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Research Article

The Müller-Lyer Illusion in Primary School-Aged Children with Neurodevelopmental Disorders and Their Peers with Typical Neurodevelopment

Elena A. Tolmacheva[1*], Marina Y. Maximenko[2], Irina G. Skotnikova[3]

[1, 3]Institute of Psychology Russian Academy of Sciences, Moscow, Russia

[2]SBEI School, Moscow, Russia

***Corresponding author:** Elena A. Tolmacheva, Institute of Psychology Russian Academy of Sciences, Moscow, Russia

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Abstract

Relevance. This article is devoted to investigation of the development of the visuo-spatial cognitive function in children with neurodevelopmental disorders. A classical psychophysical approach using geometrical-optical illusions, in particular the Müller-Lyer illusion (MLI), provides a unique and valuable test to assess visuo-spatial perception in both children and adults. **Objective.** The purpose of this study was to investigate vulnerability to the MLI in primary school-aged children with neurodevelopmental disorders compared to their typically developing peers. **Methods and materials.** Participants were 30 children with neurodevelopmental disorders aged 11-12 years and 38 children with typical neurodevelopment aged 9-11 years. Prior to the test with the MLI children had to perform a control test on precision in standard line-length estimation that helped them to focus attention and adapt to working at the computer. Quantitative measurements in both tests were performed with the use of the interactive computer software. **Results.** It was established that children with neurodevelopmental disorders are more vulnerable to the MLI compared to their peers with typical neurodevelopment. In the standard line-length estimation test, no significant difference in precision was found between the groups, although children with neurocognitive deficits had a significant decrease in precision in the last set of trials that might be a sign of mental exhaustion. **Conclusions.** The data obtained emphasizes a substantial deficit in visuo-spatial perception in children with disorders in neurodevelopment and give evidence to propose that the MLI test, when quantitatively measured by the method of adjustment, may serve as a valuable diagnostic tool for assessing visuo-spatial functions in primary school-aged children.

Keywords: Vision; Visuo-Spatial Perception; Precision; Quantitative Measurements; The Müller-Lyer Illusion; Neurodevelopmental Disorders

Introduction

Vision and visuo-spatial perception are fundamental cognitive processes for human mental development. A selective deficit in the visuo-spatial cognitive function is regarded as one of the major factors that may affect a child's well-being and lead to neurodevelopmental disorders [10]. However, this issue has been studied far less than other cognitive domains such as verbal functions, memory, attention and learning. Geometrical-optical illusions represent a unique visual phenomenon in which the perceived geometrical properties of the corresponding object or visual scene differ from the objective reality. A classical psychophysical approach uses geometrical-optical illusions to assess visuo-spatial perception in both children and adults. The Müller-Lyer illusion (MLI) is a well-known geometrical-optical illusion, first described by German psychiatrist Franz Carl Müller-Lyer in 1889 year [18]. A classical configuration of the MLI is

depicted on Figure 1. The classical theory on the origin of the MLI proposed by [7] was based on the idea of "inappropriate constancy scaling" or, in other words, the neural mechanisms underlying inappropriate scale selection in visuo-spatial perception. Under natural conditions these mechanisms ensure a proper perception of the objects on the visual scene regardless of their distance, but lead to an optical illusion in an artificial situation.

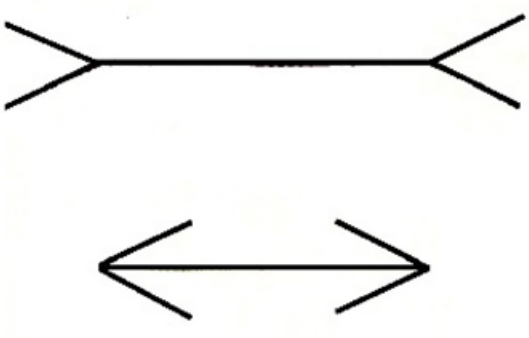


Figure 1:A classical configuration of the Müller-Lyer illusion.

Developmental aspects of vulnerability to the MLI in children compared to adults have been empirically investigated since the beginning of the 20th century [21]. A new round in studies of the illusory effects in visuo-spatial perception became possible with the advent of computer technology and software allowing more precise quantitative measurements of the illusory distortions. To the best of our knowledge, the first experiments where the illusory effects in children were measured with the use of interactive computer software have been performed by Rozgkova, Ognivov and colleagues (2005, 2006). These studies have revealed that primary school-aged children are more vulnerable to the MLI compared to young adults aged 17-25 years. This difference has been more pronounced than when it was measured using paper-based stimuli. A higher resistance to the MLI in adults was assumed to be due to cognitive neurodevelopment and maturation of the cortical mechanisms underlying the visuo-spatial cognitive function. Brosvic and colleagues (2002) have studied vulnerability to the MLI in participants aged from 3 to 20 years and revealed that its dynamics are largely asymptotic and reach the adult level at the age of 13-15 years. Similar results were consistently found in other studies [15-27].

