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ATTENTION AND CHUNKING IN VISUAL SEARCH AMONG LETTER STIMULI

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Abstract

The experimental study of top-down influences upon visual search for a target letter in large letter arrays has been performed. The core question of this study was whether words embedded into random letter strings — and not perceptually segregated for an observer — can influence efficiency of the search for letters embedded either in words, or in random letter sequences between words. The experiment was based on an original modification of the classic selective attention test developed a century ago by H. Muensterberg. Participants performed visual search for a predefined letter of the Russian alphabet in letter matrices which included Russian words. In the first experimental condition, target letters always belonged to words, but the participants were not warned about the words, or about the arrangement of target letters in the matrix. In the second experimental condition, target letters never belonged to words. In the third (control) condition, there were no words embedded into letter matrices. The study revealed a dissociation between visual search efficiency and subjective representation of the search task. Although presentation conditions did not influence search rate, the participants significantly differed in their subjective experience of this influence. If target letters belonged to words, the words subjectively facilitated performance; whereas, if target letters did not belong to words, the words subjectively hampered the search. Moreover, if target letters were embedded in words, the participants noticed the words twice as often as in the opposite condition. We interpret this result as a dissociation between top-down processes in the visual system, and top-down influences upon visual search arising from chunking in visual information processing.

Keywords: visual attention, visual search, top-down influences upon visual information processing, word superiority effect, Muensterberg's test.

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The issue of top-down influences upon visual information processing has been widely discussed in contemporary cognitive psychology and neuroscience (Hochstein, Ahissar, 2002). The distinction of bottom-up and top-down processes is one of the cornerstones of cognitive psychology, as it reflects the contribution of the observer and the external stimulation to cognition. Although this dichotomy has been criticized by some authors (e.g., Awh et al., 2012), the criticism might be eliminated by distinguishing two sources of top-down influences: the observer's prior experience (former knowledge, or *structural* representations stored in the memory and automatically activated by the task); and goals and strategies actively applied by the observer to perform the task successfully. The latter determine *functional* organization of the observer's perceptual activity (Falikman, 2011).

A suitable example that illustrates both types of top-down influences is the "word superiority effect" (WSE), first described by James McKeen Cattell towards the end of the 19th century (Cattell, 1886) and then rediscovered in cognitive psychology in the late 1960's (Reicher, 1969; Wheeler, 1970). The WSE refers to the better recognition of letters presented within words compared to isolated letters, and to letters presented within random letter strings when presentation conditions (such as brief or noisy presentation, backward masking, etc.) make letter recognition difficult. Whereas J.M. Cattel used the amount of letters perceived from the brief presentation as a basic measure of the effect, cognitive psychologists use mostly the accuracy of single letter recognition within a word compared to isolated presentation, or presentation within an unpronounceable nonword string of the same length. For example, in a Reicher-Wheeler paradigm, an observer is presented with a word or a nonword string, followed by a mask. The observer is then asked to name a letter from the cued position in that string, making a 2-alternative forced choice (2-AFC). For example, for the letter R in the word "bird", an observer could be asked to choose between R and N (as both "bird" and "bind" are legal English words). The observer is usually more efficient in this task than in making the same 2-AFC for the string "bqrd".

The standard WSE is an example of top-down influences driven by the observer's prior knowledge or experience: the letter is recognized more efficiently because it is included in the larger structural unit, or *chunk*, a term coined by George Miller in his famous discussion of short-term memory storage units (Miller, 1956). The authors of the most popular models that provide an explanation for the WSE – specifically, the Interactive Activation Model (McClelland, Rumelhart, 1981) and the Dual Route Cascaded Model (Coltheart et al., 2001) — believe that explanations should be based on the observer's prior experience. Both models emphasize the automatic nature of the WSE and leave no room for its interaction with visual attention, except narrowing of spatial attention and further processing to just one letter (Johnson, McClelland, 1974).

