 doi:10.20944/preprints202103.0442.v1

Article

The Relation Between Physiological Parameters and Colour Modifications in text Background and Overlay During Reading in Children With and Without Dyslexia

Tamara Jakovljević [1, *], Milica M. Janković [2], Andrej M. Savić [2], Ivan Soldatović [3], Gordana Čolić[4], Tadeja Jere Jakulin [5], Gregor Papa [6] and Vanja Ković [7]

[1] Jožef Stefan International Postgraduate School, 1000 Ljubljana, Slovenia
[2] University of Belgrade - School of Electrical Engineering, 11000 Belgrade, Serbia; piperski@etf.rs (M.J.); andrej_savic@etf.rs (A.S.)
[3] Institute of Medical Statistics and Informatics, Faculty of Medicine, University of Belgrade,11000 Belgrade, Serbia; ivan.soldatovic@med.bg.ac.rs
[4] The College of Social Work, 11000 Belgrade, Serbia; gordana.colic22@gmail.com
[5] FTŠ Turistica, University of Primorska, 6320 Portorož, Slovenia; tadeja.jerejakulin@upr.si
[6] Computer Systems Department, Jožef Stefan Institute, 1000 Ljubljana, Slovenia; gregor.papa@ijs.si
[7] Laboratory for Neurocognition and Applied Cognition, Faculty of philosophy, University of Belgrade, 11000 Belgrade, Serbia; vanja.kovic@f.bg.ac.rs
[*] Correspondence: tamara.jakovljevic@hotmail.com; Tel.: +381-631210489

Abstract: Reading is one of the essential processes during the maturation of an individual. It is estimated that 5-10% of school-age children are affected by dyslexia, the reading disorder characterised by difficulties in the accuracy or fluency of word recognition. There are many studies which have reported that colour overlays and background could improve the reading process, especially in children with reading disorders. As dyslexia has neurobiological origins, the aim of the present research was to understand the relationship between physiological parameters and colour modifications in the text and background during reading in children with and without dyslexia. We have measured differences in electroencephalography (EEG), heart rate variability (HRV), electrodermal activities (EDA), and eye movement of the 36 school-age children (18 with dyslexia and 18 of control group) during the reading performance in 13 combinations of background and overlay colours during the reading task. Our findings showed that the dyslexic children have longer reading duration, fixation count, fixation duration average, fixation duration total, and longer saccade count, saccade duration total, and saccade duration average while reading on white and coloured background/overlay. It was found that the turquoise, turquoise O, and yellow colours are beneficial for dyslexic readers, as they achieved the shortest time duration during the reading tasks when these colours were used. Also, dyslexic children have higher values of beta and the whole range of EEG while reading in particular colour (purple), as well as increasing theta range while reading on the purple overlay colour. We have observed no significant differences between HRV parameters on white colour, except for single colours (purple, turquoise overlay and yellow overlay) where the control group showed higher values for Mean HR, while dyslexic children scored higher with Mean RR. Regarding EDA measure we have found systematically lower values in children with dyslexia in comparison to the control group. Based on present results we can conclude that both colours (warm and cold background/overlays) are beneficial for both groups of readers and all sensor modalities could be used to better understand the neurophysiological origins in dyslexic children.

Keywords: dyslexia; reading; children; background colour; overlay colour; text colour; sensors; physiological parameters; EEG; ECG; EDA; eye tracking

 doi:10.20944/preprints202103.0442.v1

1. Introduction

It is estimated that more than 10 percent of the world population is affected by dyslexia. Dyslexia is a learning disability whose main characteristics are difficulties with accurate or fluent word recognition of the neurobiological origin. It is also characterized by poor spelling and decoding abilities which results in problems in reading comprehension and reduced reading experience [1]. Developmental dyslexia is manifested by individuals who require special motivation and intellectual effort to achieve fluent reading and it is usually defined as an unexpected difficulty in reading [2,3]. The World Federation of Neurology recognizes children with dyslexia as those who, despite the common school curriculum, cannot attain reading, writing and spelling skills in proportion to their intellectual abilities. [4,5]. Although definitions and understandings of dyslexia vary, there is a general opinion that children who fail to accurately read need careful support and monitoring at an early school age. At that age, the most effective approach for children with reading difficulty is early identification and professional support which assists their needs [6-8]. For example, in Sweden children are being diagnosed with dyslexia only at the age of thirteen on average [9]. At the early-school age, it is not so difficult to mark the grade level of reading, but it is difficult to understand other problems which usually impede overall school achievements and cause emotional distress and lack of motivation [10,11]. Children who have this type of reading difficulty do not have difficulties in their general performance in other segments of the curriculum. Some of them may also have emotional difficulties [12-14]. Through early intervention, the risk of those difficulties may be reduced before they emerge in the 4th grade. In the research dedicated to the early indicators of dyslexia [15] children were monitored from preschool age to the end of the fourth grade of primary school. It is found that indicators of dyslexia can be isolated at preschool age. There is evidence that dyslexia can be prevented and predicted in early school-age children [16-18]. Today scientists are better able to understand the child's nervous system using functional neuroimaging and how it operates in the case of dyslexia [19].

There is good evidence that dyslexia has a neurological basis [20,21]. Namely, it may be reflected in the psycho-physiological states of the body during the reading task. Those neuro-physiological processes are measurable by different biosignals such as eye-tracking, brain waves, heart rate and electrodermal activity [22]. The present study is based on sensor technologies that monitor the neural, physiological, and behavioral processes during reading in children with and without dyslexia. Given that colours can affect the state of our body and emotions [23], the study investigates the relationship between physiological parameters and colour modifications in the text and background during reading in children with and without dyslexia. It is evident that colours have been used in reading performance in children with dyslexia in order to improve their skills and for other purposes [24-28] such as increasing reading fluency and speed. The so-called visual stress syndrome [29,30] is observed in dyslexic individuals very often, but the role of colour involvement during the reading performance remains controversial [31-35]. Recently, this concept has led to the broadened use of colored overlays to mitigate reading disorders and improve reading. It is reported that symptoms of visual stress [36] are caused by sensitivity to certain light frequencies. In practice, applications of colored filters have led to the use of lenses and overlays in reading. Colored overlays filter the light using plastic reading sheets tinted with color [37]. Many dyslexic subjects reported that colored overlays can them with widespread difficulties arising in the reading process [38-42]. Moreover, it has been reported, without taking into consideration children with dyslexia, that color overlays could improve the reading process in school-age children [43]. Further, other scientists [44,40] have shown that problems caused by dyslexia could be relieved by visual changes in the presentation of the reading text. Based on these studies, others have focused on designs of computer screen texts, where colour in combination with other parameters such as background, text colour or font size have been adjusted in order to help those with dyslexia [45,46]. These conditions have inspired Pinna and Deiana [47,48] to study how reading time and comprehension could be influenced by colours.

Based on the previous studies [49,50] and results, the main purpose of the present study is to extend previously established experimental protocol to children with dyslexia and to better understand the neurological basis of this disorder and its relation to the colours.

Aside from the use of colour overlays, it was also found that the use of different background colours [45] increased reading performance of subjects with dyslexia and has been recommended by the British Dyslexia Association [51]. In the current study we present the first research that measures the impact of 13 combinations of background and overlay colours on the reading performance measured by sensor hub (electroencephalography - EEG, electrocardiography - ECG, electrodermal activity - EDA, and eye-tracking). The main assumptions of this study are:

-Background and overlay colours have an impact on the readability of text for children with and without dyslexia in such a way that warm background colours are beneficial for readability for both groups' reading performance, whereas cool background colours decrease the text readability for both groups. On the other hand, warm and cold overlay colours are beneficial for readability for both groups' reading performance.

