architecture of cognitive processing.

Keywords: Cross-cultural differences · Cognitive processing · Eye movements · Visual semantic search · Linguistic experience · Writing system

1 Introduction

The assumption that people of different cultures use different cognitive processing styles or strategies is repeatedly supported by academic research [1, 2]. Most studies compare respondents who belong to Western or European culture to those who come from Eastern or Asian cultures. The idea that Western culture instills an analytical style of

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information processing, while Eastern culture implies a holistic style has become topical. The style preferences result in different patterns of attention distribution (either to the salient object or to the background characteristics) and judgment (either based on an object's attributes and their categorization, or on the basis of contextual information and similarity) [3]. Characteristics of language systems, particularly, features of scripts are considered among the factors of culture that may be important along with social relations.

The development of European culture is associated with alphabetic writing systems, while Asian civilizations have relied on hieroglyphic scripts for many centuries. The alphabetic script involves a subtle distinction between individual morphemes and word composition that can be broken down into elements. Hieroglyphic writing is based on the perception of more holistic configurations. Although hieroglyphs generally take up less space than words, they have a greater semantic capacity. Reading one character provides more information than reading one letter [4]. Thus, it can be assumed that the characteristics of a script determine certain strategies for information processing. People who practice hieroglyphic writing should use a more holistic type of cognitive processing when analyzing visual information with shorter fixations and longer gaze movements.

Differences in the characteristics of cognitive processing between the representatives of Eastern and Western cultures have been found in a number of studies using eye movements. In particular, in the work of H. Chua, J. Boland and R. Nisbett [5], where the subjects attempted to memorize complex foregrounded figures, it was shown that the oculomotor pattern of Chinese participants was characterized by a greater number of shorter fixations and transitions between figure and ground. A review by Y.-K. Tsang and H.-Ch. Chen [6] found that, while some aspects of eye movement control in reading seem to be universal (e.g., the availability of orthographic information in the parafoveal preview), others are more script-specific (e.g., the size of the perceptual span).

This study is aimed to determine the extent to which information processing is governed by the properties of a language and its writing system. The research compares the performance and eye-movement patterns during lexical search across three groups of respondents: Russian, Japanese, and Chinese students. The experimental task was to search and identify meaningful words in a foreign language in a field of chaotically arranged Latin letters. We assumed that the number of successfully identified words, fixation and saccade duration, as well as the scanning pattern can differ among respondents who have mastered different scripts since their early years.

2 Method

2.1 Sample

The study involved 64 respondents: 43 women and 21 men. 22 participants were included in the Russian-speaking sample, 20 respondents composed the Japanese sample, 22 people represented the Chinese sample. The average age of the subjects was 19, 20 and 23 years, respectively. The Russian-speaking group included 22 participants with the average age of 19. The Japanese-speaking group was represented by 20 respondents with the average age of 20. Finally, the Chinese-speaking group included 22 participants of 23 years of age on average. The ratio of men to women was equal in all three groups. The students demonstrated similar levels of English proficiency supported by the results of the Word Associates Test [7] offered to each participant prior to the experimental series.

2.2 Stimuli and Task

The subjects were presented with letter matrices for analysis (See Fig. 1a). The stimulus material included eighteen matrices with randomized letters of the Latin alphabet. Randomization procedure was thoroughly described in our previous work [8]. It was performed in accordance with the frequency of letter use in the English language. Each matrix incorporated 10 different words. The length of the target words varied from 4 to 9 letters. The task of the subjects was to find a word and mark it by pressing a computer mouse button.