The first study of the MLI in children with dysontogenesis [9] has found that Form A (arrowheads pointing out) and not Form B (arrowheads pointing in) changed in strength when age was varied from 8-18 yrs in children with typical neurodevelopment and in comparison to children with intellectual disability (formerly called mental retardation). Recently, it has been found that the enhanced vulnerability to the MLI is characteristic of primary school-aged children and teenagers with attention deficit hyperactivity disorder (ADHD) [13], while no difference in sensitivity to the MLI has been shown for children with specific learning disorder compared to their typically developing peers [13]. ADHD is a complex neurodevelopmental condition that is primarily the result of either a deficit in the neurodevelopment of the frontal and/or posterior regions of the left and right cerebral hemispheres or a dysfunction in the ascending reticular activating system [29]. Therefore, a disadvantage of these data is that they provide mixed results regarding brain neuronal mechanisms. Research on deficits in visuo-spatial functions in children with autism spectrum disorder (ASD) also yields mixed and sometimes contradictory findings [8-13-14]. The main reason is that ASD is a disorder with heterogeneous etiology that may or may not be co-morbid with various neurocognitive deficits, e.g. in visuo-spatial perception. In addition, grouping participants from early childhood to early adolescence obscures the diverse cortical development trajectories of autistic children compared to their neurotypical peers.

The present study was aimed to investigate the MLI in primary school-aged children with specific neurodevelopmental disorders in comparison to their peers with typical neurodevelopment. Our hypothesis was that children with neurodevelopmental disorders are more vulnerable to the MLI. The age period of 9 to 12 years old - late childhood or the "pre-teen" years - represents the most appropriate timeframe for studying the visual-spatial cognitive function development, when a deficiency in both cognitive processes and control and programming functions of the frontal lobe are most clearly manifested.

Materials and Methods

Participants: We have investigated 68 children (27 of them boys and 41 girls) 9-12 years old attending the local primary school. There were 30 children (12 boys and 18 girls) with specific neurodevelopmental disorders 11-12 years old and 38 children with neurotypical development (15 boys and 23 girls) 9-11 years old. The diagnostic procedure was based on medical and psychological assessments and conclusion of a consilium that included a child psychiatrist, a neurologist, a psychologist, a speech therapist and a defectologist. This specific category of children had residual organic impairments of the central nervous system due to hypoxia or a birth trauma without severe intellectual disabilities or motor disorders. All of these children had learning difficulties in different subjects, a reduced work capacity and a rapid exhaustion. These children studied according to the basic general educational program adapted to specific children's learning difficulties. Participants were excluded from the experiment if they had any ophthalmologic disorders or motor limitations that might affect the results of the tests. We have excluded two participants with strabismus.

Materials: The quantitative measurements of the illusory distortion in the MLI test were obtained via the classical psychophysical method of adjustment, where the subjects adjust the comparison stimulus back and forth around the point of subjective equality, thereby minimizing movement error arising from ascending and descending trials [16]. We used the special interactive computer software that allowed adjusting the length of the test line (TL) in order to make it equal to the reference line (RL) in the stimulus configuration on the screen to obtain the quantitative data on illusory distortion in the MLI test [20-23]. The same procedure was used for measurements on precision in the standard line-length estimation test. The stimuli configurations were presented on the screen at four consecutive orientations (I-IV), as shown in Figure 2.

Subjects viewed the stimuli binocularly and a viewing distance was approximately 50-60 cm. Stimuli were located in a 140 x 140 mm area and presented either horizontally or vertically on the middle of the screen of the monitor (SAMSUNG, 17 inches in diagonal). In the templates for displaying the MLI the angle between the stem-line and the wings was 24˚, while the length of each wing was 15 mm. The distance between the two stem-lines on the screen in all samples was 35 mm. The angle size of the displayed visual stimuli was 18-20 degrees that corresponds to the location of the stimuli in the central part of the visual area.

Testing procedure: Prior to the test with the MLI children had to perform a control test on a precision in standard line-length estimation that helped them to adjust and focus attention and adapt to working at the computer. So there were two series of twenty comparison stimuli - **one for the control test and one for the MLI test -** each consisting of four sets of five trials. Comparison stimuli were presented on the screen consecutively at four different orientations in the configuration of the stimuli (I-IV), as shown in Figure 2, in a fixed order across the four sequentially sets of trials. The initial length of the RL varied between 36 and 44 mm, while the TL varied between 43 and 56 mm, see Table 1. The initial difference in length between the TL and the RL in five consecutive trials was 8, 24, 0, 16 and 40 % and it was always fixed. The variation was necessary to prevent the habituation effect during the testing procedure.