-All measures (eye-tracking, HRV, EEG, EDA) could be beneficial for better understanding the neurophysiological origin of the dyslexic children and their distinction from non-dyslexic children.

2. Materials and Methods

2.1. Subjects

Thirty-six participants took part in this study (18 with dyslexia, and 18 without dyslexia, matched according to gender and school grade). Children in the control group were randomly chosen from the second to sixth grade of three elementary schools in Belgrade. Children with dyslexia were selected from several elementary schools in Belgrade in coordination with a certified speech therapist. For the group of dyslexic children, inclusion criteria were that they have been diagnosed with dyslexia, and that they have a normal, or corrected to normal vision. For the control group of children, the inclusion criteria were that they have normal, or corrected to normal vision, no learning and reading disabilities or attention disorders. The exclusion criterion for both groups was presence of large artifacts in the acquired signals. In our sample, no such cases were observed. Also, no participants were excluded from the dataset from the statistical analysis, according to these criteria. The experiment was conducted in a classroom at the Faculty of Philosophy, University of Belgrade, where children participated individually under the same experimental conditions. Every child had received instruction from the researcher before the experiment (to read in silence, how to position their head at the chin rest, how to look at the external monitor etc.). After the reading test, the participants received a present (sticker and chocolate) and diploma. The collected data were fully anonymized. Only team members had access to the grade and gender of the children participating in the study. The research team has collected informed consent from the parents for the children's participation through speech therapists or school directors and teachers.

The experimental procedure was approved by the ethical committee of the Psychology Department of the University of Niš (a branch of the Serbian Psychology Association) No 9/2019.

2.2. Experiment Setup

During the experiment, participants were seated in front of the computer screen with a keyboard at the table, placing their head on the chinrest, making sure they were holding the same distance from the monitor. After the participants received instructions from the

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 17 March 2021 doi:10.20944/preprints202103.0442.v1

researcher, they read the story presented on the computer screen in silence. Stimuli presentation was launched by pressing the space button (self-paced reading). The stimuli presentation started with a paragraph with black text on a white background (as a referent slide) as school-age children are used to it in everyday life. After the referent slide, which would always appear at the beginning of the presentation, the following slides were presented in a pseudo-randomized order of background/overlay colours. Background colours were always presented with black text and overlays according to colour calculation in the section Experiment design of the previous study [22] (marked by O in further text, e.g. "blue O stands for blue overlay"). The story was divided into 13 paragraphs/slides, so the text on each slide was kept in the original order but in different colours (in order to avoid the effect of factors such as semantic or affective content, vocabulary, text complicity or syntax).

2.3. Experiment Design

Experimental design was exactly the same as in the [22] except for the difference laid out in the description of Figure 1 and Data processing part.

Figure 1 shows the sensor hub consisting of a portable multimodal ECG/EEG/EDA and eye-tracking system for acquisition of physiological data during the reading performance. Real-time monitoring and storage were at one laptop instead of two which was the case in the previous experiment design [22] because the system was synchronized by keyboard stream instead of the photosensitive sensor. The laptop was connected with an external keyboard and external monitor positioned in front of every child.

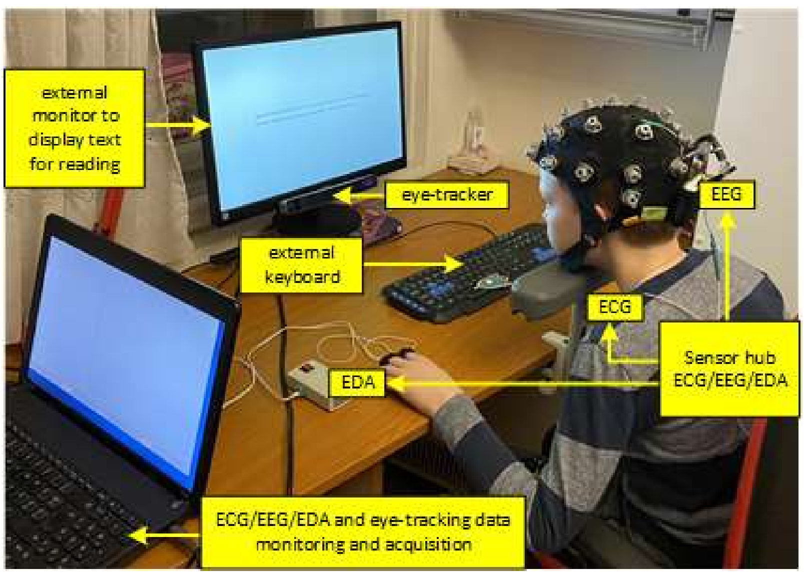

Figure 1. Sensor hub ECG/EEG/EDA computer for data acquisition, external keyboard and monitor, and eye-tracking system.

2.3.1. Data Processing

1) Offline EEG processing was applied on the dataset of all subjects. EEG signals of all subjects and channels were band-pass filtered (4th order Butterworth filter) to extract the EEG activity in the following 5 frequency ranges: Delta (0.5 - 4 Hz), b) Theta (4 - 7 Hz), c) Alpha (7 - 13 Hz), d) Beta (15 - 40 Hz) and e) broadband EEG activity (0.5 - 40 Hz).

Filtered signals of all channels were squared and segmented according to the keyboard event markers. Each epoch was associated with the reading of a single slide. For each subject, electrode site, frequency band and epoch, the median value of filtered and squared EEG was calculated in order to obtain single band-power values for each epoch. Calculating the median band-power over epoch duration is used to remove impulse-noise due to movements, blinks or other artefacts. Additional visual inspection of power epochs was conducted in order to ensure that the obtained median values represent the valid quantification of the band-power activity. Median power values of each slide/band were normalized by calculating the percentage change using the following equation:

$$Pc = (medP - medPt)/medPt$$

where Pc is the measure of power change for each band/slide, medP is the median value of power for band/slide and medPt the median value of power in frequency band for the whole recording.

2) Offline heart signal processing for extraction of heart rate variability (HRV) parameters in the time domain: a) Mean value of beat-to-beat intervals (BBIs) - Mean RR (ms); b) Standard deviation of normal BBIs - SDNN(ms); c) Mean value of heart rate - Mean HR (beats/min); d) Standard deviation of heart rate - STD HR (beats/min); e) Coefficient of variance of normal BBIs - CVRR=SDNN/Mean RR (n.u.); f) Root mean square of differences of successive BBIs - RMSSD(ms).

3) The average value of electrodermal activity was calculated for each slide.

2.3.2. Statistical analysis

Here we presented results as percentage, means ± standard deviation or taking into account data type and distribution. We compared groups (dyslexic vs. nondyslexic) using parametric tests, an independent samples t-test. All p-values which were less than 0.05 were considered significant. The data were analysed within the SPSS 20.0 software (IBM Corp. Released 2011. IBM SPSS Statistics for Windows, Version 20.0. Armonk, NY: IBM Corp.). The Bonferroni corrections as a control for multiple comparisons were applied in all the statistical analysis where necessary.

