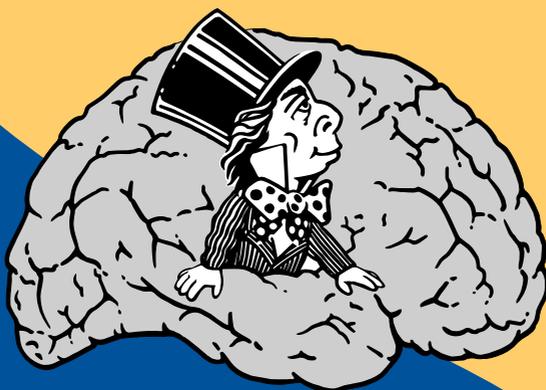


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## EYE-TRACKING INDICES OF MENTAL ATTENTIONAL LOAD IN CHILDREN AND ADULTS

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**Abstract.** Eye tracking is a non-invasive method that has proven invaluable in studying attention, cognitive control and other higher order mental processes. The term mental attentional capacity was introduced by Juan Pascual-Leone in the Theory of Constructive Operators within the framework of a neo-Piagetian approach to cognitive development, where it is also known as the M-operator. It corresponds to the number of schemes that can be maintained and processed in the focus of mental attention (MA) and thus could be interpreted as a maturational component of working memory. To our knowledge, no eye tracking studies have been conducted so far with parametric measures of mental attentional capacity, which involve evaluating the effect on mental attentional load on eye movements. In the current study, groups of adults and children completed all levels of MA load in two interference conditions (high and low). The results of this study show that the eye movements of adults and children during a cognitive task are affected differently by MA load.

**Keywords:** eye movements, mental attentional capacity, working memory, cognitive load, inhibition, development, children

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The term Mental Attentional Capacity was introduced by Juan Pascual-Leone in the Theory of Constructive Operators within the framework of neo-Piagetian approach to cognitive development, where it is also known as the M-operator (Pascual-Leone, 2011). It corresponds to the amount of schemes, that can be maintained and processed in the focus of mental attention and thus could be interpreted as a maturational component of working memory (Arsalidou et al., 2010). Measures of mental-attentional capacity that ensure a linear increase in task-difficulty across levels without an increase in need for executive control have been developed specifically for use in developmental science. The colour matching task is a parametric measure of mental attentional capacity developed by Arsalidou et al. (2010) and later replicated by Powell et al. (2014) which has six (6) levels of difficulty and two versions (low-interference “Balloons” and high-in-

terference “Clown”). Specifically, measures of mental attentional capacity have parametric levels of difficulty, unchanging executive demand across levels and are characterized to be culture fair because they have minimal language requirements (Arsalidou & Im-Bolter, 2017). In both versions of the colour matching task the goal of the player is to compare the colours they see in the picture to the colours they saw in the previous picture and press a button to indicate whether the colours are the same or different as quickly and as accurately as possible, disregarding the position of the colours. The levels of difficulty correspond to number of colours to hold in mind and compare (i.e. there is one relevant colour that participants need to remember in level one (1) and six relevant colours in level six (6)). The second version of the task is proposed to be more difficult with the inclusion of interference due to the fact that participants need to additionally ignore the information about which item of clothing the colours were associated with, which requires executive inhibitory control.

A small number of studies have investigated the relation between eye-movements and cognitive processes related to working memory and inhibition in developmental populations. Due to the complexity of the topic the majority of the studies were conducted within different theoretical paradigms, accessing different but conceptually related constructs, such as interference skills, inhibitory control, executive attention and cognitive control. Overall, research into the relation between eye movements and mental attentional capacity across development is sparse and fragmented, due to differences in theoretical approaches and use of unique combinations of eye-tracking indices and working memory tasks. Moreover, to our knowledge, no eye tracking studies have been conducted so far with parametric mental-attentional capacity measures.

While the current study was largely exploratory, several specific predictions were made. We expected that increase in task difficulty corresponding to an increase in mental attentional load will be associated with an increase in number of fixations (for use of saccades and fixations as a measure of mental effort see review Eckstein et al., 2017) and a corresponding decrease in duration of fixations for adults. For children we expected the number fixations to increase as a function of difficulty and decrease as a function of age (i.e., children would show more fixations than adults). We also expected an increase in the number of fixations in high interference condition as compared to low interference, which would reflect additional cognitive demand.

## Method

A total of 53 participants were recruited for the present study. The adult group consisted of 35 participants (mean age = 22.8, range 18 – 35,  $SD = 4.1$ , 17 male) and the children group of 18 participants (ages 8 – 9, grades 3 and 4). Data from several participants were discarded from analysis due to technical problems during data recording and the eventual sample included 48 participants (33 adults, 15 children). Participants were invited to complete a series of trials in the Colour Matching Task after a detailed verbal explanation of the task, which strictly followed a set script. During this task their eye-movements were recorded with the

use of The EyeLink Portable Duo (SR Research) recording at frequency 1000 Hz in remote head-free-to-move mode. Prior to each experimental task for both versions of CMT, calibration for the pupil was done for 9 points and colour-blindness was ruled out for all participants. After completing the task participants were also asked to complete a short questionnaire, detailing their strategies for performing the task successfully. The adult participants completed the task in the laboratory while the children completed the task at school.

## Results

ANOVA revealed no significant effect of condition (e.g. high or low interference) on fixations both for adults and children. However, significant effect of level of mental attentional demand on fixations was found for both age groups. For adults a significant effect of difficulty level was found for both number of fixations participants made ( $F = 50.05$ ,  $p = .0003$ ,  $\eta^2 = .967$ ) and fixation duration ( $F = 28.081$ ,  $p = .001$ ,  $\eta^2 = .939$ ) was found and was followed up by post-hoc Tukey HSD tests. For both variables significant differences were observed between lower (level 1 and level 2) and higher levels (levels 4–6) of difficulty.