However, the WSE might also result from the observer's strategy mentioned above as the second type of top-down influences upon visual processing. This is exactly what happens in rapid serial visual presentation (RSVP). When letters which compose the word are presented in the same location, one after another, at a rate of about 10 letters per second, the WSE emerges only when the observer is instructed to "read a word" and makes attempts to do so (Falikman, 2002; Stepanov, 2009; Falikman, Stepanov, 2012). If the observer is not warned about words presented letter by letter in the RSVP stream, then no WSE emerges and the words are never recognized as such. However, if the observer is instructed to "read words", but random letter sets are presented instead, performance is still significantly better than with the instruction to "name as many letters as possible", which could be considered as evidence for the strategic nature of the WSE. Otherwise, when all the letters forming a word are presented simultaneously, the WSE emerges regardless of the goals and intentions of the observer. However, it's easy to destroy the effect either by drawing the observer's attention to just one letter before the presentation (Johnston, McClelland, 1974), as noted above, or by setting a task that requires the observer to shift spatial attention within a word as a chunk, which seems to be destroyed by redirections of attention (Pantyushkov, et al., 2008).

Such requirements are characteristic of tasks referred to as "visual search". In visual search, an observer is required to locate a certain pre-specified item (a target), or a singleton among a number of visual objects (distractors) presented simultaneously (Wolfe, 1998). If just one salient feature (such as color, curvature, or motion) distinguishes a target from the distractors, then search time does not depend on the number of distractors. However, if the target is described as a conjunction of two or more features that distinguish it from the distractors (e.g. both color and curvature), then search time increases as a linear function of the amount of distractors, which implies a serial mechanism of spatial attention being redirected from one visual stimulus to the next. The latter mechanism is characteristic of letter search among a number of spatially distributed distractor letters. Although visual search for a pre-specified letter in letter strings — both random and regular (forming words) — has been analyzed in a modest number of studies (e.g., Krueger et al., 1974; Johnson, Carnot, 1990; Pantyushkov et al., 2008), there is still a lack of coherence in understanding the search mechanisms. This may be due to adding two counteractive forces to the search in letter strings that form words: on the one hand, it is so-called "crowding" or lateral masking which hampers the search for a target flanked by similar stimuli (Reddy, Van Rullen, 2007); and, on the other hand, it is top-down influences from word representation as a part of the observer's prior experience that make letter processing within words more efficient (Fine, 2001). Nevertheless, the very identification of words as processing units (chunks) in visual search appears automatic, rather than requiring attention, and the chunks themselves could be considered as *structural* processing units, forced by the organization of information in the visual field (Falikman, 2011). The question remains: whether chunking that leads to word identification could, in principle, become a strategic perceptual act rather than an automatic operation, when all letters of the word are presented simultaneously (rather than rapidly and serially). The purpose of this study was to develop and test a simultaneous letter presentation method, which would force the visual information processing system to "assemble" words as *functional* processing units, so that corresponding processes in the visual system could be considered as "operational units of perceptual activity" (Gippenreiter, 1983).

The method which, at first glance, meets these requirements is one of the numerous vocational tests developed a century ago by Hugo Muensterberg (Burtt, 1917). In this test, a subject searches for words embedded without spaces in random letter strings for a limited time period. The amount of located words is considered an individual measure of selective attention. It is assumed that word location and identification is not an automatic operation, but rather requires attention — just as word reading in rapid serial visual presentation. In this case, word identification would not occur spontaneously when an observer performs another task with the same stimulation (such as the search for pre-specified letters embedded in words surrounded by random letters), and would not influence performance in this task. On the contrary, if segregation of a word as the closest context for the target letter occurs automatically, one should expect word identification — at least when attention is drawn towards the letter and thus the word. This could slow down performance on the letter search task because, in this case, word segmentation might be necessary to single out a target letter. At the same time, if words as processing chunks are segregated from random letter strings automatically, and target letters do not belong to words, the search might become faster since the observer has the opportunity to skip these larger chunks without further analysis.