3. Results

3.1. White (Default) Background—Reading Performance Results

Reading performance (non dyslexic vs. dyslexic) and physiological parameters measured by the sensor hub on a white background color are presented in Table 1. For all of the eye-tracking measures we have found a significant difference between groups, except for the Fixation Duration Average. Dyslexic children showed significantly higher scores in comparison to non-dyslexic children in all eye-tracking measures, except for Fixation Frequency and Saccade Frequency. A significant difference was also observed with the EDA parameter, where non-dyslexic children have higher values in comparison to dyslexic children. In all HRV parameters, we observed no significant difference between dyslexic and non-dyslexic children. In Mean HR and STD HR non-dyslexic children achieved higher values, while dyslexic children have shown higher scores in all other HRV parameters. Regarding EEG power bands we found no significant differences between groups. In all EEG measures, dyslexic children show higher values. Due to the distortion of the normal distribution of the data, the parameters are presented as medians and interquartile range and compared using a non-parametric alternative to t test, Mann-Whitney U test.

Table 1. Eye-tracking, EEG, EDA and HRV parameters in non-dyslexic and dyslexic children — significant p values are marked as bold.

Parameters	Reading		p Value *
	Non dyslexic (n = 18)	Dyslexic (n = 18)	
Reading duration			
RD (s)	16.4 (11.9-23.5)	54.6 (26.1-70.7)	**0.002**
EEG parameters (median power band)[a]			

Alpha (μV2)	- 5 (-11 to +9)	-3 (-6 to +8)	0.772
Beta (μV2)	3 (-7 to +13)	6 (-2 to +13)	0.477
Delta (μV2)	-10 (-17 to +30)	3 (-11 to+18)	0.809
Theta (μV2)	-8 (-13 to +8)	3 (-7 to +9)	0.296
Whole Range (μV2)	-8 (-14 to +26)	5 (-13 to +17)	0.851
Eye tracking parameters			
Fixation Count	25 (23-30)	35.5 (29-67)	**<0.001**
Fixation Frequency (count/s)	1.5 (1.37-1.80)	1.1 (0.6-1.6)	**0.036**
Fixation Duration Total (s)	15.1 (10.8-21.6)	48.3 (23.9-59.4)	**0.001**
Fixation Duration Average (ms)	593.8 (518.2-696.5)	809.7 (575.8-1586.9)	0.071
Saccade Count	24 (20-28)	29.5 (25-42)	**0.003**
Saccade Frequency (count/s)	1.45 (1.28-1.60)	0.90 (0.50-1.40)	**0.013**
Saccade Duration Total (ms)	469.7 (434.1-538.2)	736.5 (583.8-1509.7)	**<0.001**
Saccade Duration Average (ms)	20.1 (18.9-21.7)	23.1 (21.0-33.0)	**0.004**
EDA value			
EDA (μS)	8.29 (6.04-12.01)	5.67 (4.67-7.47)	**0.012**
HRV parameters			
Mean RR (ms)	659.4 (596.2-705.5)	693.6 (645.4-759.4)	0.092
STD RR (ms)	39.7 (22.2-57.3)	42.6 (32.5-59.9)	0.631
Mean HR (beats/min)	91.0 (84.4-100.6)	86.5 (79.0-92.9)	0.244
STD HR (beats/min)	6.28 (3.66-7.61)	5.22 (4.47-6.78)	0.988
RMSSD (ms)	50.9 (26.2-77.6)	44.7 (33.5-76.2)	0.527
CVRR=SDRR/MeanRR (ms)	0.08 (0.04-0.10)	0.07 (0.06-0.09)	0.828

Results are presented as median (25-75 percentile)
* Mann-Whitney U test (exact p value)
[a]EEG parameters are presented as difference from baseline (minus is decreasing trend from the baseline while plus is increasing trend from baseline)

3.2. Modifications in Background and Overlay Colors—Reading Performance Results

In Table 2 we show median values for the overall results for each parameter per single colour. Dyslexic and non-dyslexic children were compared on each of the parameters, namely, reading duration, eye-tracking measures, EDA, HRV and EEG parameters. The results show that children in the dyslexic group differed significantly from the children in the control group consistently on the all eye-tracking measures, except on a few single colours for the few measures, namely Fixation Count (Turquoise O, Purple O), Fixation Duration Average (Orange, Purple O), Saccade Count (Blue, Orange, Turquoise, Purple O), Saccade Duration Total (Blue, Turquoise O), Saccade Duration Average (Turquoise, Red O, Turquoise O). We have observed the significant differences between groups on EDA measure in all colours, except Yellow, Turquoise O and Orange O. Children from the control group scored higher across the EDA measure. Regarding HRV measures we observed significant differences between groups in Mean RR (Purple, Turquoise O, Yellow O) where dyslexic children scored higher, and in Mean HR (Purple, Turquoise O, Yellow O), where a control group scored higher. Children with dyslexia have shown significantly higher values of the Beta band on Purple and Theta band on Purple O colour in comparison to the control group, while the control group showed significantly higher values for the Theta band on Turquoise O colour.

Table 2. Differences between dyslexic and non-dyslexic children on reading duration, EEG, eye-tracking, EDA and HRV parameters, ($p < 0.05$ is marked with peach color, where dyslexic children scored with higher values, and green color where non-dyslexic children scored with higher values).

Colours	Red	Blue	Yellow	Orange	Purple	Turquoise	Red O	Turquoise O	Blue O	Orange O	Purple O	Yellow O
Reading duration (ms)	.002	.008	.004	.001	.002	.002	.001	.002	.002	.001	.002	.001
Fixation Count	.001	.106	.002	.046	.001	.010	.001		.015	.024		.001
Fixation Frequency (count/s)	.008	.005	.273	.041	.018	.003	.026	.011	.011	.046	.016	.010
Fixation Duration Total (ms)	.002	.016	.004	.001	.002	.002	.001	.031	.003	.002	.005	.001
Fixation Duration Average (ms)	.058	.043	.343		.043	.005	.050	.107	.058	.050		.025
Saccade Count	.018		.005		.001	.057	.002		.049	.062		.001
Saccade Frequency (count/s)	.008	.004		.020	.004	.003	.036	.009	.011	.015	.013	.004
Saccade Duration Total (ms)	.001		.003	.058	.001	.025	.001		.010	.023	.056	.001
Saccade Duration Average (ms)	.020	.015	.021	.052	.001				.034	.031	.040	.004
Alpha (μV2)												
Beta (μV²)					.010							
Delta (μV²)												
Theta (μV²)								.004			.048	

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 17 March 2021 doi:10.20944/preprints202103.0442.v1

Whole range (μV2)					.012							
GSR (uS)	.029	.053		.038	.022	.057	.041		.049		.053	.035
Mean RR (ms)					.047			.040				.027
STD RR (ms)												
Mean HR (beats/min)					.047			.040				.027
STD HR (beats/min)												
RMSSD (ms)												
CVRR=SDRR/MeanRR (ms)												

Reading performance and physiological parameters comparisons (non-dyslexic vs. dyslexic children) over the average scores for all colors together are presented in Table 3. A significant difference was obtained regarding all eye/tracking measures, reading duration, median Beta power band, as well as for EDA, Mean RR, Mean HR, RMSSD, and CVRR. We observed no significant difference between non dyslexic and dyslexic children in all other measures.

