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# CAN DEPLOYMENT OF ATTENTION BE STRATEGICALLY CONTROLLED?

***Marjena Popović***[1] ***and Sunčica Zdravković***
Department of Psychology, University of Novi Sad, Serbia

*The main goal of the experiment was to test whether deployment of attention could be strategically controlled. Subjects viewed five-letter arrays. Each array included a letter unique in shape (i.e. target). One of the letters in each array (target or non-target) also differed from other letters in color or in position in relation to the array. That letter will be referred to as a feature singleton. The probability ratio of the feature singleton being the target or a non-target letter was varied throughout three experiments. The ratios were (1) 0.5 (target) : 0.5 (non-target); (2) 0.2 (target) : 0.8 (non-target); (3) 0.8 (target) : 0.2 (non-target). Subjects in all three experimental conditions deployed serial processes, but failed to maintain complete intentional control during the course of the search.*

**Key words:** *visual attention, visual search, exogenous, endogenous*

[1] ✉: marjenap@gmail.com

The traditional view of visual search states that the search consists of two functionally independent and sequential stages (Theeuwes, 1992) – parallel and serial. Also, there is a consensus on characteristics of both of the stages.

Exogenous processes take place in the visual cortex; therefore, only basic characteristics of visual stimuli (such as color and orientation) could be coded in parallel (Kanwisher & Driver, 1992; Treisman & Gelade, 1980). These processes are insensitive to perceptual load – increase in coinciding information does not affect the search, because the processes are unlimited in capacity and the processing of all information in the visual field is done simultaneously (Feature Integration Theory FIT, Treisman & Gelade, 1980). It was assumed and later demonstrated that the time spent on the search for a target among any number of non-targets will be independent of the number of elements between the target and the starting point of the search (e.g. the fixation dot). An assumption of automaticity could be derived from the two stated characteristics of perceptual processes. Automatic processes are commonly considered out of reach for intentional control; hence, exogenous attention is rather thought to be influenced by the qualities of stimuli.

Endogenous attention, on the other hand, takes place in the frontal lobe (Kanwisher & Driver, 1992). It is under intentional control and examples would be search for more subtle features (such as saturation or opacity) or search for a conjunction of more features. In such cases it is considered that the search needs to be sequential, and it is a quality of this stage. Since sequential search requires intentional allocation of resources, it has limited capacity (Treisman & Gelade, 1980). This leads to a conclusion that endogenous attention is sensitive of perceptual load; also, increase in information between the start point of a search, and the target of that search will result in an increase in the time required for the search.

In visual search paradigm observers search for a target among a certain number of non-targets. Usually, the target is a highly visually salient item – an item that is clearly distinguishable in one or more basic visual attributes (it stands out from its background and other elements of the display). Those items are frequently referred to as feature singletons, being unique in a basic feature (Egeth & Yantis, 1997). Except for the target, the stimuli set can consist of any number of non-targets varying in saliency, some of them even being feature singletons themselves.

According to the traditional view, feature singletons should a priori attract attention exogenously. However, some research shows that basic features attract attention only if they are task-relevant. If they are not, they do not attract attention (Jonides & Yantis, 1988; Theeuwes, 1991). This disputes one of the traditional key differences between the exogenous and endogenous attention – the first one being unintentional, and the second being under intentional control.

Hence we could wonder whether the cognitive system could attenuate exogenous attention? If so, to what extent?

The research mentioned earlier could not answer this question for one reason: they were designed in an all-or-none way – the feature singletons were either always task relevant for one group of participants, or always task irrelevant for the other group (Theeuwes, 1991). In order to answer this question we applied a different experimental design varying the task relevancy-task irrelevancy probability ratio in the three experiments presented here.

Traditionally, information obtained by exogenous attention is thought to be of no use in the second stage which is being run by endogenous attention (Feature Integration Theory, Treisman & Gelade, 1980). Being unintuitive, this assumption was interesting for researchers, and has yielded some more recent visual search models, such as the Guided Search (GS) model (Wolfe et al., 1989). The crucial statement of the first GS model was that information from the first stage could be used to guide attention in the second (Wolfe et al., 1989). The latest version of the GS model states that the "attentional guidance is a control signal, derived from early visual processes" (Wolfe, 2007, p. 101). It should be noted that the signal is not as simple as the output of the first stage (Wolfe, 2007).