In our experiment, participants searched for a predefined letter in a matrix of 600 letters (10 letter strings × 60 items each) among which Russian words were embedded. The participants were not warned about the presence of the words. The inter-group experimental plan was used and three conditions were compared. In two experimental conditions, the letter matrix contained as many words as target letters. In the 1st experimental condition, target letters were always embedded in the words; in the 2nd experimental condition, they never belonged to words. In the control condition, participants searched for target letters in random letter matrices which did not contain words, and thus performed a standard letter cancellation test (with one target) developed by the French psychologist Benjamin B. Bourdon towards the end of the 19th Century[1].

Method

Participants. 216 subjects (82 male, 134 female), undergraduate and postgraduate students of Lomonosov

[1] The test was first described in the paper: Bourdon, B. (1895). Observations comparative sur la reconnaissance, la discrimination et l'association [Observations on memory, discrimination and association]. *Revue Philosophique, 40*, 153–185.

Moscow State University and the National Research University Higher School of Economics, aged 17–29 (mean age 20), right-handed, with normal or corrected-to-normal vision. The subjects were randomly divided into three groups, in accordance with three experimental conditions. Each group included 72 participants.

Stimulation. Three types of letter matrices printed on paper sheets were used. The matrices were generated using a Python script which composed letter strings from preset lists of stimuli. Each matrix included 10 strings of 60 lowercase letters of the Russian alphabet, with no spaces, and contained 24 target letters. Three Russian consonants ("н", "т", "р") with roughly equal frequency in the Russian language were used as targets; one of these consonants could be assigned as a target for different participants. Each participant worked with just one matrix, searching for just one letter. In the control condition (CC), all strings in the matrix consisted of "nonwords" (unpronounceable letter sets which were actually anagrams of 6-letter Russian words but could not be recognized as words – an example in English might be "isgtrn"); no letters in any of the nonwords were repeated, and each string included 10 nonwords with no spaces between them. In the 1st and the 2nd experimental conditions (EC1 and EC2), the letter matrices included 24 words (also with no letters repeated). In EC1, target letters were always embedded in the words (4 times in each position, from the 1st to the 6th, in different six-letter words). In EC2, the words never contained the target letter, so all words were embedded in letter strings somewhere between the target letters. The words (with roughly average frequency in the Russian language) and the nonwords were borrowed from our recent study (Gorbunova, Falikman, 2012). In total, nine versions of matrices (3 conditions x 3 target letters) were used in the study, printed onto A5 paper, Times New Roman, font size 14.

Procedure. Letter matrices were presented to participants individually, with an instruction to cross-out with a pencil all letters "н" (or "т", or "r") as quickly as possible. An experimenter interrupted performance after 1 minute. After that, a participant received a brief questionnaire consisting of three 2-alternative forced-choice questions: (1) Whether he/she noticed the words in the matrix (yes/no); (2) If yes, whether he/she noticed that the target letters have always/never been embedded in the words (yes/no); (3) Whether the words either distracted them from the search, or helped them to search for the target letters if noticed (helped/distracted). The CC subjects only answered the question about whether they noticed words in the matrix (which in fact were absent).

For data analysis, IBM SPSS Statistica 20.0.0.2 was used.

Results

ANOVA revealed no statistical differences in performance for all three conditions: $F(2, 215) = 0.018$, $p < 0.98$. Mean search efficiency for all three conditions (% of the total amount of targets in the matrices) and standard deviations are provided in Table 1.