Dyslexic children demonstrated longer time duration for the reading performance in comparison to the non-dyslexic (control group). They have also shown a higher Fixation count, Fixation Duration Total, Fixation Duration Average, Saccade Count, Saccade Duration Total, Saccade Duration Average, while the control group showed higher scores of Fixation Frequency and Saccade Frequency. Children with dyslexia also scored higher in all of the EEG bands, except Theta band. EDA was higher in the control group, as well as Mean HR, while all other HRV parameters were higher in dyslexic children.

Table 3. Reading duration, HRV, eye tracking and EDA parameters in non-dyslexic and dyslexic children across all colors together (18x13 colours=234 readings)—significant p values are marked in bold.

Parameters	**Reading**		***p* Value ***
	Non dyslexia(n = 18x13)	**Dyslexic(n = 18x13)**	
Reading duration			
RD (s)	21.63 ± 15.30	49.20 ± 29.81	**<0.001**
EEG parameters (median power band)			
Alpha (μV2)	2.5 ± 12.2	1.8 ± 11.4	0.529
Beta (μV2)	-0.9 ± 16.5	5.1 ±27.5	**0.005**
Delta (μV2)	5.9 ± 38.1	9.1± 47.5	0.415
Theta (μV2)	2.7± 15.0	2.2± 16.4	0.735

 doi:10.20944/preprints202103.0442.v1

Whole Range (μV2)	1.1 ± 29.1	6.2± 36.2	0.101
Eye tracking parameters			
Fixation Count	27.20 ± 08.50	45.29 ± 29.59	**<0.001**
Fixation Frequency (count/s)	1.53 ± 0.54	1.15 ± 0.70	**<0.001**
Fixation Duration Total (s)	20.16 ± 14.57	43.57 ± 27.02	**<0.001**
Fixation Duration Average (ms)	697.20 ± 297.21	1108.41 ± 786.90	**<0.001**
Saccade Count	24.33 ± 7.85	35.63 ± 23.65	**<0.001**
Saccade Frequency (count/s)	1.37 ± 0.52	0.97 ± 0.69	**<0.001**
Saccade Duration Total (ms)	517.22 ± 189.82	1122.51 ± 1514.83	**<0.001**
Saccade Duration Average (ms)	21.34 ± 3.51	27.82 ± 12.11	**<0.001**
EDA value			
EDA (μS)	8.86± 3.77	6.30 ± 2.36	**<0.001**
HRV parameters			
Mean RR (ms)	652.47± 96.37	690.61 ± 75.06	**<0.001**
STD RR (ms)	44.79 ± 37.31	47.49 ± 20.25	0.331
Mean HR (beats/min)	93.54 ± 11.94	87.89 ± 9.47	**<0.001**
STD HR (beats/min)	5.70 ± 3.07	5.96 ± 2.09	0.283
RMSSD (ms)	54.21 ± 48.26	56.71 ± 31.06	**0.001**
CVRR=SDRR/MeanRR (ms)	0.07 ± 0.04	0.08 ± 0.02	**<0.001**

* independent sample t test
Results are presented as mean ± standard deviation

4. Discussion

In the 36 children (18 dyslexic and 18 control group) we have evaluated relations between physiological parameters and colour modifications in the text, background, and overlays during reading performance regarding reading duration, eye-tracking, EEG bands, EDA and HRV parameters using simultaneously monitored sensor signals. The findings of the present study regarding reading duration on different background and overlay colors, as well as on white background with black text show that there is a significant difference between groups. To start with, dyslexic children took longer to read the text. Concerning the eye-tracking measures, we found significant differences between groups in all measures, except Fixation Duration Average for reading on white background with black text. Dyslexic children showed higher values for Fixation count, Fixation Duration Total, Fixation Duration Average, Fixation Duration Average, Saccade Count, Saccade Duration Total, Saccade Duration Average, while non-dyslexic children score higher on Fixation frequency and Saccade Frequency, which is in agreement with the previous studies [52-56] where it was reported that dyslexic have longer fixation duration, reading time and saccade duration. It was also found that the control group scored higher on Fixation Frequency and Saccade Frequency in reading on white as well on coloured background/overlay, which is aligned with previous research where it was reported that typical readers simultaneously process the number of letters and adapt to them according to the task, while dyslexic children only processed a few letters during the reading task [57]. Furthermore, older or better readers need more time to adapt to an unexpected [58,59].

In the literature regarding EEG power bands (Alpha, Beta, Delta, Theta, and Whole range) it is reported that dyslexic children have an increasing trend or disrupted oscillations in the range of Delta and Theta [60-62], and specifically increasing Beta [61,63]. Regarding the whole range, it was reported that this measure could be used for distinction between dyslexic children and individuals with normal reading abilities [64,65]. In the present study we found no significant differences in EEG bands between groups during the reading task on white background with black text, where dyslexic

 doi:10.20944/preprints202103.0442.v1

children showed an increasing trend in all EEG measures in comparison to the control group. Considering the reading performance in all colours together we found significantly higher values in the beta range in dyslexic children in comparison to the control group.

The present study gives further support to the reports in which it was found that colours have an important role in the reading process [24,38,45,47,48, 66-73].

Regarding EEG it is shown that during the reading on purple background colour children with dyslexia have a significantly increasing trend of the Beta and Whole range bands, and significantly increasing trend in the Theta band while reading on purple overlay, which confirms the second hypothesis where children with dyslexia could be segregated from children without dyslexia based on these parameters. The control group of children scored with increasing values of Theta band on turquoise overlay colour in comparison to the group of dyslexic readers.

The results of the present study regarding eye-tracking measures and reading in colours affirmed the previous study [46] where is was reported that the third colour from the selected colour set with the shortest reading duration in individuals with dyslexia was yellow, as is confirmed in the present study, while our study shows that the first colour with shortest reading duration is Turquoise and the second Turquoise O, which is opposite to the previous study where the first one was peach and the second one orange. Our study shows that the Red color has the longest reading duration in dyslexic children, followed by Read O and Yellow O. Regarding the control group, they scored with the shortest reading duration with Violet O, Blue O, and Orange O, while the longer reading duration was recorded on Blue, Red O, Yellow O. The overall results regarding eye-tracking measures and reading in colour are aligned with the studies [36,73] where it was reported that influence of colours and colored overlays is minimal to the readers with dyslexia regarding reading duration and we can confirm the first hypothesis that both warm and cold colors could be beneficial for the reading performance in both groups. Furthermore, the study confirms the second hypothesis that there are systematic differences between groups on the white, single colours and all colours together, whereas the control group showed significantly higher values on the Fixation Frequency and Saccade Frequency, while dyslexic children scored higher in all eye-tracking measures, except for a few, namely Fixation Count (Turquoise O, Purple O), Fixation Duration Average (Orange, Purple O), Saccade Count (Blue, Orange, Turquoise, Purple O), Saccade Duration Total (Blue, Turquoise O), Saccade Duration Average (Turquoise, Red O, Turquoise O).

Regarding electrodermal activity it is important to mention that EDA is linearly correlated to arousal and reflects emotional response and cognitive activity [74,75] and it is one of the most used psychophysiological measures for definition of the stress level [76]. High electrodermal activity reflects a high level of stress. The present study reports that in both situations, reading on white and coloured overlays/background children with dyslexia scored significantly lower in comparison to the group of non-dyslexic children, as was also reported in previous studies [77,78]. This finding confirms the second hypothesis, where EDA measure could be used to distinguish children with and without dyslexia. Based on this we can conclude that the control group had a higher stress level or emotional response to the colors, which is aligned with the report where it was found that good readers need more time to adapt to a new form of text [59], and which may produce an emotional response in such situations [77-79]. Regarding additional colours we have found that the EDA measure was significant in all colours, between groups, except for Orange, Turquoise O and Orange O, which could confirm the previous reports that pastel colours have a calming effect [80,81].

