

Reading in Focus: Understanding ASD Reading Performance through Pupillometry and Cognitive Load.

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Abstract. This study aimed to evaluate the cognitive workload characteristics influencing reading performance among children with autism spectrum disorder (ASD) by examining variations in pupil dilation. A sample of 20 children with ASD, aged 5-13 years, exhibiting difficulties in reading fluency and displaying abnormal characteristics, participated in this research. Utilizing an eye tracker device with Tobii Studio 60, the study assessed cognitive workload through task performance and physiological measures, focusing on eye pupillometry as primary indicators. Reading materials, presented as images on digital cue cards combined into a video, were administered in the Malay language to each participant individually. Our results revealed significant differences in pupil dilation corresponding to low, moderate, and high cognitive workloads, suggesting a direct correlation between pupil dilation and the cognitive demands of reading tasks among children with ASD. Specifically, the one-way ANOVA indicated a significant variation in eye dilation scores (DF 2,12439=255.529, $p < 0.05$), with post hoc comparisons revealing marked differences between low, moderate and high cognitive workload levels. Additionally, a paired t-test comparison between left and right eye dilations underscored a significant disparity, further emphasizing the physiological nuances associated with reading challenges in this population. The study concludes that pupil dilation, as a non-invasive physiological measure, effectively reflects the cognitive workload during reading tasks in children with ASD. These findings offer profound implications for designing targeted interventions that accommodate the unique cognitive profiles of children with ASD, potentially enhancing reading ability and comprehension through tailored technological educational approach. The observed differences underscore the importance of considering individual variability in cognitive processing when addressing ASD reading difficulties need in the future.

Keywords: Cognitive Engineering, Neuroergonomics, Reading Cognitive Load, Eye Pupillometry, Autism Spectrum Disorder (ASD)

1. Introduction

Children with Autism Spectrum Disorder Condition (ASDC) often exhibit unique cognitive profiles that significantly impact their reading abilities. Understanding the specific cognitive factors that influence these abilities is crucial for the development of targeted interventions aimed at improving educational outcomes for these children. Autism Spectrum Disorder (ASD) is a neurodevelopmental condition characterized by deficits in social communication and the presence of repetitive behaviours and restricted interests. These characteristics often contribute to challenges in academic settings, particularly in reading fluency and comprehension [1]. Children with ASDC frequently display difficulties in decoding text, understanding syntax, and grasping the semantic content of reading materials [2]. These challenges are exacerbated by the cognitive load imposed by reading tasks, which can overwhelm their processing capabilities. Assessing cognitive workload is vital in educational contexts, as it provides insights into the mental effort required to perform tasks. Cognitive workload refers to the mental resources needed to carry out a cognitive task and can be influenced by the task's complexity and the individual's cognitive capacity [3]. In children with ASDC, understanding cognitive workload can help identify the specific demands that different reading tasks impose, thus guiding the design of interventions tailored to their unique needs [4].

The primary objective of this study is to evaluate the cognitive workload characteristics that influence reading performance among children with ASDC by examining variations in pupil dilation. Pupil dilation is a physiological measure that reflects cognitive workload, as it increases with greater mental effort [5,6] By using eye-tracking technology, this study aims to assess how different levels of task difficulty impact cognitive workload in this population. This study addresses two key research questions:

- How does pupil dilation correlate with cognitive workload in children with ASDC?
- Are there any differences in cognitive workload during reading tasks of varying difficulty? [7].

Understanding these relationships will provide valuable insights into the cognitive processes underlying reading in children with ASDC, offering a basis for developing more effective educational strategies and interventions.

1.1 Cognitive Workload and ASDC

The mental effort needed to comprehend information and complete activities is referred to as cognitive workload, and it varies greatly between people. Relating to ASDC children, the cognitive workload is often elevated due to the unique cognitive and sensory processing challenges they face [8,9]. Previous research has demonstrated that children with ASDC exhibit atypical patterns of cognitive workload during tasks requiring attention and executive function [10]. Designing successful educational interventions that can take into account the cognitive profiles of children with ASDC requires an understanding of these patterns. Adapting Tailoring educational content to reduce cognitive workload can enhance learning outcomes and improve task engagement for these children [11].

1.2 Pupil Dilation as a Measure of Cognitive Workload

Pupil dilation is a well-established physiological marker of cognitive workload. The autonomic nervous system regulates pupil size, which increases in response to heightened mental effort and cognitive workload [4]. Studies have shown that pupil dilation is sensitive to various cognitive demands, including memory load, problem-solving, and language processing [12,13]. In the context of ASDC, measuring pupil dilation can provide insights into the cognitive processes and difficulties experienced by children during reading tasks. This non-invasive measure allows researchers to quantify cognitive workload in real-time, offering a dynamic understanding of how children with ASDC manage cognitive demands.