At the same time, EC1 participants noticed words in the matrices significantly more often than EC2 subjects

Table 1

Summary table of results (EC1 — the 1st experimental condition with target letters always embedded in words; EC2 — the 2nd experimental condition with target letters never appearing in words; CC — the control condition with no words among letters in letter strings)

	Performance (group mean, %)	**SD**	**Noticed words, % of subjects**	**Noticed a relation between target letters and words, % of subjects**	**Among those who noticed words**	
					Found them useful, %	Found them distracting, %
EC1	81.6	13.0	65.3	19.4	57.4	8.5
EC2	81.4	15.6	37.5	9.7	18.5	44.4
CC	82.5	12.3	11.1	–	–	–

(Pearson's $\chi^2 = 13.7$, $p < 0.0001$). The interrelation between the arrangement of target letters and words in the matrix was also discovered in EC1 significantly more often than in EC2 ($\chi^2 = 4.7$, $p < 0.03$). Those who noticed words in EC1 reported that the words helped them to perform the task, whereas those who noticed words in EC2 found them hampering ($\chi^2 = 17.8$, $p < 0.0001$). In CC, 11% of subjects "noticed" words. The quantitative data from subjective reports is also provided in Table 1.

A statistical comparison of performance between subgroups of EC1 and EC2 participants, distinguished in accordance with their subjective reports, has also been performed. Despite pronounced differences in their answers on the questionnaire, no statistical differences between performance in any pair of subgroups (noticed / not noticed words; found them useful / distracting) have been revealed, both within and between experimental conditions.

Significant differences in search efficiency for three target letters used in the study have been found: $F(2, 215) = 17.0$, $p < 0.0001$. Paired-comparison tests show that the participants searched for "p" significantly better than for "н" and "т" which, in turn, did not differ in search efficiency. The mean efficiency of the search for all three target letters in all three conditions can be found in Table 2. According to ANOVA, this factor does not interact with the condition factor: $F(4, 215) = 0.64$, $p < 0.63$.

Discussion

The study has revealed that spontaneous spotting of words in random letter strings, as in the Muensterberg's selective attention test (Burtt, 1917), is possible when performing a letter search. However, it is mediated by mutual arrangement of target letters and words in the letter matrices. When target letters always appear in words, the words are discovered almost twice as often as when the targets appear among other random letters between words. However, the amount of observers that spontaneously discovered

Table 2

Search efficiency for three letters used as targets in three experimental conditions, % located and crossed-out

	Target		
	т	н	р
EC1	79.3	77.4	88.0
EC2	80.9	74.5	88.7
CC	79.0	80.5	88.0
Mean	79.7	77.5	88.2

the mutual arrangement of target letters and words was relatively low and also depended on whether the target letters were embedded in the words. When target letters belonged to words (EC1), less than 20% of participants noticed the regularity in the mutual arrangement of the target letters and words. But when target letters did not belong to words, the regularity was noticed by less than 10% of participants.

At the same time, participants estimated the words in the matrix as "useful" or "distracting" depending on the task (and the estimates were opposite to our initial hypothesis), though in fact the words didn't influence task performance at all — the amount of located targets was the same for all three conditions (all differences lay within 1%, with a mean standard deviation of about 13.6%).

One might assume that the letter search task was too easy, which led to the "ceiling effect" (equally high performance in all three conditions). However, the comparison of search efficiency between three letters used as targets revealed a significantly faster search for one of them ("p") against the other two. This must be due to the specific visual feature of this letter — the tail below the letter string level which produces search asymmetry (Treisman, Souther, 1985), allowing subjective pop-out of this letter during the search (Wolfe, 1998). This demonstrates that the measure of search efficiency is sensitive enough, the temporal interval of 1 minute was enough to estimate performance, and the ceiling effect cannot explain the absence of differences between the conditions.

Therefore, the dissociation between performance and subjective reports has been observed. Whereas subjectively the presence of words in random letter strings influences search (one way or another) depending on the mutual arrangement of target letters and words, objectively no such influence has been observed. If we relate this result to the definition of attention as "phenomenal and productive manifestation of the leading level of organization of one's activity" (Gippenreiter, 1983, for discussion see: Dormashev, Osin, 2010), as proposed within the framework of the activity theory (Leontiev, 1978), it might be assumed that performance in our search task does not involve a unified attentional process with phenomenal (conscious representation) and productive (performance) aspects, but rather that it involves two distinguishable processes where just one process is related to attention.

