RESEARCH PAPER

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Does binocular instability influence static body balance in adults with developmental dyslexia?

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The aim of the study was to investigate if body balance control deficits in dyslexia are present in dyslexic adults and if unstable binocular fixation relates to impaired body balance. Fifteen dyslexics adults and 15 age-matched non-dyslexics participated in the study. Posturography data were collected in two sessions: during quiet standing (single-task) and while performing a mental task while standing on the platform (dual-task). Each session was conducted under three distinct visual conditions: monocular fixation, binocular fixation, and eyes closed. Four parameters of the center of pressure (CoP) signal were analysed: medio-lateral sway (X_{SD}), antero-posterior sway (Y_{SD}), sway area (Area95) and mean CoP velocity (V_{avg}). A psycho-physical tests with Wesson card and a modified Mallett test were used to measure fixation disparity (FD). Slight underconvergence at the fixation point results in exo-FD, and conversely, overconvergence results in eso-FD. The results indicated that in dyslexics, the exo-FD values were higher than in controls. In both groups, body stabilization was better with binocular fixation compared to eyes closed (lowest value of V_{avg} and CoP sway). Moreover, dyslexic adults demonstrated impaired body balance. The posturographic deficits remained unaltered by the viewing conditions, indicating that binocular fixation did not contribute to body instability, despite the higher incidence of fixation disparity in the dyslexic group. The existence of both posturographic deficits and the presence of FD may reflect deficits at the cerebellar level.

Key words: developmental dyslexia, reading problems, fixation disparity, binocular instability, posturography, body balance

INTRODUCTION

Developmental dyslexia is a common reading and writing disorder that occurs independently of a normal intelligence level and favourable learning conditions (Shaywitz, 1998). It should be noted that in addition to literacy problems, dyslexics often have motor and visual deficits (Menghini et al., 2006; Kapoula & Bucci, 2007; Bucci et al., 2012), suggesting a multimodal nature of the underlying disorder. It has been suggested that reading problems in dyslexic patients may be accompanied by visual dysfunction (particularly in the accommodative and vergence systems), manifested by convergence difficulties, reduced fusional vergence ranges, and impaired accommodation (Evans et al., 1994; Kapoula et al., 2007; Brenk-Krakowska et al., 2012). It should be emphasized that an increasing number of dyslexic patients are diagnosed with oculomotor coordination disorders, manifested by prolonged fixations and frequent regressions (Kirkby et al., 2008), as well as asymmetric and uncoordinated vergence movements (Bucci et al., 2008). In addition, although dyslexic patients do not show significant heterophoria, they often show fixation disparity (FD) associated with binocular instability (Jainta & Kapoula, 2011; Brenk-Krakowska et al., 2012; Przekoracka-Krawczyk et al., 2017). FD means that the images of a bifixed object are not projected exactly onto the corresponding retinal points in both eyes, but are still within the Panum's fusional area (double vision does

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not occur). Slight underconvergence at the fixation point results in exo-FD, and conversely, overconvergence results in eso-FD (Jainta & Jaschinski, 2002). FD in dyslexics is usually diagnosed on the basis of subjective clinical tests such as the Mallett test or the Wesson card (Brenk-Krakowska et al., 2012; Przekoracka-Krawczyk et al., 2017). In the authors' previous studies using the Wesson card, dyslexic adults have shown at least some tendency to FD in the exo-direction (Brenk-Krakowska et al., 2012; Przekoracka-Krawczyk et al., 2017). A weaker fusion lock on the Wesson card compared to the Mallet test may contribute to the difficulty in maintaining vergence stability, and this may explain why a greater degree of exo-FD was observed in this group.

The existence of visuomotor monocular and binocular visual deficits can be explained by the cerebellar hypothesis, according to which problems with the automatization of body movements are due to deficits at the cerebellar level (Fawcett & Nicolson, 1999; Nicolson & Fawcett, 1995, 1999; Nicolson et al., 1999; Nicolson et al., 2001).This hypothesis has been supported by research on procedural motor learning, i.e., the acquisition of motor skills in an implicit (unconscious) manner, as well as by posturographic studies on the maintenance of body balance, in which the cerebellum was found to be largely responsible for these functions. For example, it has been shown that dyslexic subjects have poor procedural motor learning skills (Molinari et al., 1997; Vicari et al., 2003; Przekoracka-Krawczyk et al., 2017) and that children with dyslexia have weak body balance (Moe-Nilssen et al., 2003; Stoodley et al., 2005; Kapoula & Bucci, 2007).