According to GS model, if serial processing is preceded by parallel search the targets unique both in relevant and irrelevant features should be found in shorter time than the targets unique only in relevant features. This should be the case independent of the experimental condition.

# EXPERIMENT 1

## Method

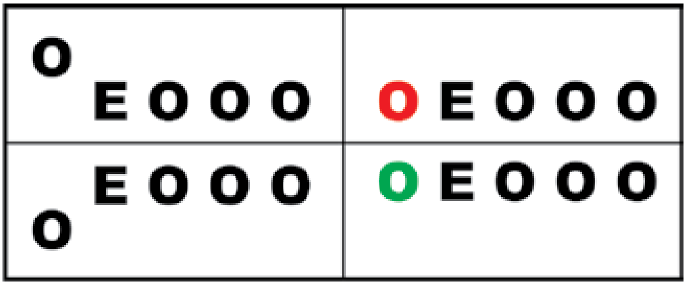
*Participants:* 10 first-year psychology students from the Novi Sad University participated as unpaid volunteers. All of the participants were right handed, had normal or corrected-to-normal vision and reported having no color-vision defects.

*Apparatus*: Displays were generated by a computer operating on a 1.61 GHz AMD Sempron 2600 processor, with 256 Mb of RAM. The stimuli appeared on a 17" CRT Samsung monitor, using 1024×768 resolution graphics mode. Responses were collected via a serial port mouse. The fixation point and the letter array were presented in black on a white background. Each subject was tested in a dimly lit room. The monitor was located at eye level, at about 45 cm from the participant.

*Stimuli:* The stimuli set consisted of a horizontally aligned five letter array. Each array consisted of two different letters, of which one appeared once in the array and the other appeared four times (figure 6). The target letter was defined as the letter unique in shape. Letter pairs AU, EO, HC and VS were to appear in the same stimuli set, as either target or non-target letters. Switching of the roles of target and non-target display elements, as well as introducing four letter pairs was necessary in order to prevent the development of an automatic consistently mapped (CM) detection response (Shiffrin & Schneider, 1977).

Two criteria were considered for the choice of the letter pairs: (1) general appearance and (2) organization of specific elements. The first criterion distin-guishes between rounded letters (U, O, C, S), and letters with sharp edges (A, E, H, V). In order to go by the second criterion, letter with the same orientation lines in the same positions (e.g. letters U and H have two vertically oriented lines in the left and right end of letter) were not paired together. Letter pairs AU, EO, HC and VS were used in the same display. All of the letters were uppercase, bold and equal in height - 2 cm; the width varied between 2 and 2.5 cm depending on the letter.

***Figure 1: Examples of stimuli sets containing a feature singleton***




*Procedure:* The observers were placed in front of the screen, which contained a black fixation dot (7×7 mm). The dot was presented at the center of the visual field for 500 milliseconds. The stimulus field was presented for 100 milliseconds. A response mask (matrix consisting of five cells in a single row, positioned at exactly at the same locations as the letters in the stimuli array), remained present until a response was emitted, or for a maximum of 750 milliseconds. Participants were instructed to click the cell in the matrix corresponding in position the letter different in shape in the previously presented array. Participants were informed that all the differences between the letters except the ones in shape were irrelevant to the task.

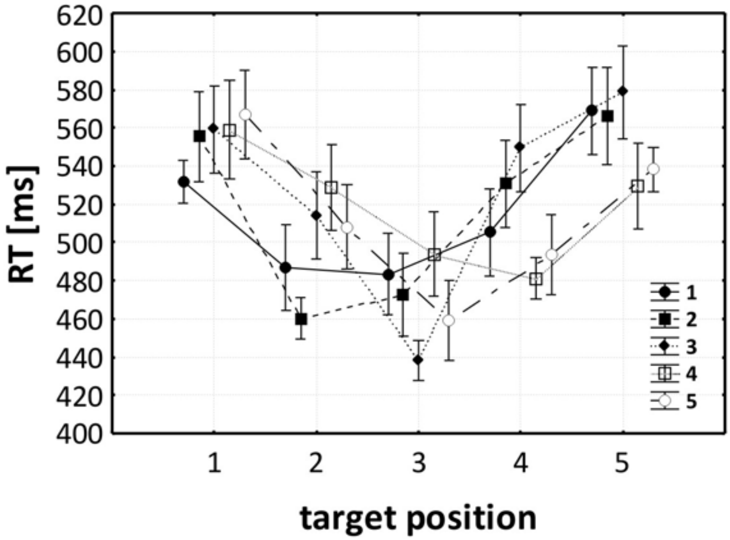
In each letter array a single letter differed from all others in position (figure 1, left side) or in color (figure 1, right side). That letter is referred to as a feature singleton. The probability ratio of feature singleton being the target or non-target letter was 50%.