This result could be interpreted as a dissociation between top-down *processes* in letter strings processing and top-down *influences* upon performance on the search task. This difference between types of processes in the information processing system, and influences upon processing — although implied in some recent studies (e.g., Latinus et al., 2010) — is not yet commonplace for the contemporary cognitive psychology of attention. However, it seems necessary for the interpretation of our results.

On the one hand, spontaneous capturing of a word from a letter string when attention is brought to one of the letters forming the word (and even without bringing attention to such a letter in the letter search task in nonword strings) could be interpreted as a manifestation of top-down processes in the information processing system — processes driven by representations of higher-level chunks (words) stored in the observer's memory (although such spontaneous capturing is by no means mandatory). On the other hand, such spontaneous capturing of words does not modulate efficiency of the target letter search, a fact that could be considered as a lack of top-down influences from higher-level chunks (words) upon the letter search task. Initially, we proposed that chunking *between* target letters (condition EC2, when targets never belonged to words embedded in letter strings) would speed up search. However, such chunking appeared to emerge quite rarely (only about one third of our participants noticed the words between target letters in this condition), and there were no significant differences in performance between different conditions and subgroups of subjects, that provided different subjective reports.

At the same time, our results raise a question about the original Muensterberg's vocational test, widely used in professional psychodiagnostics to measure "selective attention". It seems that performance in this test engages two types of top-down processes involved in visual perception. The first process is the spontaneous (automatic) detection of words as processing units that match representations stored in the observer's memory — in cognitive psychology, this is referred to as segmentation and regarded as a *preattentive* process "producing the objects which later mechanisms are to flesh out and interpret" (Neisser, 1976, p. 89). The second process is the voluntary identification of such units in accordance with the task at hand. Whereas the former process could hardly be considered as attentional (although quite probably interacts with attention), the latter process is basically in line with the classic definition of attention as a process of *"apperceptive combination"* which is "continually taking place between the elements of the single contents of experience" (Wundt, 1897, p. 223). Although the Muensterberg's test has been applied for about a century, demonstrating high correlations with academic and professional achievement, it seems that this is not the whole story and its research potential is far from being exhausted.

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Внимание и структурирование в зрительном поиске среди буквенных стимулов

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Резюме

В статье представлены результаты экспериментального исследования нисходящих влияний на решение задачи зрительного поиска буквы в больших буквенных массивах. Источником нисходящих влияний может быть как прошлый опыт наблюдателя, так и специальные стратегии решения зрительных задач. В центре данного исследования стоял вопрос о том, могут ли перцептивно не выделенные для наблюдателя слова повлиять на эффективность поиска буквы, входящей в состав слова. Исследование было проведено с использованием авторской модификации классического теста Мюнстерберга для диагностики избирательности внимания. Испытуемые решали задачу поиска заранее заданной буквы в массивах букв, содержащих слова русского языка. В первом условии целевые буквы всегда размещались в словах, о чем испытуемый не был предупрежден. Во втором условии буквы всегда были за пределами слов. В третьем условии массивы букв не содержали слов. Проведенное исследование выявило диссоциацию продуктивных показателей решения задачи и ее субъективной репрезентации: несмотря на то что условия предъявления объективно не оказали влияния на скорость поиска, испытуемые по-разному оценивали их влияние на решение задачи. Когда целевая буква входила в состав слов, присутствие слов субъективно облегчало решение задачи, а когда целевая буква находилась за пределами слов, присутствие слов субъективно затрудняло ее отыскание. Кроме того, испытуемые вдвое чаще замечали слова в массивах букв, когда целевая буква входила в состав слов. Мы интерпретируем данный результат как диссоциацию нисходящих процессов в обработке зрительной информации и нисходящих влияний на процесс решения задачи зрительного поиска, связанных с укрупнением единиц обработки зрительной информации.

Ключевые слова: зрительное внимание, зрительный поиск, нисходящие влияния на обработку зрительной информации, эффект превосходства слова, тест Мюнстерберга.