The instruction given to the participants was the same for the both tests: "using arrows or [+], [-] bottoms on the keyboard to make the TL and the RL equal in length". Participants were given no feedback on their responses until the experiment was complete. In total, each participant performed adjustment in forty trials: twenty trials in the standard line-length estimation test and the same for the MLI test. The testing procedure lasted around 10-20 min. Results, computed automatically according to the formula (RL-TL)*RL/100, revealed the estimate of adjustment in each trial in percents.

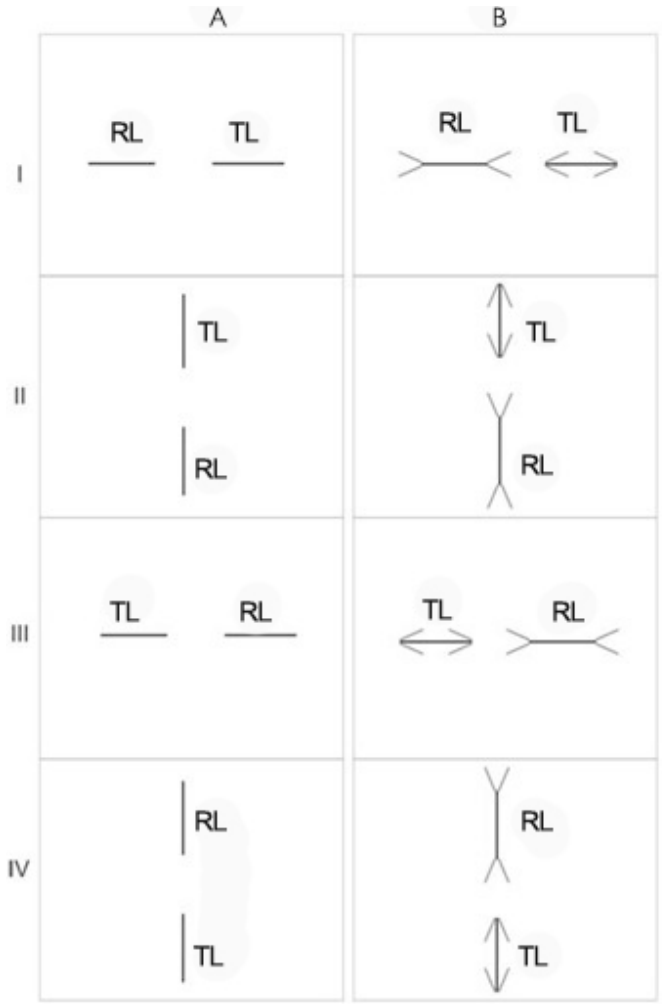


Figure 2:Templates for adjustment in (A) the standard line-length estimation test and (B) the Müller-Lyer illusion tests. I, II, III, IV – left/right and top/down orientations of the stimulus configuration.

RL – the reference line; TL – the testing line.

The Number of the trial	The Initial length of the RL, mm	The Initial length of the TL, mm
1	40	43
2	36	45
3	44	44
4	42	49
5	40	56

Table 1.The initial lengths of the reference line (RL) and testing line (TL) in the stimulus configuration that was kept fixed for five consecutive trials in each set of measurements for both the standard line-length estimation test and the MLI test.

Statistics and data analysis: The data are presented in percentages as the MEAN ± SE. We used absolute values when calculated the mean of the estimations for adjustment or inaccuracy in line-length estimations in the group, and the original values when calculated this parameter in line-length estimations for each individual. One-way ANOVA (4 levels) was used for statistical evaluations for repeated measurements with the subsequent pair-wise comparison for independent variables by Mann-Whitney U-tests and Wilcoxon signed-rank test for dependent variables. The level of statistical significance was set at 5% for all variables.

Results

The obtained results on the estimates of adjustments in both the standard line-length estimation test and the MLI test in four consecutive sets of five trials in the two groups of primary school-aged children are presented in Table 2.