## Results and discussion

Each participant viewed 400 different trials. Responses with reaction time below 100 ms were omitted from analysis, because such short reaction time is physically impossible, and is probably a result of a random reaction. The data was analyzed with analysis of variance for the reaction time. A three-factor analysis was performed, factors being *target position* (5 levels), *feature singleton position* (5 levels) and *feature singleton type* (4 levels: up and down, green and red, figure 1).

The factor *target position* was statistically significant: $F(4,2812)=60.297$, $p<0.001$. The factors *feature singleton position* and *feature singleton type* were not significant. However, interaction between factors *target position* and *feature singleton position* is statistically significant: $F(16,2812)=8.71$, $p<0.001$ (figure 2).

***Figure 2: Effect of interaction between factors target position (x axis) and feature singleton position (line pattern) on reaction time [ms]***




An isolated effect of target position on reaction time, in a way that the targets closer to the fixation dot are recognized in lesser time, would suggest that partici-pants performed serial search which is indicative of endogenous attention. Also, an isolated effect of feature singleton position on reaction time, in a way that the targets closer to the position of a feature singleton are recognized in lesser time, would suggest that participants performed parallel search which is indicative of exogenous attention. Consequently, this experiment created a condition in which the two types of search were forced to compete.

In the situation when both the target and the feature singleton is the same letter, and is also in the central position in the array, reaction time is the shortest (figure 2, line pattern 3). Both exogenous and endogenous attention are working together, and in the same direction, thus shortening the reaction time. For line patterns 2 and 4 (figure 2), the shortest reaction times are again the ones in situations when both the target and the feature singleton is the same letter, but these targets are not in the central position (fixation dot), but on the left and right of it. It seems that for these line patterns, exogenous attention prevails.

However, line patterns 1 and 5 (figure 2) show the shortest reaction time in situations when the target is closest to the fixation dot, disregarding the position of the feature singleton. This would suggest serial search. It should be noted that while the line patterns 1 and 5 are mutually similar, they differ significantly from the line pattern 3. The shortest reaction times for all three line patterns are at the same point, but the shortest RT for line pattern 3 is significantly shorter than the shortest RT for line patterns 1 and 5.

The further implications of obtained results will be discussed in the general discussion. The second experiment followed the main line of our inquiry about the probability ratio and search strategies.

## EXPERIMENT 2

In this experiment the probability ratio of a feature singleton being target was decreased. This was supposed to produce an effect on reaction time which would signify change in strategy. In the case when feature singleton is not informative, the exogenous search should be attenuated leading to prolonged reaction time.

### Method

Ten new observers participated in the following experiment. Stimulation and procedures used were exactly the same as those used in the previous experiment. The only difference was the probability ratio of a feature singleton being a target or non-target element of the display. The probability of a feature singleton being a target was 20%, and accordingly, the probability of a feature singleton being a non-target was 80%.