A relation between HRV parameters and modification in the text background and overlay in children with and without dyslexia is reported in the present study. During the reading on the white background with black text, which is typical for school-age children, we found no significant differences between dyslexic and non-dyslexic children. Our result gives further support to the previous studies where researchers reported that there

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 17 March 2021 doi:10.20944/preprints202103.0442.v1

is no systematic difference between dyslexic and non-dyslexic subjects regarding the HRV analysis [77,82]. However, considering all colours together during the reading task and physiological responses, we found systematic differences between dyslexic and non-dyslexic children in a few HRV parameters, namely, Mean RR, Mean HR, RMSSD, and CVRR. Dyslexic children have higher values in all named measures, except Mean HR, where the control group showed a higher score, which could also be related to the level of stress and align with the EDA measure, where the control group also showed higher scores [80,83,84]. Mean HR was significantly higher in the control group than in the dyslexic one on Purple, Turquoise O, and Yellow O, where dyslexic children showed significantly higher values of Mean RR. Regarding emotional response in dyslexic individuals [78], the level of arousal in our study was expected, and found to be lower in the group with dyslexia, which is reflected also by the Mean HR and Mean RR measures on the single colours [83] and confirms the second hypothesis where those measures could be beneficial for distinction between dyslexic and nondyslexic individuals.

5. Conclusions

The aim of this study was to better understand the relationship between physiological parameters and colour modifications in text background and overlay during reading in children with and without dyslexia. The group of 36 school-age children (18 with and 18 without dyslexia) were reading the text on white and 12 background and overlay colors. The study evaluates differences between groups in the reading duration, EEG, HRV, EDA and eye-tracking measures. Based on the findings, we can conclude that there are systematic differences between groups regarding reading duration and eye-tracking measures, whereby dyslexic children scored higher in overall results, except for Fixation frequency and Saccade frequency, which is in line with the previous studies. Regarding single colours, where dyslexics showed the shortest time duration to finish the reading task, we have found that reading on Turquoise and Turquoise O background colour was the easiest for them, while in the third place was the Yellow color which is also reported before [46]. Further, we have observed significant differences between groups regarding EDA measures, where the control group has higher values in comparison to the dyslexic one, which confirms the finding of the previous studies as well. Looking into the relation between single colours and EDA we have observed no significant differences in Orange, Turquoise O and Orange O colours. Regarding HRV parameters we found no significant differences in most HRV measures, which aligns with the previous studies, except for the Mean HR where the control group scored higher, and which is related to the EDA and stress level as well. Also, systematic differences of the HRV measures were found in single colours for Mean RR and Mean HR in Purple and Turquoise O, where the control group scored higher on Mean HR and dyslexic on Mean RR. In the previous literature it was reported that a Whole range of brain waves could be used for the distinction between dyslexic and nondyslexic individuals. We found significant differences in the two groups on the Purple colour, where dyslexic children showed an increasing trend, as well in the Beta band for the same colour. Differences in brain waves in previous literature between dyslexic and non-dyslexic children were explained also by increasing of the Beta band and oscillations in Delta and Theta bands. We have found significant differences between groups for Turquoise O colour for the Theta band, where the control group achieved higher values.

Thus, the goal of the study was to understand colour influence in reading performance and its relation to neurophysiological responses. By combining different modalities we were trying to find a more objective approach to distinguish children with dyslexia from those without, in order to facilitate prevention through early detection or find beneficial colours which could improve their reading performance. Based on the present findings we can conclude that Turquoise, Turquoise O and Yellow could be beneficial for children with dyslexia and that all presented measures (eye-tracking, EDA,

 doi:10.20944/preprints202103.0442.v1

HRV, EEG) could be beneficial for the purpose of better understanding of the neurophysiological origin of dyslexia in children.

In future work, it will be necessary to move forward from group studies to individual studies in order to determine and establish the individual optimal parameters, as well as colors, corresponding to individual differences in the reading process. This would then lead to the development of classification algorithms for dyslexia recognition. Finally, these parameters and automatic classification may serve as objective measurement for monitoring and therapy effects.

Author Contributions: Conceptualization, T.J.; M.M.J.; A.M.S.; T.J.J.; G.P.; V.K.; methodology, T.J.; M.M.J.; A.M.S.; T.J.J.; G.P.; V.K.; software, M.M.J.; A.M.S.; V.K.; formal analysis, M.M.J.; A.M.S.; I.S.; V.K.; data acquisition, T.J.; resources, M.M.J.; G.C.; G.P.; V.K.; data curation, T.J.;qgv M.M.J.; A.M.S.; I.S.; V.K.; writing—original draft and editing, T.J.; M.M.J.; A.M.S.; V.K. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: The study was conducted according to the guidelines of the Declaration of Helsinki, and approved by the Institutional Review Board (or Ethics Committee) of the Psychology Department of the University of Niš (9/2019, 04.09.2019.).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: Data of this research is available upon request via corresponding author.

Acknowledgments: The authors acknowledge the financial support from the Slovenian Research Agency (research core funding No. P2-0098), AD Futura Found (Public Scholarship, Development, Disability and Maintenance Found of the Republic of Slovenia), IPS Jozef Stefan and the Ministry of Education, Science and Technological Development of the Republic of Serbia, and Specialist office in the field of child and adolescent psychiatry, Dr. Antin Pavlović.

Conflicts of Interest: The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

References

1. Dyslexia Information Page | National Institute of Neurological Disorders and Stroke https://www.ninds.nih.gov/Disorders/All-Disorders/Dyslexia-Information-Page (accessed Feb 26, 2021).
2. Shaywitz, S. E.; Shaywitz, B. A. Paying Attention to Reading: The Neurobiology of Reading and Dyslexia. Development and Psychopathology 2008, 20 (4), 1329–1349. https://doi.org/10.1017/S0954579408000631.
3. Shaywitz, S. E.; Shaywitz, B. A. Dyslexia (Specific Reading Disability). Biological Psychiatry. June 1, 2005, pp 1301–1309. https://doi.org/10.1016/j.biopsych.2005.01.043.
4. Benfatto, M. N.; Seimyr, G. Ö.; Ygge, J.; Pansell, T.; Rydberg, A.; Jacobson, C. Screening for Dyslexia Using Eye Tracking during Reading. PLoS ONE 2016, 11 (12). https://doi.org/10.1371/journal.pone.0165508.
5. World Federation of Neurology (WFN). Report of research group on dyslexia and world illiteracy. Dallas: WFN, 1968.
6. Peterson, R. L.; Pennington, B. F. Developmental Dyslexia. Lancet (London, England) 2012, 379 (9830), 1997–2007. https://doi.org/10.1016/S0140-6736(12)60198-6.
7. Shaywitz, B. A.; Shaywitz, S. E.; Blachman, B. A.; Pugh, K. R.; Fulbright, R. K.; Skudlarski, P.; Mencl, W. E.; Constable, R. T.; Holahan, J. M.; Marchione, K. E.; Fletcher, J. M.; Lyon, G. R.; Gore, J. C. Development of Left Occipitotemporal Systems for Skilled Reading in Children after a Phonologically- Based Intervention. Biological Psychiatry 2004, 55 (9), 926–933. https://doi.org/10.1016/j.biopsych.2003.12.019.
8. Vaughn, S.; Cirino, P. T.; Wanzek, J.; Wexler, J.; Fletcher, J. M.; Denton, C. D.; Barth, A.; Romain, M.; Francis, D. J. Response to Intervention for Middle School Students with Reading Difficulties: Effects of a Primary and Secondary Intervention. School Psychology Review. National Association of School Psychologist January 1, 2010, pp 3–21. https://doi.org/10.1080/02796015.2010.12087786.
9. Nilsson Benfatto, M.; Öqvist Seimyr, G.; Ygge, J.; Pansell, T.; Rydberg, A.; Jacobson, C. Screening for Dyslexia Using Eye Tracking during Reading. PLOS ONE 2016, 11 (12), e0165508. https://doi.org/10.1371/journal.pone.0165508.
10. Alexander-Passe, N. How Dyslexic Teenagers Cope: An Investigation of Self-Esteem, Coping and Depression. Dyslexia 2006, 12 (4), 256–275. https://doi.org/10.1002/dys.318.