Research suggests that individuals with dyslexia often have poorer postural stability in comparison to their non-dyslexic age-matched peers. It has been demonstrated that these differences may be even more noticeable when a dual-task paradigm involving increased cognitive demand is applied (Legrand et al., 2012; Bucci et al., 2013).

A review of the extant literature on balance problems in adults reveals a paucity of consistent results. Some research suggests that dyslexic adults may experience a decline in balance (Needle et al., 2006; Brookes et al., 2010; McPhillips et al., 2025).

The findings of other studies suggest that balance is not necessarily impaired in individuals with dyslexia or some subclinical balance deficits may be present (Stoodley et al., 2006; Patel et al., 2010). Postural instability has also been reported to be more strongly associated with attention deficit hyperactivity disorder symptoms than with specific reading impairments (Rochelle et al., 2009).

However, it has been established that deficits may be identified in adults with dyslexia if the level of difficulty is manipulated in dual-task paradigms (Needle et al., 2006). Furthermore, research has demonstrated that balance difficulties are present in children and adults with dyslexia when age-appropriate tests are administered, even for those without comorbid attention deficit (Brookes et al., 2010).

In general, when one tries to maintain balance while performing a mental task (dual-task conditions such as counting backwards or listening to a series of letters of the alphabet), their postural sway tends to increase, and their ability to maintain a stable posture decreases. However, in some cases, the implementation of dual-task conditions in individuals without neurological impairments has been shown to enhance postural stability. Individuals may adapt and compensate by prioritizing one task (often the more important one) or by modifying their postural strategies. This adaptation may involve increased muscle activity or altered movement patterns, particularly elevated levels of body stiffness and heightened general arousal (Dault et al., 2001; Hunter & Hoffman, 2001; Yardley et al., 2001; Przekoracka-Krawczyk et al., 2014).

Evidence suggests that visual factors, including vergence effort, contribute significantly to postural stability (Henriksson et al., 1967; Guerraz et al., 2000; Glasauer et al., 2005; Kapoula & Le, 2006; Bucci et al., 2009; Michalak et al., 2014; 2019; Przekoracka-Krawczyk et al., 2014). Given that dyslexic individuals exhibit binocular instability and oculomotor dysfunction (Evans et al., 1994; Kapoula et al., 2007; Bucci et al., 2008; 2012; Brenk-Krakowska et al., 2012; Przekoracka-Krawczyk et al., 2017), it can be expected that not only will reading and writing be impaired, but that these deficits will also contribute to poor performance on motor and postural measures where motor activities are under visual control. It should be noted that all previous studies of motor control and body balance in dyslexics have been conducted using binocular viewing. Therefore, it can be assumed that unstable binocular fixation, rather than cerebellar deficits, could be responsible for the poor performance of dyslexic subjects in posturographic tests. In order to test this hypothesis, in the current study posturographic measurements were performed in both binocular and monocular conditions as well as with the eyes closed. Body balance measurements were taken while standing still (single task) and while performing a mental task (dual task) in order to detect posturographic abnormalities that can be compensated. It was expected that if unstable binocular vision is the cause of body balance abnormalities in dyslexic subjects, the results recorded with binocular fixation should be significantly worse than those recorded with monocular fixation.

In summary, the objective of the present study was to assess body balance under different viewing conditions in order to determine whether dyslexic adults experience deficits in postural control.

METHODS

Study participants

Thirty participants took part in the experiment, containing two groups: dyslexic group (DG) with 15 subjects aged 21-28 years (7 female and 8 male) with specific reading and writing problems diagnosed during their primary education by specialists from a psychological and educational assessment center and the control group (CG) with 15 subjects aged 21-27 years (9 female and 6 male) who have never had any problems with reading and/or writing. All participants had their refractive errors corrected and their visual acuities were within normal ranges in each eye (VA 1.0 or better on the Snellen chart), stereoscopic vision was 40'' (Titmus test, Wirt circles), no manifest strabismus (excluded by cover test) and no interocular suppression (with the Worth 4-dot test). The subjects were also free from any visual or nervous system pathologies.

The study was approved by the local Ethics Committee of Adam Mickiewicz University of Poznan and was performed in accordance with the Declaration of Helsinki. An informed consent was obtained from all subjects after the explanation of the aim and nature of the procedure. Subjects gave written consent to participate in the study and were informed that they could discontinue their participation at any stage of the experiment.

