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THE EFFECT OF ATTENTIONAL LOAD ON CROWDING

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THE EFFECT OF ATTENTIONAL LOAD ON CROWDING

Crowding is a phenomenon of peripheral vision which impairs the ability to individuate an object surrounded by flankers. There has been a long-standing controversy in the literature between theories supporting or denying the role of attention in crowding. In our study, we present a new experimental approach to address this issue. It is based on a dual-task paradigm allowing us to manipulate attentional allocation towards or away from the crowded stimuli. It was expected that attentional load under a multiple object tracking task would impair the recognition of the target ring presented in the periphery both when the target was presented alone or when it was flanked. The results from the experiment support neither the role of attention in the crowding effect nor in a clear recognition of peripheral stimuli.

JEL Classification: Z

Keywords: crowding, peripheral vision, attention.

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Introduction

Crowding is a phenomenon of peripheral vision that impairs the ability to individuate an object surrounded by flankers (Fig.1; Intriligator & Cavanagh, 2001; Whitney & Levi, 2011). There has been long-standing debate about why people experience uncertainty in the perception of a peripherally flanked object. Two main lines of research can be extracted from the literature on the crowding effect.

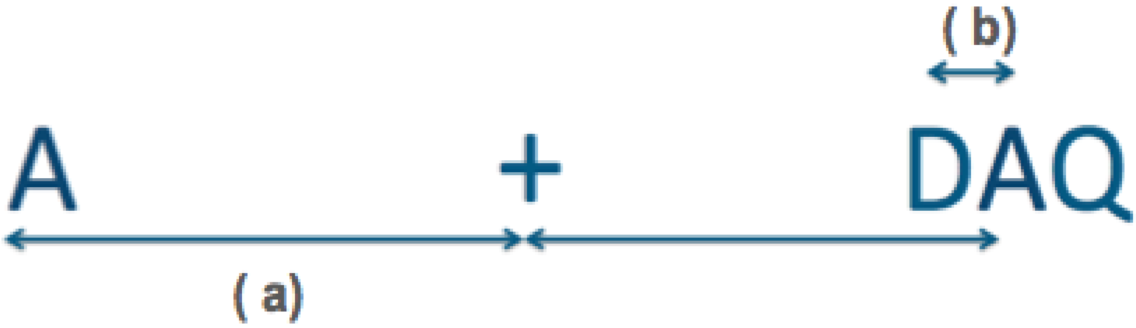

Figure 1. The demonstration of crowding effect. If you keep your eyes fixated on the cross at the distance of 40 cm from the image, then it will be easier to see letter “A” on the left side than the same letter with the same eccentricity but with surrounded distractors “D” and “Q”. Eccentricity (a distance between the letter and the point of fixation (a)) and critical spacing (a distance between the target and a flanker (b)) are shown on the image.

The first line of research claims that crowding reflects the structural limitations of the visual system. The size of the receptive fields (for example, in the V1 and V4 areas of the visual cortex) increases with eccentricity, which decreases the spatial vision of stimuli because only one receptive field will process several objects (Flom, Heath, & Takahashi, 1963; Flom, Weymouth, & Kahneman, 1963; Motter, 2018). There is a variety of research on the physiological locus of the crowding effect (see Coates & Chung (2016) for review).

The second line of research postulates that crowding occurs because of attentional limitations, not only the anatomical constraints of the visual field. For instance, Kahneman and Henik (1977) emphasized the role of attention (specifically, the ability to spread attention) in the recognition of objects surrounded by flankers. This idea was proposed because of the inability to interpret the experimental results solely in terms of the anatomical constraints of the visual field (Wolford & Chambers, 1983). Strasburger, Harvey, and Rentschler (1991) revealed that participants made localization errors at an eccentricity of 4 degrees: they reported distractor information instead of reporting target information. They interpreted this observation as the inability of participants to direct the focus of spatial attention to the target location in the visual field (Strasburger, Harvey, & Rentschler, 1991). Using a similar paradigm Nazir (1992) obtained evidence for the opposite: crowding did not depend on attention. In their seminal study, Cavanagh, He and Intriligator (1999), however, demonstrated that crowding did not affect low-level selective sensory adaptation but impaired the identification of feature conjunctions (which are supposed to require focused attention for feature binding, Treisman and Gelade (1980)) more than separate features (which are supposed to be processed without attention). This led He et al. (1996) to conclude that crowding might have to do with the limited spatial resolution of attention.