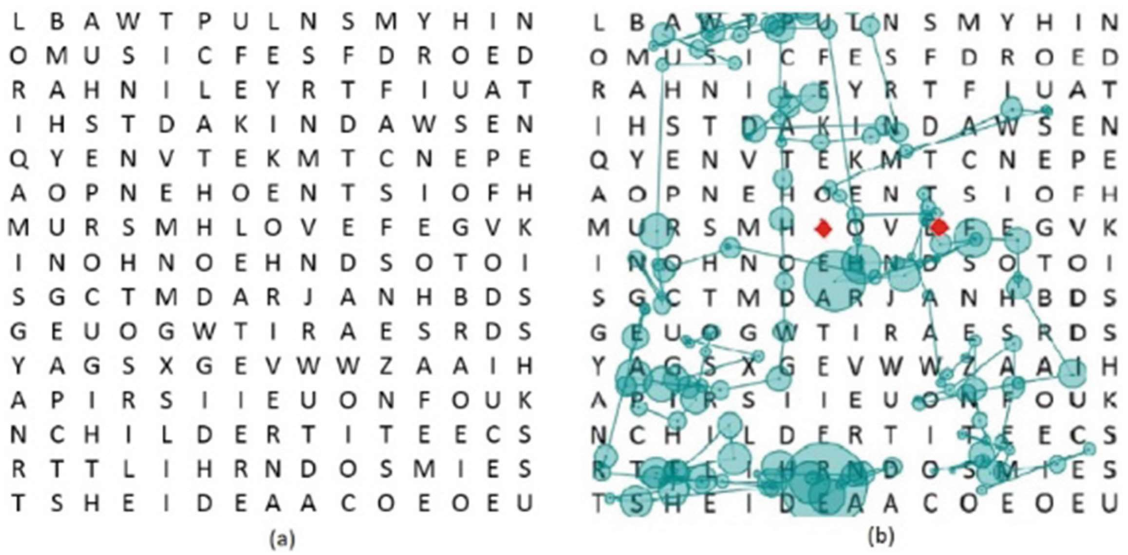

Fig. 1. (a) Sample stimulus matrix and (b) a matrix with a scan path and mouse clicks

2.3 Procedure

First, having been pretested on English verbal competence with the WAT test, the respondents completed a questionnaire that collected information on biographic data, linguistic background, and current physical state. Next, they participated in two experimental series with nine stimulus matrices presented in each series. Each of the eighteen stimuli appeared on the monitor for 40 s. A calibration point was displayed between stimuli. All procedures were conducted in accordance with the Declaration of Helsinki and were approved by the local ethics committee of Lomonosov Moscow State University.

2.4 Recorded Data

The indicators of eye movement (fixation duration and saccade amplitude) were recorded by the SMI Gaze and Eye-tracking System (SMI RED 250 Hz).

The data of 475 samples were additionally analyzed for the parameters of saccadic angles and changes in gaze direction. The procedure, used to describe the search patterns, analyzed two angles, i.e., the angle between a saccadic event and the horizontal direction ("Direction") and the angle between two consecutive saccadic events ("Intersaccadic angle"). The data about the coordinates in the starting point and the ending point of the saccades were provided by SMI BeGaze. Saccades are identified by SMI BeGaze by their velocity and acceleration thresholds. This procedure of analyzing saccadic direction angles is similar to the one described by T.A. Amor and colleagues [9] and was applied in our previous research [10].

2.5 Data Processing

Statistical processing was conducted with IBM SPSS Statistics 19 package.

3 Results and Discussion

3.1 Word Recognition Results

The total numbers of words and, specifically, the numbers of horizontally-oriented words detected by the respondents significantly differed in the three language groups ($F(2,124) = 15.4, p < 0.01$; $F(2,124) = 14.9, p < 0.01$)[1]. Russian students had more success (total m = 11.5, horizontal orientation m = 10.07, vertical orientation m = 1.32) than Japanese (total m = 8.41, horizontal orientation m = 6.72, vertical orientation m = 1.72) and Chinese students (total m = 5.3, horizontal orientation m = 4.57, vertical orientation m = 0.75). Since the level of language proficiency in all groups was approximately the same, these results can only be explained by the fact that the task itself was less demanding for native Russian language speakers. Mastering literal writing involves the skill of element-wise reconstruction of lexical units, which was the key scope in solving the experimental problem. However, mastering hieroglyphic scripts does not imply the development of these cognitive skills. Perhaps this explains why the Chinese- and Japanese-speaking students find it more challenging to construct letter chains and assess their lexical relevance.

The number of identified vertically-oriented words differs at the level ($F(2, 124) = 4.6, p < 0.05$). In this respect, Japanese students demonstrated better results in comparison to Russian and Chinese subjects. Taking into account the fact that their total scores were considerably lower than those in the other groups, this trend seems to point to a relevant feature of visual scanning in Japanese respondents. Successful strikes on the vertically-oriented words can be explained by the fact that Japanese hieroglyphic system is characterized by vertical reading.

3.2 Scanning Patterns

Examining the scan paths of individual respondents (see Fig. 1b), we noticed completely different patterns of visual search activity. In order to describe these patterns, we calculated the directions of saccades and intersaccadic angles for each trial. Considering

[1] The results of each participant in two series were analyzed. Two records were dismissed as a result of undue calibration of the apparatus.

the saccade directions, we found that significant differences in data mark two general trends (see Fig. 2). First, Russian respondents demonstrate considerably more saccades in horizontal direction to the right, which suggests the preference for sequential patterns in the Russian language (literal) writing system. Second, Japanese respondents demonstrate more saccades in the vertical directions, i.e. the upward-left direction (M = 10.33, compared to 8.9 in the Russian group and 9.1 in the Chinese group ($F(2,473) = 5.008$, $p = 0.007$)) and the downward-right direction (M = 11.21, compared to 9.87 in the Russian group and 9.43 in the Chinese group ($F(2, 473) = 4.788$, $p = 0.009$)). No evident significant trends were established in the Chinese respondents' results.