Psychological and pedagogical tests

Before the subjects were included in the study, their actual reading and writing skills levels were assessed using word-chain and sentence-chain tests (Ober et al., 1998), Szczerbiński's spelling test – polish adaptation of spoonerism tests developed by Rusiak (Perin, 1983; Rusiak et al., 2007) and reading rate test using actual and artificial words – polish adaptation of TOWRE test (Torgesen et al., 1999) prepared by Szczerbiński (Szczerbiński & Pelc-Pękala, 2013). The above tests were administered and evaluated by a qualified psychologist (one of the authors – PR). Based on the test results (Table 1) it was concluded that the level of reading and writing skills in the DG was significantly different to the skills level in the CG but no difference in the overall intelligence levels was found between the study groups (Jaworowska & Szustrowa, 1992).

Table 1. Characteristics of the dyslexic and control groups participating in the study.

Variable	Dyslexics (N=15)			Controls (N=15)			Statistics
	Mean	SD	Median	Mean	SD	Median	Z or t
Age (years)	24.53	2.69	24.00	23.13	2.53	23.00	-1.47; NS
Raven test (standard score)	91.76	7.26	93.00	89.16	10.95	93.00	-0.9; NS
Word-chain: time (sec)	135.93	29.83	140.00	77.90	9.83	79.50	-7.16***
Word-chain: errors	1.23	0.46	1.50	0.23	0.37	0.00	-6.57***
Sentences-chain: time (sec)	184.70	45.81	180.00	93.90	15.22	90.00	-7.28***
Sentences-chain: errors	2.90	1.73	3.00	0.43	0.50	0.53	-5.27***
Rate of word reading (mean correct in 30 sec; max=75)	45.90	7.33	42.00	68.67	4.65	68.50	10.15***
Rate of word reading: errors	1.40	0.60	1.50	0.13	0.30	0.00	-7.29***
Rate of non-word reading (mean correct in 30 sec; max=69)	28.10	4.87	29.50	38.57	4.41	39.00	6.17***
Rate of non-word reading: errors	2.53	0.85	2.50	0.57	0.53	0.50	-7.57***
Spoonerism: time (sec)	193.87	35.56	197.00	153.67	38.92	153.00	-2.95 **
Spoonerism: errors	4.80	2.11	5.00	2.20	1.32	2.00	-4.04***
Correct writing: time (sec) (orthographic skills)	202.70	71.13	182.00	111.10	13.83	111.00	-4.90***
Correct writing: errors (orthographic skills)	7.77	3.53	7.00	1.67	1.67	1.50	-6.05***

NS non-significant; significant differences: *p<0.05; **p<0.01; ***p<0.001.

Research procedure – the main study

The study consisted of two parts: visual and posturographic. In the first part, visual tests were administered in order to define heterophoria, fixation disparity and determine the dominant eye. Ocular dominance was defined by fixating *via* hole task. Binocularity tests were administered at the distance of 40 cm. The amount of heterophoria was measured with prismatic cover test, whereas fixation disparity (FD) was assessed with simple psychophysical procedures involving the modified Mallett fixation disparity test (test STOP, Grand Optica) and with Wesson fixation disparity card (Wesson & Koening, 1983). The modified Mallet test allows to identify FD and its direction but due to the central fusion lock it detected binocular instability only when it had significant values. Since the Wesson card does not include a central fusion lock, it is more sensitive in detecting FD. Moreover, the Wesson card allows for definition of FD severity in minutes of arc. However, it can be used only in near visual distance.

In the second part of the research, body balance was measured using ACCUSWAY^{PLUS} posturographic platform (dimensions: 502 × 502 × 45 mm) made by AMTI and the signal was recorded by and Balans Trainer software (AMTI). The participants were asked to stand with both feet on the platform (feet slightly apart) and focus on the fixation target which was an "X" at a distance of 150 cm. The distance was selected on purpose in order to ensure comparability of the test results with the previous posturography studies on dyslexic subjects (the testing distance was usually 120-170 cm). Posturography measurements were divided into three blocks: while fixating on the target with both eyes (BE), while fixating on the target with the dominant eye (DE) and with both eyes closed (CE). The sequence of blocks was randomized for each participant.

The measurement was divided into two sessions: I – standing still during which the participants were standing on the platform without performing any additional tasks (single task). During this session, the platform recorded the location of the subject's center of pressure (CoP) for approximately 60 seconds per measurement (BE, DE, CE). Session II was standing while performing a mental task and the subjects were asked to perform a mental exercise while standing in order to break their potentially present compensatory mechanisms, if any were present (dual task). The mental task was a modified Lang and Bastian test, which was used by the authors in other research (it was described in detail in (Przekoracka-Krawczyk et al., 2014). The subjects were asked to listen to a recording of a voice reading aloud the letters K, A, O, L in random order and count how many times they heard a particular letter (the target stimulus). Similar to Session I, the second session took 60 seconds per measurement (BE, DE, CE).