Thus, the contradiction between the empirical evidence raised in the two lines of research was mostly implemented within the cueing paradigm. The first line demonstrates that a cue affects object recognition (Freeman & Pelli, 2007; Strasburger, 2005; Yeshurun & Rashal, 2010), whereas the second line of experiments shows no or little cue effect on object recognition (Scolari et al., 2007; Wilkinson, Wilson, & Ellemberg, 1997). In another study Malavita, Vidyasagar and McKendrick (2017) did not reveal a correlation between attention and crowding; however, as the authors themselves mentioned, their empirical data could be only indirect evidence that attention has no role in that phenomenon. The controversy between empirical results is the current research problem.

Implementing a more relevant paradigm is a possible way to resolve the problem. The experiments in the crowding effect literature were done mostly within the cueing paradigm and there are some difficulties that could lead to controversial empirical results. Firstly, it seems that peripheral cues could impair the perception of target stimuli because they can cause additional crowding of the target. Secondly, the rapid succession of a cue and a target set of items could lead to illusory conjunctions between these two events (Treisman & Schmidt, 1982). Thus, it seems that this approach cannot provide sufficient evidence to resolve the problem of attentional engagement in crowding. A different approach is necessary.

The dual-task paradigm is where participants have to perform two tasks simultaneously (Egeth & Kahneman, 1975). Treisman successfully applied this method to reveal the role of attention in correct feature integration (Treisman & Schmidt, 1982). In their experiment the load of attention was varied while performing the secondary task (i.e. defining the shape and color of visual objects). It was revealed that in the condition of high attentional load there were more illusory conjunctions which lead to the conclusion that attention plays a role in correct feature integration (Treisman & Schmidt, 1982). This is not the only case when the dual-task paradigm showed its efficiency in revealing the role of attention in perception. It was used to demonstrate whether visual attention is required for pop-out visual search (Joseph, Chun, & Nakayama, 1997) and natural scene perception (Cohen, Alvarez, & Nakayama, 2011; Li, VanRullen, Koch, & Perona, 2002; Walker, Stafford, & Davis, 2008). There is also research on the role of working memory load on selective visual attention using the dual-task paradigm (Lavie, 2005; Soto & Humphreys, 2008; Zhang, Zhang, Huang, Kong, & Wang, 2011). It seems that the dual-task paradigm is a more useful tool to understand the role of attention in the phenomenon than the cuing paradigm which was mostly used in the crowding effect literature. The dual-task paradigm could allow us to understand whether attention plays a role in processes that underlie the crowding effect.

Multiple object tracking (MOT) is used as the primary task because the literature shows that it is one of the best tools truly load participant's attention (Cohen, Alvarez, & Nakayama, 2011). The peripheral recognition of the orientation of Landolt rings is the secondary task in terms of attentional load and one intended to probe the crowding effect. In spite of Bouma's law, that the critical spacing for letter recognition is half of the eccentricity in the periphery, there are still some differences in participants' critical spacing thresholds (Whitney & Levi, 2011). This means that there is a need to measure the crowding effect threshold for each person. As the ability to track multiple randomly moving objects also varies from person to person, it is necessary to measure the optimal speed of motion to tune the complexity of the task, otherwise, it could be that participants will waste different amounts of attentional recourses on the same task.

To sum up, this study demonstrates that the processes underlying crowding demand attentional resources. We expect that a MOT task (which would truly load attention) will amplify the crowding effect.

Methods

Participants

Twelve students from the Higher School of Economics (age: 19–21, *M* = 19.9; *SD* = .67) took part in the experiment. They reported normal or corrected-to-normal vision and no neurological or psychiatric conditions. They signed an informed consent form before the experiment.

Apparatus and stimuli

Stimulation was developed and presented through PsychoPy v 1.82.01 (Pierce, 2009) for Windows. Stimuli were presented on a Dell Latitude E6530, 1366x768 pixel spatial resolution, 15.6-inch screen, with a 60 Hz refresh frequency. The distance between the monitor and participants was 60 cm. The SMI Red-M eye tracker was used to control whether participants keep their eyes fixated on the cross which was presented in the center of the screen.

Landolt rings were used as stimuli in the matching task. They were presented on the periphery at an eccentricity of 17.5° Each ring could be oriented at 0°, 90°, 180°, 270°. The size of the rings was 1.65°.