11. Long, L.; Macblain, S.; Macblain, M. Supporting Students with Dyslexia at the Secondary Level: An Emotional Model of Literacy; 2007; Vol. 51.
12. Gabrieli, J. D. E. Dyslexia: A New Synergy between Education and Cognitive Neuroscience. Science. July 17, 2009, pp 280–283. https://doi.org/10.1126/science.1171999.
13. Department of Education Northern Ireland. (1998). Code of practice on the identification and assessment of special educational needs. Bangor, Northern Ireland: Author.
14. Department of Education Northern Ireland. (2005). The Special Educational Needs and Disability (North Ireland) Order 2005. Belfast, Northern Ireland: The Stationery Office
15. Čolić, G. R. Early Dyslexia and dysgraphia indicators. Doctoral Dissertation. University of Belgrade Faculty of special education and rehabilitation; 2018;
16. Snowling, M. J. Early Identification and Interventions for Dyslexia: A Contemporary View. *Journal of Research in Special Educational Needs* **2013**, *13* (1), 7–14. https://doi.org/10.1111/j.1471-3802.2012.01262.x.
17. Lyytinen, H.; Erskine, J.; Ahonen, T.; Aro, M.; Eklund, K.; Guttorm, T.; Hintikka, S.; Hamalainen, J.; Ketonen, R.; Laakso, M. L.; Leppanen, P. H. T.; Lyytinen, P.; Poikkeus, A. M.; Puolakanaho, A.; Richardson, U.; Salmi, P.; Tolvanen, A.; Torppa, M.; Viholainen, H. Early Identification and Prevention of Dyslexia: Results from a Prospective Follow-up Study of Children at Familial Risk for Dyslexia. In *The SAGE Handbook of Dyslexia*; SAGE Publications Inc., 2008; pp 121–146. https://doi.org/10.4135/9780857020987.n6.
18. Carroll, J. M.; Solity, J.; Shapiro, L. R. Predicting Dyslexia Using Prereading Skills: The Role of Sensorimotor and Cognitive Abilities. *Journal of Child Psychology and Psychiatry and Allied Disciplines* **2016**, *57* (6), 750–758. https://doi.org/10.1111/jcpp.12488.
19. Ferrer, E.; Shaywitz, B. A.; Holahan, J. M.; Marchione, K.; Shaywitz, S. E. Uncoupling of Reading and Iq over Time: Empirical Evidence for a Definition of Dyslexia. Psychological Science 2010, 21 (1), 93–101. https://doi.org/10.1177/0956797609354084.
20. Habib, M. The Neurological Basis of Developmental Dyslexia. An Overview and Working Hypothesis. Brain 2000, 123.
21. Sandak, R.; Mencl, W. E.; Frost, S. J.; Pugh, K. R. The Neurobiological Basis of Skilled and Impaired Reading: Recent Findings and New Directions. Scientific Studies of Reading 2004, 8 (3), 273–292. https://doi.org/10.1207/s1532799xssr0803_6.
22. Jakovljević, T.; Janković, M. M.; Savić, A. M.; Soldatović, I.; Todorović, P.; Jere Jakulin, T.; Papa, G.; Ković, V. The Sensor Hub for Detecting the Developmental Characteristics in Reading in Children on a White vs. Colored Background/Colored Overlays. Sensors 2021, 21 (2), 406. https://doi.org/10.3390/s21020406.
23. Valdez, P.; Mehrabian, A. Effects of Color on Emotions. Journal of Experimental Psychology: General 1994, 123 (4), 394–409. https://doi.org/10.1037/0096-3445.123.4.394.
24. Wilkins, A. (2003) Reading through colour, John Wiley and Sons, Inc: West Sussex, England.
25. Jansky, J. J. A Case of Severe Dyslexia with Aphasic-like Symptoms. Bulletin of the Orton Society 1958, 8 (1), 8–11. https://doi.org/10.1007/BF02657600.
26. Kruk, R.; Sumbler, K.; Willows, D. Visual Processing Characteristics of Children with Meares-Irlen Syndrome. Ophthalmic and Physiological Optics 2008, 28 (1), 35–46. https://doi.org/10.1111/j.1475-1313.2007.00532.x.
27. Johnson, S. P. How Infants Learn About the Visual World. Cognitive Science 2010, 34 (7), 1158–1184. https://doi.org/10.1111/j.1551-6709.2010.01127.x.
28. Scott, L.; McWhinnie, H.; Taylor, L.; Stevenson, N.; Irons, P.; Lewis, E.; Evans, M.; Evans, B.; Wilkins, A. Coloured Overlays in Schools: Orthoptic and Optometric Findings. Ophthalmic and Physiological Optics 2002, 22 (2), 156–165. https://doi.org/10.1046/j.1475-1313.2002.00009.x.
29. Singleton, C.; Trotter, S. Visual Stress in Adults with and without Dyslexia. Journal of Research in Reading 2005, 28 (3), 365–378. https://doi.org/10.1111/j.1467-9817.2005.00275.x.
30. Singleton, C.; Henderson, L. M. Computerized Screening for Visual Stress in Children with Dyslexia. Dyslexia 2007, 13 (2), 130–151. https://doi.org/10.1002/dys.329.
31. Henderson, L. M.; Tsogka, N.; Snowling, M. J. Questioning the Benefits That Coloured Overlays Can Have for Reading in Students with and without Dyslexia. Journal of Research in Special Educational Needs 2013, 13 (1), 57–65. https://doi.org/10.1111/j.1471-3802.2012.01237.x.
32. Ritchie, S. J.; della Sala, S.; McIntosh, R. D. Irlen Colored Overlays Do Not Alleviate Reading Difficulties. Pediatrics 2011, 128 (4). https://doi.org/10.1542/peds.2011-0314.
33. Galuschka, K.; Ise, E.; Krick, K.; Schulte-Körne, G. Effectiveness of Treatment Approaches for Children and Adolescents with Reading Disabilities: A Meta-Analysis of Randomized Controlled Trials. PLoS ONE 2014, 9 (2), e89900. https://doi.org/10.1371/journal.pone.0089900.
34. Griffiths, P. G.; Taylor, R. H.; Henderson, L. M.; Barrett, B. T. The Effect of Coloured Overlays and Lenses on Reading: A Systematic Review of the Literature. Ophthalmic & physiological optics : the journal of the British College of Ophthalmic Opticians (Optometrists). Blackwell Publishing Ltd September 1, 2016, pp 519–544. https://doi.org/10.1111/opo.12316.
35. Hlengwa, N.; Moonsamy, P.; Ngwane, F.; Nirghin, U.; Singh, S. The Effect of Color Overlays on the Reading Ability of Dyslexic Children. Indian Journal of Ophthalmology. Medknow Publications August 1, 2017, pp 772–773. https://doi.org/10.4103/ijo.IJO_541_16.
36. Uccula, A.; Enna, M.; Mulatti, C. Colors, Colored Overlays, and Reading Skills. Frontiers in Psychology 2014, 5 (JUL), 833. https://doi.org/10.3389/fpsyg.2014.00833.