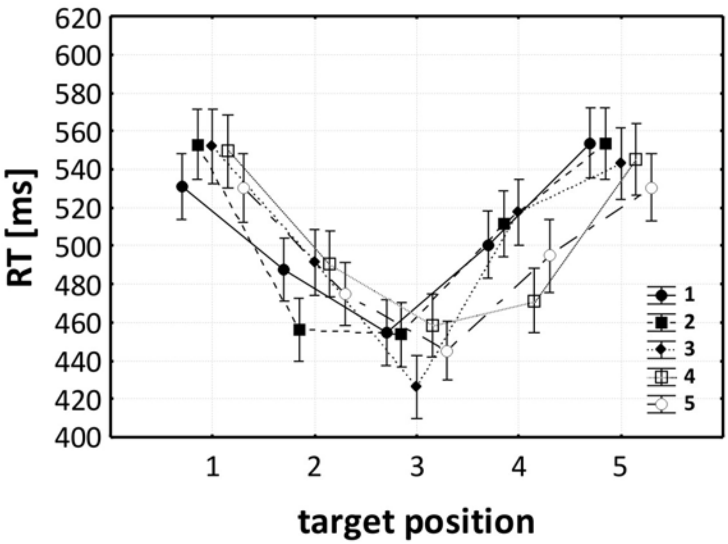
### Results and discussion

The same type of analysis was performed as in Experiment 1. The factor *target position* was statistically significant: $F(4,3241)=110.68$, $p<0.001$. The factors *feature singleton position* and *feature singleton type* were not significant. The interaction between factors *target position* and *feature singleton position* was statistically significant: $F(16,3241)=2.79$, $p<0.001$ (figure 3).

The results of the second experiment are somewhat similar to those of the first one. Again, no effect of feature singleton position on reaction time is apparent for the targets placed on the ends of the array (figure 3, line patterns 1 and 5). However, there is a difference for the lines 2 and 4 in comparison to the previous experiment. In these cases, for the targets on the second and fourth position, there is a decrease in RT when the singleton features are presented on the positions 2 or 4 (i.e. equal to the target) or on position 3 (i.e. fixation point). Line 3 remains the same in both experiments.

Compared to the previous experiment, the effect of feature singletons on reaction time for the two line patterns (2 and 4) has decreased. This is only logical, for the probability of a feature singleton being a target also decreased in 30%. It appears that, along with the decrease in the probability that a feature singleton is also the target, there is a decrease in the perceived usefulness of the feature singleton. If that is so, there is a possibility that participants have, to a certain degree, overridden the unintentionality of the parallel processes. In order to prove that line of reasoning, a third experiment was performed. In that experiment, the probability of a feature singleton being a target was increased in 30%, compared to the probability in the first experiment.

***Figure 3: Effect of interaction between factors target position (x axis) and feature singleton position (line pattern) on reaction time [ms]***




## EXPERIMENT 3

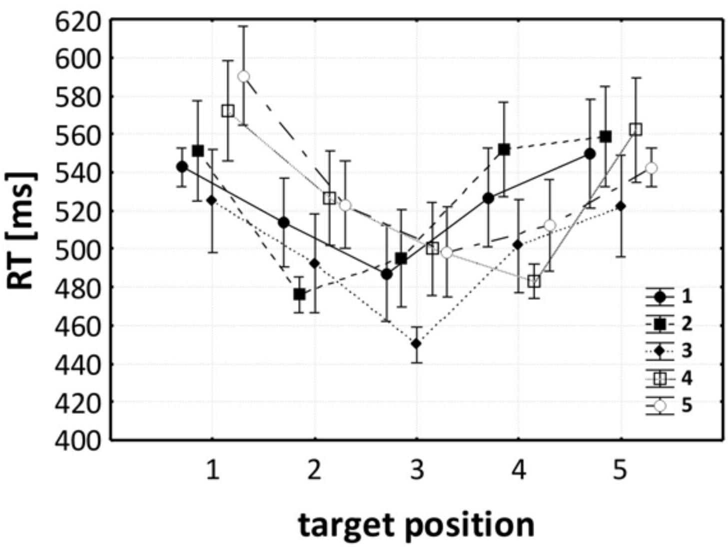
The same procedure was applied in the last experiment. The only difference was the probability ratio. The probability of a feature singleton being a target was 80%, and accordingly, the probability of a feature singleton being a non-target was 20%.

## Results and discussion

The same type of analysis was performed as in the two previously presented experiments. The factor *target position* is statistically significant: $F(4,3425)= 30.065$, $p<0.001$. The factor *feature singleton type* is not significant. However, the factor *feature singleton position* reached statistical significance: $F(4,3425)=6.82$, $p<0.001$. The interaction between factors *target position* and *feature singleton position* is statistically significant: $F(16,3425)=5.6$, $p<0.001$ (figure 4).