Eight white randomly moving circles were the stimuli in the MOT task. They were moving in a 5.2° x 5.3° box. They were not allowed to collide. If they were very close to each other, they bounced apart. The size of the circles was 0.26°.

Procedure

The experiment began with psychophysical measurements of critical spacing and object tracking speed. Then there was a dual-task stage (a combination of the MOT task and the matching task). After that threshold measurements were repeated, and the dual-task stage was repeated with a new critical spacing threshold and with a new optimal speed for object tracking. Participants were not allowed to move their eyes away from the fixation point or blink during the tasks. If they did not follow this instruction, the current trial was terminated and feedback was given. In these cases, the terminated trial was rerun at the end of the experiment. The whole experiment lasted approximately 90 minutes.

<u>The measurements of the critical spacing for crowding</u>

This stage measured the critical spacing for crowding with the staircase method for each participant. A 3-down-1-up staircase rule with nine reversals was used. Three rings were peripherally presented for 100 ms. Another test-ring oriented up, down, to the right, or to the left was presented in the center of the monitor after presenting the three rings. If a participant thought that the orientation of the test ring was the same as the target, then he/she pressed "D" on a keyboard; "K" if the orientation was different. If the participant misrecognized the central ring, then the distance between the target and surrounded distractors increased on a next trial. If the participant made correct answers three times in a row, then the distance decreased (Fig. 2). After each trial, the text “blink” was shown. This meant that the participants could blink or not fixate their eyes on the cross. It was necessary to push the space bar to initiate a next trial. The mean value of the last six reversals was taken as the threshold estimate and was used in the main block of the experiment.

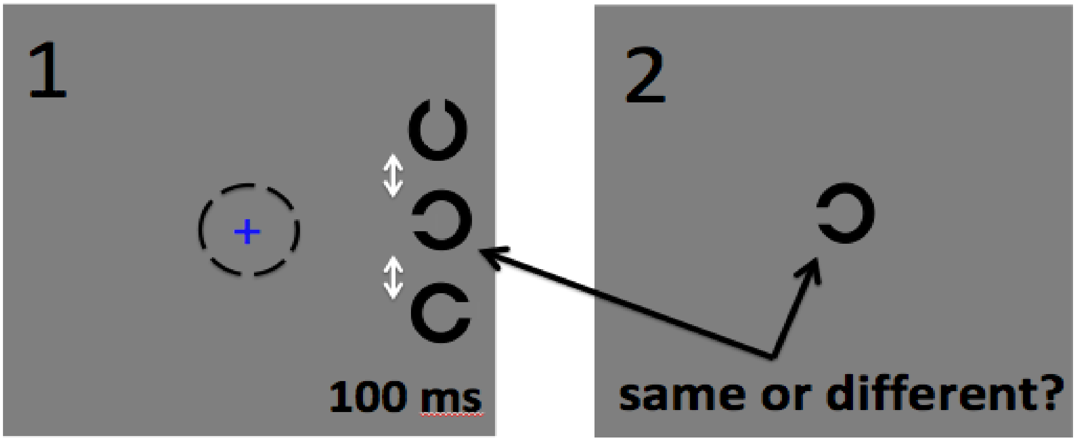

Figure 2. The procedure of the critical spacing threshold measurement sample. The white arrows illustrate the varying critical spacing. The dashed circle illustrates the allowed area for eye movements.

<u>The measurement of the optimal MOT speed</u>

This stage measured the optimal object tracking speed for the participants using the staircase method. The optimal speed is the speed at which the participant responded correctly 75% of the time. A 3-down-1-up staircase rule with nine reversals was used. At the beginning of the trial, eight white circles were presented for 1 second. Three random circles then were highlighted in green indicating MOT targets and returned to white. Then eight white circles moved for 2–4 seconds. When the motion stopped, one of the circles was highlighted in green. Participants had to indicate whether the highlighted circle was a target circle or not. If they thought that it was a target, they had to press "D" on the keyboard; "K" if it was a distractor. If the subject made an error then the speed decreased. If the subject answered correctly three times in a row then the speed increased (Fig.3). After each trial, the text “blink” was shown. This meant that the participants could blink or not fixate their eyes on the cross. It was necessary to push the space bar to initiate a next trial. The mean value of the last six reversals was taken as the threshold estimate and was presented when the stage was over.