Similar to adult data, no significant main effect of condition (i.e., Balloons vs Clowns) was observed on the number and duration of fixations. A significant effect of difficulty level for both amount of fixations that participants made ( $F = 5$ ,  $p = 6.39e-05$ ,  $\eta^2 = .141$ ) and fixation duration ( $F = 4$ ,  $p = .0009$ ,  $\eta^2 = .133$ ) was found and was followed up by post-hoc Tukey HSD tests. For the amount of fixations made and for duration of fixation significant difference was found between level 1 and all other levels of difficulty (2 to 6). Unlike the adult data, there was a difference between levels 1 and 2, and no other significant differences between levels were found.

Duration and number of fixations for every level are represented in Figures 1 and 2. Additional ANOVA conducted to test for effect of age group found significant difference between them for both number and duration of fixations.

## Discussion

Effect of level was expected in this study and appears to follow the hypothesis, with number of fixations gradually increasing with mental attentional demand and duration of fixations decreasing complimentary for the adult group. Interestingly, for children the trend was different: number of fixations increased sharply after the first level of difficulty and then remained more stable. Contrary to our predictions no main effect of level of interference was found in terms of eye-moment indices. A tentative explanation could be offered from accuracy and M-scores data that in the present sample of adults effect of increased mental attentional load (levels 4–6) interfered with condition effect, meaning that participants found higher levels of low-interference version of CMT roughly as difficult as higher levels of high-interference. Alternatively interferences effects may not be as strongly controlled by indices associated with eye-movements at least in higher levels, but instead they may be associated with aspects of executive control. Further research into this effect as a function of difficulty level may inform this interpretation.

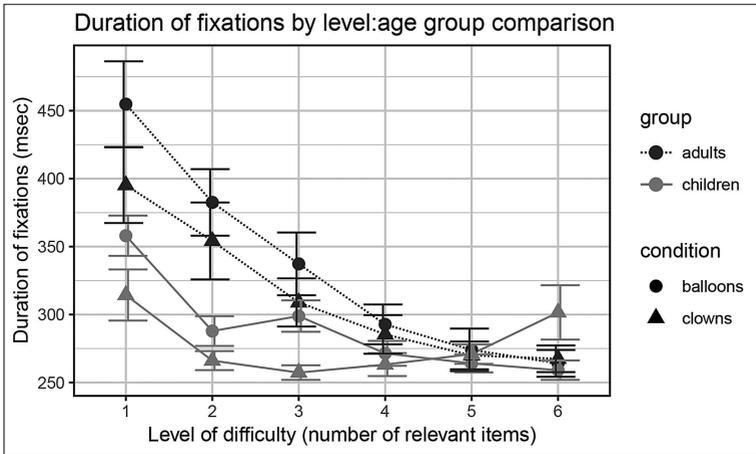


Figure 1. Duration of fixations by level: age group comparison.

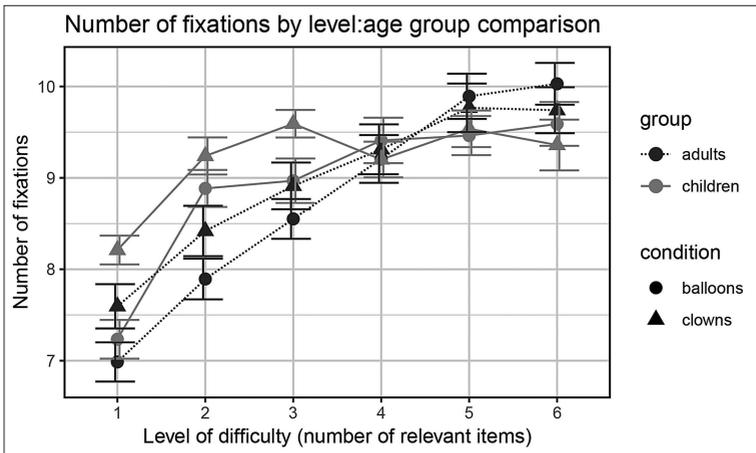


Figure 2. Number of fixations by level: age group comparison.

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## **ОКУЛОГРАФИЧЕСКИЕ КОРРЕЛЯТЫ ЗАГРУЗКИ ПРОИЗВОЛЬНОГО ВНИМАНИЯ У ДЕТЕЙ И ВЗРОСЛЫХ**

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**Аннотация.** Метод отслеживания движений глаз, также известный как окулография или айтрекинг – это неинвазивный метод, активно используемый при изучении внимания, когнитивного контроля и других высших психических функций человека. Термин «объем произвольного внимания» был введен Хуаном Паскуаль-Леоне в теории конструктивных операторов в рамках неопиажетианского подхода к когнитивному развитию, где он также известен как М-оператор. Объем произвольного внимания соответствует количеству схем, которые могут поддерживаться и обрабатываться в фокусе произвольного внимания. Произвольное внимание можно соотнести с центральным компонентом рабочей памяти (РП). Насколько нам известно, до сих пор не проводились окулографические исследования с параметрическими показателями объема произвольного внимания, которые учитывали бы эффект интерференции в задачах на РП и позволили бы дифференцировать влияние интерференции и когнитивной нагрузки на движения глаз. В текущем исследовании группы взрослых и детей проходили тестирование всех уровней загрузки произвольного внимания в задаче на РП в двух условиях интерференции (высокая и низкая). Результаты данного исследования показывают, что движения глаз взрослых и детей во время выполнения задания на РП по-разному зависят от когнитивной загрузки и интерференции.

**Ключевые слова:** окулография, движения глаз, произвольное внимание, рабочая память, развитие, дети

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