1.3 The application of Eye Tracking Technology in Cognitive Workload Assessment

Technological developments in eye-tracking have revolutionized the study of cognitive workload. Eye trackers can accurately measure gaze direction, fixation duration, and pupil size, providing comprehensive data on visual attention and cognitive processing [14,15]. Tobii Studio is a widely used

eye-tracking platform that facilitates detailed analysis of eye movements and pupil dilation [16]. In cognitive research, Tobii Studio has been employed to investigate reading behaviours, attention patterns, and cognitive workload in various populations, including children with ASDC [17]. By integrating eye-tracking data with task performance metrics, researchers can gain a deeper understanding of the cognitive challenges faced by children with ASDC and develop targeted interventions to support their learning [18].

2. Methodology

2.1. Participants and Materials

This study included a group of 20 children diagnosed with ASDC, ranging in age from 4 to 13 years. The participants were specifically chosen based on their challenges with reading fluency and other features associated with ASDC. The sample consisted of both adolescents enrolled in national education and those who were not attending school, guaranteeing adequate representation. The exclusion criteria included sensory abnormalities that affected the ability to use eye-tracking technology. An individual testing was carried out in Malay to ensure linguistic consistency. The reading materials included visually appealing graphics on digital cue cards that were suitable for the reader's age. These materials were delivered in a video format to facilitate uninterrupted reading activities.

2.2. Procedure and Equipment

Figure 1 shows layout of experiment for the conducted experiment. Participants were assisted by their teacher and monitored by the researcher during the data collection of reading activities. The eye tracker was set up 60 cm from the participants with 0.5 degrees of accuracy and 60Hz average frequency. All participant were examined in closed room with calm environment. A 9-point calibration was conducted for each participant before the experiment start to verify the accuracy. The digital cue cards were presented as a video to the participants as they completed a structured reading activity as shown in Figure 2. The testing was conducted in a controlled laboratory environment, using the think-aloud usability testing method to gather qualitative data on from the participants' cognitive processes. During the test, the participants were encouraged to verbalize their thoughts, providing further findings into their cognitive load and comprehension strategies.

The performance measures included the time taken to complete each task on the computer, reflecting the efficiency and effectiveness of reading under different cognitive workload. According to Whiteside [18], these metrics can be empirically related to task performance: effectiveness (percent task complete), efficiency (time to complete task), time to learn, and time spent on errors. These measures provide a comprehensive assessment of the participants' reading abilities and cognitive work-load.

A Tobii Studio 3.4.8 eye tracker was used to capture eye gaze and pupil dilation data. This advanced eye-tracking system provides precise measurements of visual attention and physiological responses, critical for assessing cognitive workload.

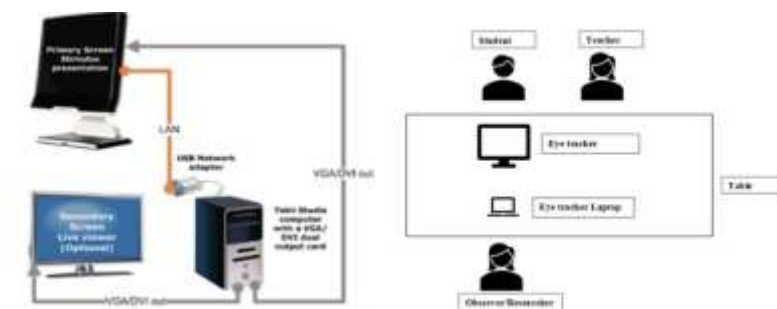


Figure 1. Layout of design experiment.

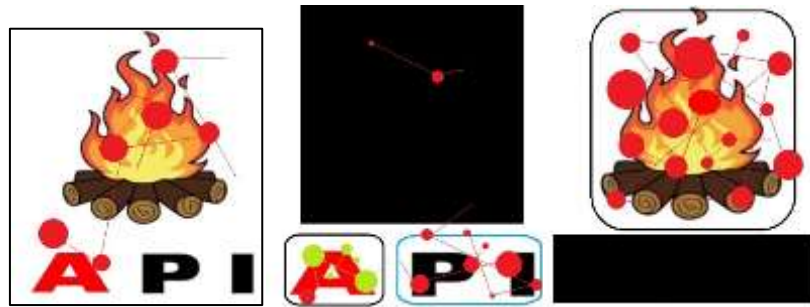


Figure 2. Digital cue card sample.

2.3. Data Collection and Data Analysis

Eye gaze and pupil dilation data were collected continuously throughout the reading tasks activities. The Tobii eye tracker recorded the size of the pupils and the direction of the gaze, providing a detailed information on the participants' visual attention and cognitive load.

The collected data were analysed using the statistical methods, including one-way ANOVA and paired t-tests. The one-way ANOVA assessed the variation in pupil dilation across different cognitive workload levels, while paired t-tests compared the dilation between the left and right eyes. Parameters measured included the degree of pupil dilation and the differences between the left and right eyes, which provide findings for the cognitive workload and potential asymmetries in cognitive processing.

By utilizing these rigorous methodologies, this study aims to elucidate the relationship between cognitive workload and reading performance among children with ASDC, providing a foundation for developing designed educational interventions.

Table 1. Characteristics of images and texts included in the experiment.