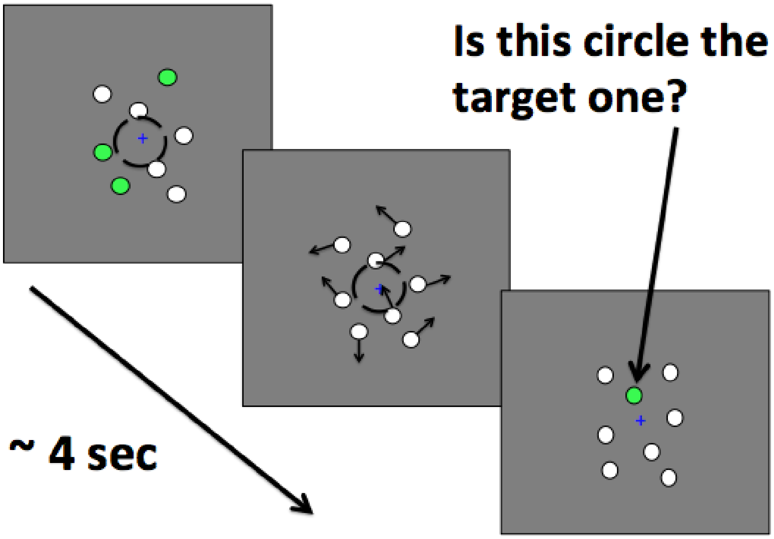

Figure 3. The procedure of the measurement of the optimal objects speed. The white arrows illustrate the varying critical spacing. The dashed circle illustrates the allowed area for eye movements.

<u>The dual-task stage</u>

There was a within-subject 2 (MOT load: No load = no tracked circles, Load = 3 tracked circles) x 2 (Crowding: Not flanked = 1 Landolt ring, Flanked = 3 Landolt rings) experimental design for the dual-task stage. The parameters from the previous two stages (the speed of the circles and the critical spacing between the target and flanker rings) were set up for this task and were re-measured and re-set up after 100 trials. There were 200 trials in total. The second part of the stage was a reverse repetition of the first one. In other words, we used counterbalancing to avoid sequence effects.

Participants were instructed to track circles if three circles were highlighted at the beginning of the stage. One or three rings were presented in the periphery. After that participants had to report on the target circle first and then complete the ring matching task. If there was no load condition then participants were instructed not to track circles and press “L” when the motion stopped (Fig 4.).