The results of the third experiments are almost exactly the same as the results of the first one. The line patterns 1 and 5 do not seem to be affected by the position of the feature singleton, while the line patterns 2 and 4 are. Furthermore, the size of the slopes between the target placed in the central position in the array and the target which is at the same time a feature singleton for line patterns 2 and 4 are the same for the Experiment 1 and the Experiment 3 (figures 2 and 4). Although it was expected that an increase in the probability of a feature singleton being a target, will be followed by an increase in the perceived usefulness of the feature singleton (according to the Experiments 1 and 2), and subsequently in higher slopes than those in experiment 1, the third experiment does not disprove the findings of the previous two. There might be an upper threshold for the perception of probabilities, and that there is simply no room for an increase in perceived usefulness of a feature singleton (the ceiling effect).

***Figure 4: Effect of interaction between factors target position (x axis) and feature singleton position (line pattern) on reaction time [ms]***




## RESULTS: EXPERIMENTS 1-3

The procedures of all three experiments were the same which allowed for statistical comparisons. It was expected that the change in probability ratio would lead to change in reaction time.

Analysis of variance for the three experiments shows that they differ significantly in reaction time F(2,9627)=28.04, p<0.005. Scheffe post-hoc test shows that the 0.2:0.8 probability ratio (Experiment 2) has a significantly shorter reaction time than the other two probability ratios.

These results showed that the lower the probability of target coinciding with feature singleton, the shorter the reaction time.

There were two types of singletons in each of the three experiments (figure 1): color and position. Two colors (green and red) and two positions were used (above and below the row of letters). The literature treats these two types of singletons differently. Color is a feature that is known to be accessible exogenously (Treisman & Gelade, 1980) while other features, such as position of an element in relation to the set, are not commonly thought to be accessible exogenously. In our three experiments the singleton type was always tested as a separate factor in the analysis of variance and never reached statistical significance.

When tested together for all three experiments *feature singleton type* reached significance: F(3,9627)=4.04, p<0.01. The difference should be expected between the two types of singletons (color and position) but it did not reach significance. Also there is no significant difference between the levels of any of the two types (i.e. between red and green or between up and down). Scheffe post hoc analysis only showed the significant difference for RTs between *red* and *up*. The obtained difference is fairly small in absolute values, which could account for the lack of significance in separate experiments.

## GENERAL DISCUSSION

The present experiment aims to explore whether strategic deployment of attention is possible. It was expected that different search strategies would be chosen throughout three experiments, based on their assumed efficiency. Participants subjected to the 0.2:0.8 probability ratio, were expected to deploy serial search, while the ones subjected to the 0.8:0.2 probability ratio were expected to deploy parallel search. Furthermore, the second group was expected to require significantly shorter time for the search.

Results of the experiment were opposite: the 0.2:0.8 conditions produced a shorter RT than the other two. It was assumed that in situations where the target is unique in both task relevant and task irrelevant feature, parallel search will be deployed. That parallel search would yield a single salient item, which is also the target. On the other hand, if a non-target element was unique in some feature, the parallel search would not be sufficient for localizing a single target, and serial search would be required. Subsequently, for the 0.2:0.8 conditions only parallel search would be deployed in 20% of situations, and serial search in 80%; for the 0.5:0.5 conditions both parallel and serial search would be deployed in 50% of situations; for the 0.8:0.2 conditions parallel search would be deployed in 80% of situations, and serial search in 20%. In all of the experimental conditions, serial search might or might not be preceded by a parallel search.

However, this was not the case. Results suggest that perceiving the irrelevant features as helpful in identifying the target results with a higher distraction effect in situations when a non-target is unique in an irrelevant feature. Although in the 0.2:0.8 conditions the irrelevant feature is distracting from the target in 80% of situation, and in the 0.8:0.2 conditions only in 20% of situations, the intensity of that distraction is higher in the 0.8:0.2 conditions. The stated difference in intensity of distraction is followed by a difference in RT.

For the 0.2:0.8 conditions, 80% of searches done in the singleton detection mode would result in segregation of two elements (with respect to the Guided Search Model by Wolfe, 2007), of which only one is the target. This leads to a conclusion that subjects found it easier to apply the singleton search mode, even though in 80% of the tasks, intentional search had to be made in order to choose between the two previously selected items. In that case, the cost of the additional decision making which was necessary to complete the task was not too much to pay for the benefit of the less demanding singleton search. At what point does that benefit get too much to pay? This is a question to be answered in some further research.