Groups	Measure-ments	The Regular Lines Length Estimation Test				The MLI Test			
		Orientation				Orientation			
		I	II	III	IV	I	II	III	IV
Children with Neuro -Developmental Disorders (N=30)	MEAN	3,49	3,20	3,16	4,90#	38,7	42,2	42,1	38,7
	ST. ERROR	0,57	0,47	0,38	0,49	1,60	1,87	1,84	1,44
Children with Typical Neurodevelopment (N=38)	MEAN	3,05	3,41	3,68	3,12	27,7**	28,4**	27,6**	28,2**
	ST. ERROR	0,38	0,41	0,41	0,42	1,10	1,30	1,23	1,21

Table 2: The mean errors (in %) in the estimate of adjustment in the standard line-length estimation test and the MLI test in four consecutive sets of five trials (I-IV) in primary school-aged children with neurodevelopmental disorders (N=30) and their peers with typical neurodevelopment (N=38).

Statistical significance: # - indicates a significant difference between the two consequent measurements in the same group of children at $p<0.05$. ** - indicates a significant difference between the two groups of children at $p<0.001$.

The ANOVA for the repeated measurements has shown no significant group effect for precision in the standard line-length estimation test ($F_{group}=1.29$, df=1, 66; $p<0.259$). The ANOVA for the repeated measurements performed separately for each group has shown a significant effect of the order across the four sets of trials in the group of children with neurodevelopmental disorders ($F_{set}=3.1$, df=3, 87; $p<0.032$). The Wilcoxon signed-rank test has shown a significantly lower precision in the fourth set of measurements compared to the third one ($p<0.005$), that might be a sign of mental exhaustion or satiety of the current activity in the performance of children with neurocognitive deficits. The difference in the mean precision of measurements in the fourth set of the standard line-length estimation test between the two groups of children was around 2%. The results are depicted on Figure 3.

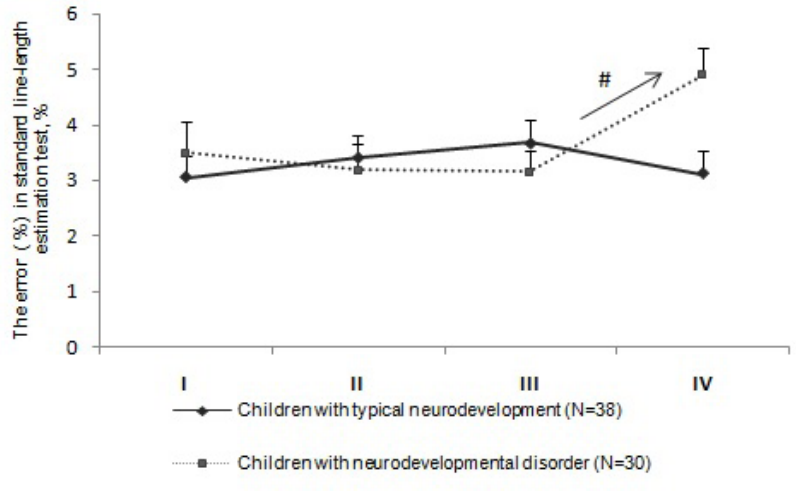


Figure 3:The mean errors in the estimate of adjustment in the standard line-length estimation test.

The ANOVA for the repeated measurements in the MLI test has revealed a significant group effect (F_{group}=58.9, df=1, 66; p<0.001) and no significant effect of the order of measurements. Mann-Whitney U-test performed separately for each set of measurements has shown that children with neurodevelopmental disorders are more vulnerable to the MLI compared to their peers with typical neurodevelopment and this effect was significant for each of the four (I-IV) sequential sets of trials (p<0.001). The mean magnitude of the illusory distortions (in percentages) across the four sets of measurements were: 38.7%±1.6, 42.2%±1.9, 42.1%±1.18 and 38.7%±1.4 in the group of children with neurodevelopmental disorders correspondingly and 27.7%±1.1, 28.4%±1.3, 27.6%±1.2 and 28.2%±1.2 in their peers with typical neurodevelopment. The data are depicted in Figure 4 and Table 3.