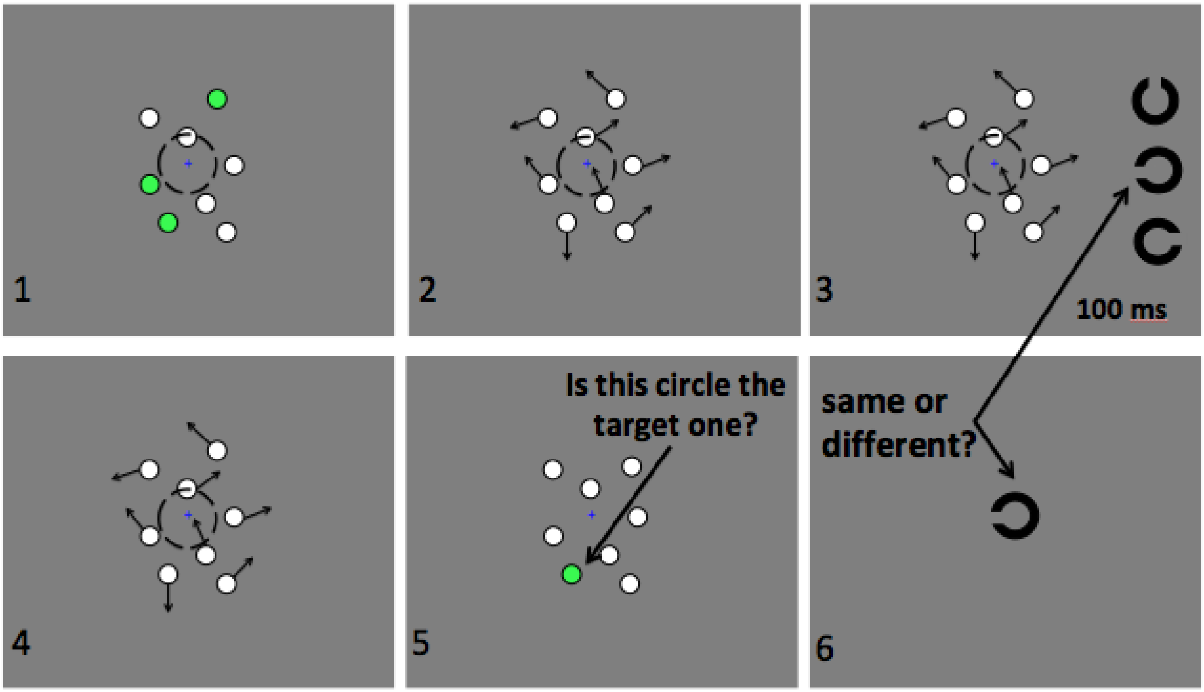

Figure 4. The figure illustrates the condition with 3 periphery Landolt rings with random orientation and with multiple objects tracking task. 1) presentation of the target circles for 2 seconds. 2) the start of random motion. 3) presentation of Landolt rings for 0.100 sec. 4) the motion is continued. 5) participants have to report if the object is a target one. 6) participants have to report if the orientation of the presented ring is the orientation of the central ring, which was presented earlier.

<u>The single Landolt ring stage</u>

This stage estimated the adequacy of the selected eccentricity. The procedure is similar to the procedure in the critical spacing threshold measurement stage except that there was no staircase method and only one ring was presented in the periphery. There were 52 trials. If the accuracy was less than 75%, the subject's results were excluded. Participants ran the stage at the beginning and at the end of the experiment.

Results

A two-way ANOVA test was used to evaluate the significant differences in the accuracy between the conditions. The percentage of correct orientation recognitions in all four conditions of the dual-task were calculated. Only the trials where participants made correct responses in the MOT task were used for the analysis.

Eye-tracking results were not included in the analysis because the experimental script automatically excluded the trials where participants made saccades or blinked during the MOT phase of a trial.

A within-subject two-way ANOVA was performed to examine the influence of load and the number of rings on task performance. The statistical test revealed significant influence both of load ($F(1, 11) = 4.304$, p = .0439, $\eta_p^2 = 0.089$) and flankers ($F(1, 11) = 50.988$, $p < .001$, $\eta_p^2 = 0.537$). However, there was no interaction effect ($F(1, 11) = 0.731$, $p = 0.3973$, $\eta_p^2 = 0.016$; Fig. 5).

A post-hoc Tukey HSD test revealed significant differences between conditions Load & Not Flanked (*M* = 62.01, *SD* = 6.09) vs. Load & Flanked (*M* = 53.6, *SD* = 6.5; $p < .001$) and No Load & Not Flanked (*M* = 80.1, *SD* = 11.4) vs. No Load & Flanked (*M* = 62.01, *SD* = 6.09; *p* = .0003).

Statistical differences were not found between Load & Not Flanked (*M* = 76.6, *SD* = 13.8) vs. No Load & Not Flanked (*M* = 80.2, *SD* = 11.4; *p* = .824) and Load & Flanked (*M* = 53.6, *SD* = 6.5) vs. No Load & Flanked (*M* = 62.01, *SD* = 6.09; *p* = .1784).

The analysis did show significant differences ($t(11) = 2.801$ $p = .017$) between No Load with 1 ring (*M* = 80.1, *SD* = 11.4) vs. only one ring (*M* = 88.1, *SD* = 6.4), i.e. the condition where the MOT task was not presented in the center. Test revealed significant differences ($t(11) = 3.41$ $p = .006$) between Load & Not Flanked (*M* = 62.01, *SD* = 6.09) vs. only one ring (*M* = 88.1, *SD* = 6.4; Fig. 6).