37. Hoyt, C. S. Irlen Lenses and Reading Difficulties. Journal of Learning Disabilities. December 1990, pp 624–626. https://doi.org/10.1177/002221949002301010.
38. Wilkins, A. Coloured Overlays and Their Effects on Reading Speed: A Review. Ophthalmic and Physiological Optics 2002, 22 (5), 448–454. https://doi.org/10.1046/j.1475-1313.2002.00079.x.
39. Gregor, P.; Newell, A. F. An Empirical Investigation of Ways in Which Some of the Problems Encountered by Some Dyslexics May Be Alleviated Using Computer Techniques. In Annual ACM Conference on Assistive Technologies, Proceedings; Association for Computing Machinery (ACM): New York, New York, USA, 2000; pp 85–91. https://doi.org/10.1145/354324.354347.
40. Dickinson, A.; Gregor, P.; Newell, A. F. Ongoing Investigation of the Ways in Which Some of the Problems Encountered by Some Dyslexics Can Be Alleviated Using Computer Techniques. In Annual ACM Conference on Assistive Technologies, Proceedings; Association for Computing Machinery (ACM), 2002; pp 97–103. https://doi.org/10.1145/638249.638268.
41. Kriss, I.; Evans, B. J. W. The Relationship between Dyslexia and Meares-Irlen Syndrome. Journal of Research in Reading 2005, 28 (3), 350–364. https://doi.org/10.1111/j.1467-9817.2005.00274.x.
42. Lightstone, A.; Lightstone, T.; Wilkins, A. Both Coloured Overlays and Coloured Lenses Can Improve Reading Fluency, but Their Optimal Chromaticities Differ. Ophthalmic and Physiological Optics 1999, 19 (4), 279–285. https://doi.org/10.1046/j.1475-1313.1999.00442.x.
43. Jeanes, R.; Busby, A.; Martin, J.; Lewis, E.; Stevenson, N.; Pointon, D.; Wilkins, A. Prolonged Use of Coloured Overlays for Classroom Reading. British Journal of Psychology 1997, 88 (4), 541–548. https://doi.org/10.1111/j.2044-8295.1997.tb02656.x.
44. Gregor, P.; Dickinson, A.; Macaffer, A.; Andreasen, P. SeeWord - A Personal Word Processing Environment for Dyslexic Computer Users. British Journal of Educational Technology 2003, 34 (3), 341–355. https://doi.org/10.1111/1467-8535.00331.
45. Rello, L.; Bigham, J. P. Good Background Colors for Readers: A Study of People with and without Dyslexia. 2017. https://doi.org/10.1145/3132525.3132546.
46. Rello, L.; Baeza-Yates, R. How to Present More Readable Text for People with Dyslexia. Universal Access in the Information Society 2017, 16 (1), 29–49. https://doi.org/10.1007/s10209-015-0438-8.
47. Pinna, B.; Deiana, K. New Conditions on the Role of Color in Perceptual Organization and an Extension to How Color Influences Reading. Psihologija 2014, 47 (3), 319–351. https://doi.org/10.2298/PSI1403319P.
48. Pinna, B.; Deiana, K. On the Role of Color in Reading and Comprehension Tasks in Dyslexic Children and Adults. i-Perception 2018, 9 (3), 204166951877909. https://doi.org/10.1177/2041669518779098.
49. Gabrieli, J. D. E. Dyslexia: A New Synergy between Education and Cognitive Neuroscience. Science. Science July 17, 2009, pp 280–283. https://doi.org/10.1126/science.1171999.
50. Lyon, G. R.; Shaywitz, S. E.; Shaywitz, B. A. A Definition of Dyslexia. Annals of Dyslexia. Springer New York LLC 2003, pp 1–14. https://doi.org/10.1007/s11881-003-0001-9.
51. British Dyslexia Association. Dyslexia style guide, January 2012. http://www.bdadyslexia.org.uk/.
52. Rayner, K. The Role of Eye Movements in Learning to Read and Reading Disability. Remedial and Special Education 1985, 6 (6), 53–60. https://doi.org/10.1177/074193258500600609.
53. Eden, G. F.; Stein, J. F.; Wood, H. M.; Wood, F. B. Differences in Eye Movements and Reading Problems in Dyslexic and Normal Children. Vision Research 1994, 34 (10), 1345–1358. https://doi.org/10.1016/0042-6989(94)90209-7.
54. Olson, R. K.; Kliegl, R.; Davidson, B. J. Dyslexic and Normal Readers' Eye Movements. Journal of Experimental Psychology: Human Perception and Performance 1983, 9 (5), 816–825. https://doi.org/10.1037//0096-1523.9.5.816.
55. Martos, F. J.; Vila, J. Differences in Eye Movements Control among Dyslexic, Retarded and Normal Readers in the Spanish Population. Reading and Writing 1990, 2 (2), 175–188. https://doi.org/10.1007/BF00401801.
56. Rayner, K. Eye Movements and the Perceptual Span in Beginning and Skilled Readers. Journal of Experimental Child Psychology 1986, 41 (2), 211–236. https://doi.org/10.1016/0022-0965(86)90037-8.
57. Prado, C.; Dubois, M.; Valdois, S. The Eye Movements of Dyslexic Children during Reading and Visual Search: Impact of the Visual Attention Span. Vision Research 2007, 47 (19), 2521–2530. https://doi.org/10.1016/j.visres.2007.06.001.
58. Rayner, K.; Yang, J.; Castelhano, M. S.; Liversedge, S. P. Eye Movements of Older and Younger Readers When Reading Disappearing Text. Psychology and Aging 2011, 26 (1), 214–223. https://doi.org/10.1037/a0021279.
59. Rayner, K.; Yang, J.; Schuett, S.; Slattery, T. J. Eye Movements of Older and Younger Readers When Reading Unspaced Text. Experimental psychology 2013, 60 (5), 354–361. https://doi.org/10.1027/1618-3169/a000207.
60. Fraga González, G.; van der Molen, M. J. W.; Žarić, G.; Bonte, M.; Tijms, J.; Blomert, L.; Stam, C. J.; van der Molen, M. W. Graph Analysis of EEG Resting State Functional Networks in Dyslexic Readers. Clinical Neurophysiology 2016, 127 (9), 3165–3175. https://doi.org/10.1016/j.clinph.2016.06.023.
61. Arns, M.; Peters, S.; Breteler, R.; Verhoeven, L. DIFFERENT BRAIN ACTIVATION PATTERNS IN DYSLEXIC CHILDREN: EVIDENCE FROM EEG POWER AND COHERENCE PATTERNS FOR THE DOUBLE-DEFICIT THEORY OF DYSLEXIA; 2007; Vol. 6.
62. Goswami, U.; Wang, H. L. S.; Cruz, A.; Fosker, T.; Mead, N.; Huss, M. Language-Universal Sensory Deficits in Developmental Dyslexia: English, Spanish, and Chinese. Journal of Cognitive Neuroscience 2011, 23 (2), 325–337. https://doi.org/10.1162/jocn.2010.21453.