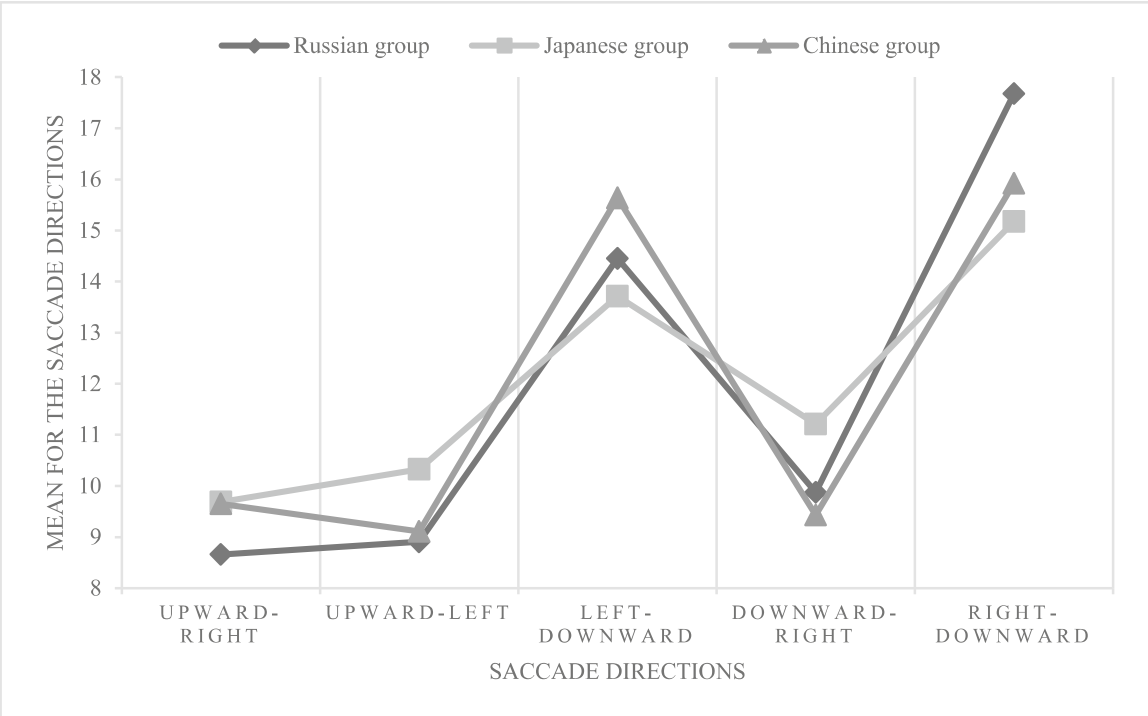

Fig. 2. Statistically significant differences between groups in the saccade directions

The analysis of the saccade directions showed that the Japanese students resorted to vertical transitions significantly more often when searching for words. This may be due to the distinct characteristics of the Japanese scripts, where the vertically-oriented positioning of words is typical.

The analysis of variance for the change in saccade directions during the search demonstrated that students of the Japanese group more often than others showed inter-saccadic angle values within the range of 90–135° ($F(2,473) = 17.02$, $p < 0.001$). This means that the switches between horizontal and vertical guides were rather common in their trials. This trend may indicate a higher lability of eye-movements and easier switch between horizontal and vertical directions. These data are consistent with the higher performance in identifying vertically-oriented words.

Participants in the group of Russian students demonstrated progressive saccades with intersaccadic angles of 0–45° ($F(2,473) = 12.58$, $p < 0.001$) significantly more often, which corresponds to a sequential eye-movement pattern with the priority for horizontal guide-lines in reading.

The group of Chinese students show the smallest number of recurrent saccades with intersaccadic angles in the range of 135–180° ($F(2,473) = 3.899$, $p = 0.021$). That means they rarely return to the previously scanned material as compared to the representatives of the other groups. Perhaps this is due to the logographic writing of the Chinese language, where each unit is interpreted unambiguously, reducing the need for returns in visual scanning. This feature of scanning seems to impede the total performance in the lexical search task, since the cognitive processing in lexical decision presumes recurrent letter-strings analysis. Namely, if the relevant letter combination does not fall into the focus of a fixation at once, the subject tends to skip the target and never returns to the same area of the matrix.