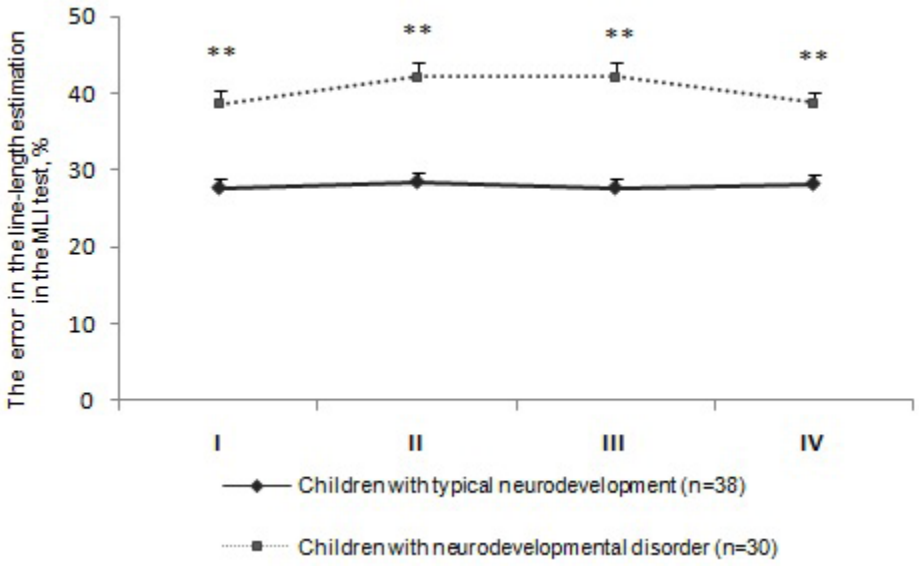


Figure 4:The mean errors in the estimate of adjustment in the Müller-Lyer illusion test.

Table 3. The mean magnitude of the illusory distortions (in %) across the four sets of measurements in the group of children with neurodevelopmental disorders (N=30) and their peers with typical neurodevelopment (N=38).

The Order of the Set of Trials in the MLI test	Children with Neurodevelopmental Disorders (N=30)	Children with Typical Neurodevelopment (N=38)
Set 1	38.7% ± 1.6	27.7% ± 1.1
Set 2	42.2% ± 1.9	28.4% ± 1.3
Set 3	42.1% ± 1.18	27.6% ± 1.2
Set 4	38.7% ± 1.4	28.2% ± 1.2

Discussion

This study provides evidence that primary school-aged children with specific neurodevelopmental disorders are more vulnerable to the MLI in comparison with their peers with typical neurological development. The obtained data revealed no difference in precision in the standard line-length estimation test between the two groups, although children with neurocognitive deficit were characterized by a significant decrease in precision in the last set of trials that might be a sign of mental exhaustion or satiety of the current activity.

[11] have shown that increased susceptibility to the MLI in psychiatric patients correlates to a decreased sensitivity to stereopsis and 3-dimensional percepts. Taking this data into account, the contrasting results obtained in the MLI test and the standard line-length estimation test may suggest diverse dynamics in the development of neural mechanisms underlying visual information processing in two-dimensional and three-dimensional visual scenes. In support, a steady increase in speed of binocular integration and a decrease in stereo vision thresholds were found in children from 7 to 15 yrs [26]. Furthermore, the other morphological study has revealed that the age of 9 –10 years (in girls) and 11–12 years (in boys) is a critical period where corpus callosum growth in posterior sections starts to dominate over growth in anterior section [12]. Considering that occipital and parietal lobes are involved in visuo-spatial perception, these data complete the claim of [6] that the neurodevelopment of stereoscopic capacity is nearly complete in children at 3 to 5 years.

Neuroimaging evidence localizes the neural substrate associated with the strength of the MLI bilaterally in the lateral occipital cortex as well as in the right superior parietal cortex [28]. A pure landmark task activated both the right posterior-parietal cortex and right temporo-occipital cortex. Event-related brain potentials (ERPs) have indicated activation of the anterior cingulate cortex and superior frontal cortex in combination with interactions within the visual and frontal-parietal cortices pointing to the high-level cognitive control in expression of the MLI [22]. [1] have shown that the magnitude of the MLI in adults correlates with local gray matter density in the parahippocampal cortex, but not in other brain areas.

In our previous study we have found a significant correlation between the vulnerability to the MLI and mathematical skills in children with typical neurodevelopment and no correlation with Russian language skills [25]. Interestingly, if symbolic number processing and children's arithmetic competence is thought to be related to the left intraparietal sulcus [4], numerosity and length processing is regarded to be located in the right intraparietal sulcus [5]. It has been suggested that impaired functional asymmetry and a deficiency of right-hemispheric and/or frontal lobe functions is one of the risk factors for an enhanced vulnerability to the MLI and the development of various types of deviant behavior in adolescence [24].

The present study highlights a deficit in the development of the visuo-spatial cognitive function, which is characterized by heightened susceptibility to the MLI regardless of precision in the standard line-length estimation test in primary school-aged children with neurodevelopment disorders compared to their peers with typical neurodevelopment. The obtained results suggest that the MLI test, when quantitatively measured by the method of adjustment, may serve as a valuable diagnostic tool for assessing visuo-spatial functions in primary school-aged children.

Data availability statement

The data that support the findings of this study are not openly available due to reasons of sensitivity and are available from the corresponding author upon reasonable request.

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