63. Klimesch, W.; Doppelmayr, M.; Wimmer, H.; Gruber, W.; Röhm, D.; Schwaiger, J.; Hutzler, F. Alpha and Beta Band Power Changes in Normal and Dyslexic Children. Clinical Neurophysiology 2001, 112 (7), 1186–1195. https://doi.org/10.1016/S1388-2457(01)00543-0.
64. Lehongre, K.; Morillon, B.; Giraud, A.-L.; Ramus, F. Impaired Auditory Sampling in Dyslexia: Further Evidence from Combined FMRI and EEG. Frontiers in Human Neuroscience 2013, 7 (JUL), 454. https://doi.org/10.3389/fnhum.2013.00454.
65. Hoeft, F.; McCandliss, B. D.; Black, J. M.; Gantman, A.; Zakerani, N.; Hulme, C.; Lyytinen, H.; Whitfield-Gabrieli, S.; Glover, G. H.; Reiss, A. L.; Gabrieli, J. D. E. Neural Systems Predicting Long-Term Outcome in Dyslexia. Proceedings of the National Academy of Sciences of the United States of America 2011, 108 (1), 361–366. https://doi.org/10.1073/pnas.1008950108.
66. Uccula, A.; Enna, M.; Mulatti, C. Colors, Colored Overlays, and Reading Skills. Frontiers in Psychology. Frontiers Research Foundation 2014. https://doi.org/10.3389/fpsyg.2014.00833.
67. Wilkinson, K. M.; O'Neill, T.; McIlvane, W. J. Eye-Tracking Measures Reveal How Changes in the Design of Aided AAC Displays Influence the Efficiency of Locating Symbols by School-Age Children without Disabilities. Journal of Speech, Language, and Hearing Research 2014, 57 (2), 455–466. https://doi.org/10.1044/2013_JSLHR-L-12-0159.
68. Choi, C.-J.; Kim, K.-S.; Kim, C.-M.; Kim, S.-H.; Choi, W.-S. Reactivity of Heart Rate Variability after Exposure to Colored Lights in Healthy Adults with Symptoms of Anxiety and Depression. International Journal of Psychophysiology 2011, 79 (2), 83–88. https://doi.org/10.1016/j.ijpsycho.2010.09.011.
69. Griffiths, P. G.; Taylor, R. H.; Henderson, L. M.; Barrett, B. T. The Effect of Coloured Overlays and Lenses on Reading: A Systematic Review of the Literature. Ophthalmic & physiological optics : the journal of the British College of Ophthalmic Opticians (Optometrists). Blackwell Publishing Ltd September 1, 2016, pp 519–544. https://doi.org/10.1111/opo.12316.
70. Morrison, R. Effect of Color Overlays on Reading Efficiency; 2011.
71. Blaskey, P.; Scheiman, M.; Parisi, M.; Ciner, E. B.; Gallaway, M.; Selznick, R. The Effectiveness of Irlen Filters for Improving Reading Performance: A Pilot Study. Journal of learning disabilities 1990, 23 (10), 604–612. https://doi.org/10.1177/002221949002301007.
72. Hlengwa, N.; Moonsamy, P.; Ngwane, F.; Nirghin, U.; Singh, S. The Effect of Color Overlays on the Reading Ability of Dyslexic Children. Indian Journal of Ophthalmology. Medknow Publications August 1, 2017, pp 772–773. https://doi.org/10.4103/ijo.IJO_541_16.
73. Denton, T. F.; Meindl, J. N. The Effect of Colored Overlays on Reading Fluency in Individuals with Dyslexia. Behavior Analysis in Practice 2016, 9 (3), 191–198. https://doi.org/10.1007/s40617-015-0079-7.
74. Boucsein, W.; Boucsein, W. Principles of Electrodermal Phenomena. In Electrodermal Activity; Springer US, 2012; pp 1–86. https://doi.org/10.1007/978-1-4614-1126-0_1.
75. Boucsein, Wolfram. Electrodermal Activity; Springer Science+Business Media, LLC, 2012.
76. Carlucci, L.; Watkins, M. W.; Sergi, M. R.; Cataldi, F.; Saggino, A.; Balsamo, M. Dimensions of Anxiety, Age, and Gender: Assessing Dimensionality and Measurement Invariance of the State-Trait for Cognitive and Somatic Anxiety (STICSA) in an Italian Sample. Frontiers in Psychology 2018, 9 (NOV), 2345. https://doi.org/10.3389/fpsyg.2018.02345.
77. Hunter, E. J.; Johnson, L. C.; Keefe, F. B. Electrodermol and Cardiovascular Responses in Nonreaders. Journal of Learning Disabilities 1972, 5 (4), 187–197. https://doi.org/10.1177/002221947200500402.
78. Tobia, V.; Bonifacci, P.; Ottaviani, C.; Borsato, T.; Marzocchi, G. M. Reading under the Skin: Physiological Activation during Reading in Children with Dyslexia and Typical Readers. Annals of Dyslexia 2016, 66 (2), 171–186. https://doi.org/10.1007/s11881-015-0109-8.
79. Uno, T.; Grings, W. W. AUTONOMIC COMPONENTS OF ORIENTING BEHAVIOR. Psychophysiology 1965, 1 (4), 311–321. https://doi.org/10.1111/j.1469-8986.1965.tb03263.x.
80. Al-Ayash, A.; Kane, R. T.; Smith, D.; Green-Armytage, P. The Influence of Color on Student Emotion, Heart Rate, and Performance in Learning Environments. Color Research and Application 2016, 41 (2), 196–205. https://doi.org/10.1002/col.21949.
81. Mehta, R.; Zhu, R. Blue or Red? Exploring the Effect of Color on Cognitive Task Performances. Science 2009, 323 (5918), 1226–1229. https://doi.org/10.1126/science.1169144.
82. Fraga González, G.; Smit, D. J. A.; Molen, M. J. W.; Tijms, J.; Geus, E. J. C.; Molen, M. W. Probability Learning and Feedback Processing in Dyslexia: A Performance and Heart Rate Analysis. Psychophysiology 2019, 56 (12), e13460. https://doi.org/10.1111/psyp.13460.
83. Moharreri, S.; Dabanloo, N. J.; Parvaneh, S.; Nasrabadi, A. M. How to Interpret Psychology from Heart Rate Variability? In 2011 1st Middle East Conference on Biomedical Engineering, MECBME 2011; IEEE, 2011; pp 296–299. https://doi.org/10.1109/MECBME.2011.5752124.
84. Drachen, A.; Yannakakis, G.; Nacke, L. E.; Pedersen, A. L. Correlation between Heart Rate, Electrodermal Activity and Player Experience in First-Person Shooter Games. In Proceedings - Sandbox 2010: 5th ACM SIGGRAPH Symposium on Video Games; ACM Press: New York, New York, USA, 2010; pp 49–54. https://doi.org/10.1145/1836135.1836143.