There is a result constellation that emerged in all of our experiments. Namely, the differences between the shortest reaction times of the three line patterns could be explained in two ways. The first possibility is that for the line patterns 1 and 5, the shortest reaction times are prolonged as a result of the distraction caused by a feature singleton placed on a non-target item, while the shortest reaction time of the line pattern 3 is considered the baseline value. This explanation is consistent with the GS model of attention: the exogenous search yields two salient items, one of them being the target and the other being the feature singleton. Then, the endogenous processes "decide" which of the two the target is.

The opposite explanation is also possible; the shortest reaction times of line patterns 1 and 5 can be considered baseline values, while the shortest reaction time of the line pattern 3 is considered a result of facilitation by a feature singleton placed on a target item. This explanation is, however, consistent with the results of the experiment. All of the shortest reaction time values on each of the line patterns are significantly different from the shortest reaction time on line pattern 3, but at the same time, none of them are mutually different.

None of the models mentioned (FIT and GS) seem to be able to explain the difference between the line patterns 2 and 4 within experiments. In all three experiments, if targets are positioned at the ends of the array, the feature singleton has no, or an insignificant effect on reaction time; whereas for the targets positioned to the left and right of the central position, feature singleton has a significant effect on reaction time. These results are inconsistent with the GS model. The model suggests that the serial process searches only the items which were previously indicated as possible targets by the parallel processes. If that was the case, a target placed further left or further right from the central position would not require any more search time, than targets placed just next to the central position; for it is not the absolute distance from the start point to the target that determines the time of the search, but the number of elements in between. The same combination of parallel and serial search would be as efficient for the end positions, as it was for the inner positions, if one follows the line of reasoning of the GS model. Why wasn't the same strategy used if that is so? Are there any other factors contributing to the decision about the deployment of attention? Probably not. The conclusion that the GS model cannot be used to explain the results is more likely.

No effect of feature singleton type suggests that both types of features in the experiment attract exogenous attention. The effect does not exist in any of the experimental conditions, not even in the 0.2:0.8 conditions. In that condition, there was no task related reason for the allocation of attention towards the feature singleton; therefore, that allocation must have been unintentional. The position of an element in relation to the set is a feature that has been proven to be accessible unintentionally in this research; whether that unintentional processing is spatially parallel, is a question that cannot be answered by the present experiment.

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REZIME

# POSTOJI LI MOGUĆNOST DA SE SVESNO KONTROLIŠE STRATEGIJA PAŽNJE?

***Marjena Popović i Sunčica Zdravković***
Odsek za psihologiju, Univerzitet u Novom sadu

Glavni cilj ove studije je bio provera mogućnosti svesne kontrole primene različitih vrsta pažnje. Subjektima su prikazivani nizovi od pet slova. Svaki niz je imao metu: slovo koje je bilo različito od ostalih. Takođe, svaki niz je sadržao i slovo koje bi se izdvajalo po svojim fizičkim karakteristikama, u našim eksperimentima te karakteristike su bile boja i pozicija. Upotrebljavane su dve boje (crvena i zelena) i dve pozivcije (ispod i iznad niza).Ova jedinstvena fizička karakteristika (boja ili pozicija) je mogla da bude primenjena ili na metu ili na neko drugo od preostala 4 slova. Verovatnoća da jedinstvena karakteristika bude primenjena na metu je varirana u tri eksperimenta. U prvom je bila 50:50%, u drugom je bilo manje verovatno da je jedinstvena karakteristika na meti (20:80%), dok je u trećem eksperimentu bila veća verovatnoća da jedinstevena karakteristika bude na meti (80:20%). Konstalacija rezultata sugeriše da su ispitanici u sva tri eksperimenta vršili serijalno procesiranje. Međutim nisu uspeli u potpunosti da zadrže intencionalnu kontrolu nad rocesom pretrage.

***Ključne reči:*** *vizuelna pažnja, vizuelna pretraga, egzogena pažnja, endogena pažnja*

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