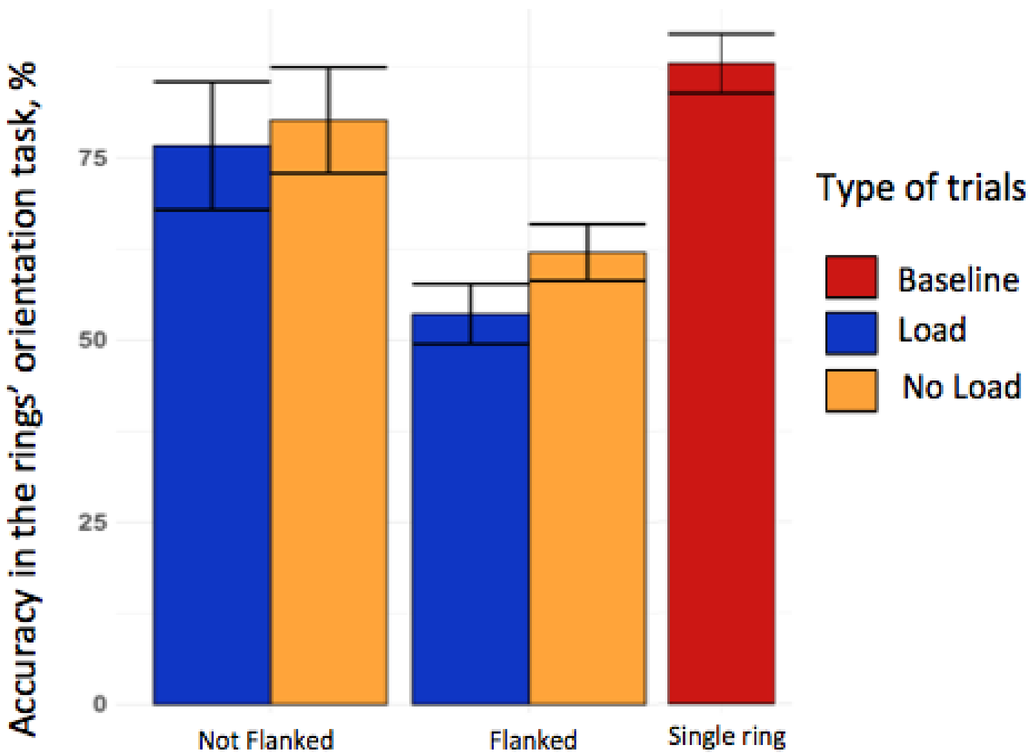

Figure 5. The results of the experiment are shown in the graph. The error bars illustrate 95% confidence interval.

Student's paired test revealed significant statistical differences between the first (*M* = 195.2; *SD* = 50.4) and the second (*M* = 142.5; *SD* = 40.7) critical spacing measurements ($t(11)=5.15$, $p = .0003$). However, there were no significant differences in the optimal MOT speed measurements ($t(11) = 1.89$, $p = .085$).

Discussion

This research tested whether processes that underlie the crowding effect demand attentional resources. We expected that attentional load under MOT will amplify the crowding effect. Nevertheless, the hypothesis was not confirmed.

We found that participants made approximately the same number of errors in the ring discrimination task in both the Flanked & Load and the Flanked & No Load conditions, which means that MOT did not amplify the crowding effect. This could indicate that attention does not play role in the crowding effect. These results support the conclusions from one line of research in the cuing paradigm (Freeman, Pelli, 2007; Strasburger, 2005; Yeshurun, Rashal, 2010). However, we should bear in mind two facts. First, the mean percentage of correct answers in the Flanked & Load and the Flanked & No Load conditions are close to the chance level (57.692 and 58.144, respectively), which means that we cannot draw strong conclusions from the data. Secondly, it seems that the chosen staircase parameters were not efficient in the critical spacing threshold measurements, because the results demonstrate significant statistical differences between Flanked & No Load vs. Not Flanked & No Load and Flanked & Load vs. Not Flanked & Load. This means that participants experience crowding even with the measured optimal distance between the target Landolt ring and the surrounding flankers. If they do not experience crowding, then performance should be equally successful in the Flanked and Not Flanked trials for each load condition.

The study also revealed that participants make the same number of errors in the ring orientation task in both the Not Flanked & Load and the Not Flanked & No Load conditions, which means that MOT did not impair the recognition process even of the one stimulus was presented in the periphery. The data do not support the idea that central attention is involved in the recognition process of the peripheral vision, because there were no significant impairments in the Load and No Load conditions.

Further, the participants got used to the complexity of the matching task because there were statistically significant differences between the first and the second measurements of the critical spacing threshold. However, there were no statistical differences in the optimal MOT speed. This means that the critical spacing threshold improved the during experiment, which is not the case for the MOT tracking speed.

To sum up, the current study was an attempt to demonstrate the processes that underlie the crowding effect's demand for attentional resources. Despite the fact that the results from the experiment support neither the role of attention in crowding, nor in a clear recognition of peripheral stimuli, we could not draw strong conclusions. Thus, there is a need to develop experimental design in order to avoid floor effects and to use more efficient threshold measurements.

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