Levels	Low	Moderate	High
Low	Identifying Alphabets & Image	Spelling with two syllable & Image Identification	Image, Spelling & Fill in the blanks with three syllables
Moderate	Image & Words	Image & Spelling Identification with two syllables	
High	Image & syllable		

3. Results and Discussion

3.1 Pupil Dilation and Cognitive Workload Assessment

The data analysis of pupil dilation using one-way ANOVA revealed significant differences in eye dilation scores corresponding to varying levels of cognitive work-load during reading tasks among ASDC children. Additionally, the ANOVA results in Table 1 indicated a significant variation in pupil dilation across low, moderate, and high cognitive workload levels (DF 2, 12439 = 255.529, $p < 0.05$). These findings illustrate the relationship between pupil dilation and the cognitive demands of reading tasks, reflecting the increased mental effort required as task difficulty increases.

Table 2. A paired t-test left and right eye comparison.

Right	N	Mean	SD	F	Sig
Low	3625	3.201	0.370		
Moderate	6837	3.406	0.465		
High	1980	3.352	0.432	266.363	0.000
Total	12442	3.338	0.422		

DF=2,12441

This study considered multiple parameters, including activity, words, and syllables, to assess the cognitive workload. The pupil dilation data that collected using the Tobii Studio 60 eye tracker, were categorized into three levels: low, moderate, and high. These categories helped the researchers to identify how different levels of task difficulty will affect the cognitive workload, providing a nuanced understanding of the cognitive processes in children with ASDC.

3.2 Post Hoc Comparison

Post hoc comparisons using Dunn's multiple comparison test, due to violated homogeneity of variance (Levene's test $p < 0.05$), revealed significant differences in cognitive workload levels, with low pupil dilation scores (MD = -0.1733, $p < 0.05$) differing significantly from moderate/high scores (MD = -0.17114, $p < 0.05$). One-way ANOVA showed significant differences in left eye dilation across cognitive workload levels (DF 2, 12439 = 255.529, $p < 0.05$), with lower workloads (3.186 ± 0.312) leading to higher dilation than moderate (3.36 ± 0.409) and high (3.357 ± 0.431) workloads. Similarly, right eye dilation also differed significantly (DF 2, 12441 = 266.363, $p < 0.05$), with higher dilation at low workloads (3.201 ± 0.370) compared to moderate (3.406 ± 0.465) and high (3.352 ± 0.432) levels. Table 3 shows the results of a paired t-test indicated a significant difference between left and right eye dilation (df = 12506, $t = -23.579$, $p < 0.05$), with the right eye having a higher mean dilation (3.3429 ± 0.45) than the left eye (3.3146 ± 0.40353), suggesting asymmetry in cognitive processing during reading tasks.

3.3 Left vs. Right Eye Dilation

Analysis of pupil dilation for the left eye using one-way ANOVA showed the significant differences across in cognitive workload levels (DF 2, 12439 = 255.529, $p < 0.05$). The mean values for pupil dilation scores showed that, in comparison to moderate (3.36 ± 0.409) and high (3.357 ± 0.431) workload levels, lower cognitive workloads (3.186 ± 0.312) produced considerably greater pupil dilation.

Similarly, the right eye showed the significant differences in pupil dilation scores (DF 2, 12441 = 266.363, $p < 0.05$). The mean values for the right eye indicated higher pupil dilation scores at low workload levels (3.201 ± 0.370) compared to moderate (3.406 ± 0.465) and high (3.352 ± 0.432) workload levels.

Table 3. A paired t-test left and right eye comparison.

		Mean	N	SD	t	df	sig.
Pair 1	Left	3.3146	12507	0.40353			
	Right	3.3429	12507	0.44857	-23.579	12506	0.000

Table 3 indicates a paired t-test comparing left and right eye dilation. There was a significant difference (df = 12506, $t = -23.579$, $p < 0.05$). The right eye had a higher mean dilation score (3.3429 ± 0.45) compared to the left eye (3.3146 ± 0.40353). This suggests asymmetry in cognitive process during reading tasks, possibly reflecting differential cognitive workload management between the two eyes

4. Conclusion

The results of the study demonstrate how sensitive pupil dilation is as an indication of cognitive workload in children with ASDC. The significant differences in pupil dilation across different cognitive workloads imply that the cognitive demands rise with the difficulty of reading tasks, and this rise resulted in increased pupil dilation. This finding is critical for developing the educational interventions designed to the cognitive profiles of children with ASDC, as it provides a non-invasive measure to monitor and adjust cognitive workload during reading activities.

The study obtained accurate eye-tracking data by ensuring the subjects retained their visual cues during the reading assessment. The use of one-way ANOVA and paired t-tests as the statistical analysis provided robust findings, proving the study's objective to assess cognitive workload characteristics that affect reading performance among ASDC children through variations of pupil dilation examination. These findings may help the educational sectors and policymakers in strengthening strategies to enhance reading fluency and comprehension among children with ASDC by considering individual cognitive workload capabilities. This could potentially improve their reading skills and comprehension through a customized technological educational approach.

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