3.3 Cognitive Processing Features

One of the significant characteristics of cognitive processing is the ratio of fixation duration and saccade amplitude in eye movement patterns [11, 12]. For both of these parameters, significant differences were found between groups ($F(2,1114) = 85.66$, $p < 0.01$; $F(2,1114) = 42$, $p < 0.01$, respectively)[2]. The values presented in Fig. 3 indicate that Japanese respondents used a strategy differing from the one of the other groups. The Russian sample was characterized by high indices of the average fixation duration ($m = 239.5$ ms) and low indices of the saccade amplitude ($m = 4.1°$). Similar trends, though

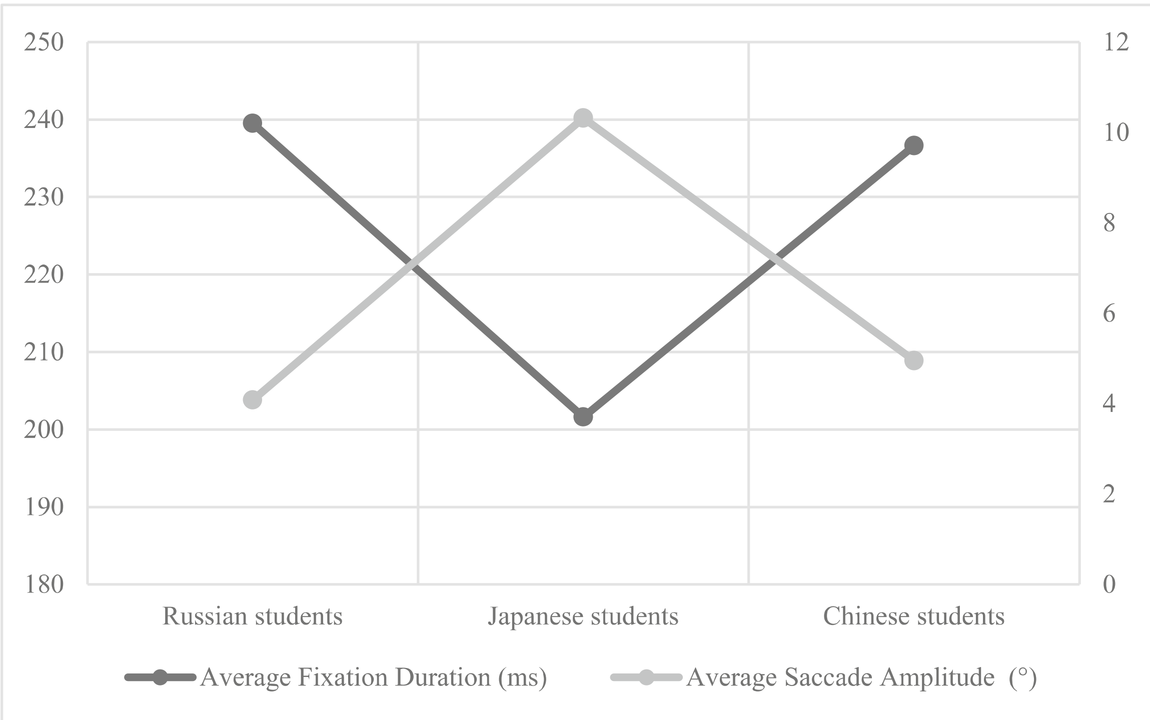

Fig. 3. The ratio of fixation duration and saccade amplitude in eye movement patterns

[2] The total of 1152 trials were recorded, though 36 of them were dismissed as a result of undue calibration of the apparatus.

with less dramatic values, were observed in the Chinese respondents (m = 236.63 ms for fixation durations and m = 4.95° for saccadic amplitudes). For the Japanese sample, the opposite tendency was recorded: lower indices of the average fixation durations (m = 201.6 ms) and higher indices of saccade amplitudes (m = 10.3°).

This finding suggests that Russian respondents used a method of cognitive processing based on focal attention, while native Japanese speakers demonstrate an ambient and sliding type of processing. The cognitive processing strategy applied by the Chinese respondents seems similar to the one, used by Russian-speakers. However, if this strategy is to be considered comprehensively in connection with the scanning pattern, a specific method to solve the lexical search task is observed in the trials of Chinese respondents. This pattern agrees with the general trends of modern Chinese language development towards simplification of hieroglyphic writing and introduction of sound-letter writing. The results can also be attributed to the peculiarities of reading directions in the respondents' native language.

4 Conclusion

The analysis of the task performance, saccade directions and the ratio of fixation durations and saccade amplitudes in the identification of visual verbal stimuli shows that the writing system of the native language affects the parameters of visual semantic search. It appears that linguistic experience, being connected to mastering a particular writing system, plays a role in determining the cognitive architecture of the two core components of search: the patterns of visual scanning and the style of cognitive processing.

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