Four posturographic parameters were analysed: X_{SD} – standard deviation of medio-lateral sway; Y_{SD} – standard deviation of antero-posterior sway; Area95 – area of 95th percentile ellipse covering 95% of data points (i.e., points in which the CoP was located); V_{avg} – the average velocity of CoP movement during measurement, calculated as follows: length of the movement route/60 sec and expressed in cm/s.

Data were statistically analysed using the Statistica 13.3 software, employing analyses of variance (repeated measures ANOVA). The factors were: task (two levels: single task, dual task), group (two levels: DG, CG) and observation condition (3 levels: BE, DE, CE).

Additionally, Student's t-test for independent groups (for the magnitude of heterophoria and FD values) and the Chi-square (χ^2) test with Yates's correction for continuity (for FD occurrence) were also performed using the same statistical software. The level of significance for differences was defined as $P\leq0.05$.

RESULTS

Binocular instability

The average heterophoria was comparable in both groups and amounted to -1.7 Δ (exo) SD 1.1, in the DG and -1.3 Δ (exo) SD 1.2, in the CG. The difference was statistically insignificant (t_{27}=0.89, P=0.380).

In the modified Mallett test, none of the subjects from the CG exhibited FD, while in the DG, FD was observed with high frequency i.e., in 6 subjects from the group (5 exo-FD and 1 eso-FD), corresponding to a 40% FD occurrence (*vs* 0% in CG; χ^2=5.21; P=0.022).

In the Wesson test, 2 subjects from the CG exhibited FD in the exo-direction but with very low values not exceeding 1 min of arc (mean value 0.1 min of arc), whereas in the DG all subjects exhibited FD in the exo-direction with an average value of 5.1 min of arc (range from 1 to 10.5 min of arc). Both the occurrence of FD (100% *vs.* 13%, $\chi 2$=19.55, P<0.001) and the differences in the measured FD values between the study groups were statistically significant (t_{27}=-5.77, P<0.001).

Posturographic measurements

Medio-lateral sway

The results for the mean movement of the CoP along the *x* axis are presented in Fig. 1.

In general, X_{SD} parameter was dependent on observation condition ($F_{2,56}$=5.45, P=0.007, η^2=0.16). *Post-hoc* test showed that X_{SD} value was significantly better with BE than with CE (0.36 *vs.* 0.41 cm, P=0.005) but no difference was found between DE and BE (0.38 *vs.* 0.36; P=0.260) or between DE and BE (P=0.209). The main effect of group was insignificant ($F_{1,28}$=1.26, P=0.271, η^2=0.04), however X_{SD} differs between groups in different tasks, what was indicated by the significant task and group interaction ($F_{1,28}$=4.75, P=0.036, η^2=0.14). *Post-hoc* test showed that in the dual task, body stabilization of the CG was better in the dual task than in the single one (0.33 cm for dual task and 0.39 cm for single task, P=0.039). Such effect was not observed in the DG (0.40 cm for dual task and 0.41 cm for single task, P=0.997). Moreover, *post-hoc* test showed also, that in the dual task, CG indicated better body stabilisation than DG (0.33 *vs.* 0.41 cm, for CG and DG, respectively, P=0.046), but the difference between groups in the single task was insignificant (0.39 *vs.* 0.40 cm, for CG and DG, respectively, P=0.980). Interaction between observation condition and group ($F_{2,56}$=1.86, P=0.165, η^2=0.06), and between observation condition, group and task ($F_{2,56}$=0.15, P=0.861, η^2=0.01) were insignificant.

Antero-posterior sway

The results for the mean sway of the CoP along the *y* axis are presented in Fig. 2.

In general, Y_{SD} parameter was higher in the single than in the dual task (0.53 *vs.* 0.48 cm, $F_{1,28}$=8.29, P=0.008, η^2=0.23) and higher for the DG for the CG (0.56 *vs.* 0.45 cm; $F_{1,28}$=7.51, P=0.011, η^2=0.21). However, no significant interaction was observed between the task and group factors ($F_{1,28}$=1.12, P=0.298, η^2=0.04) indicating that worse CoP sway in the antero-posterior direction for DG was found in single and dual tasks. Visual condition did not influence Y_{SD} parameter, what was indi-

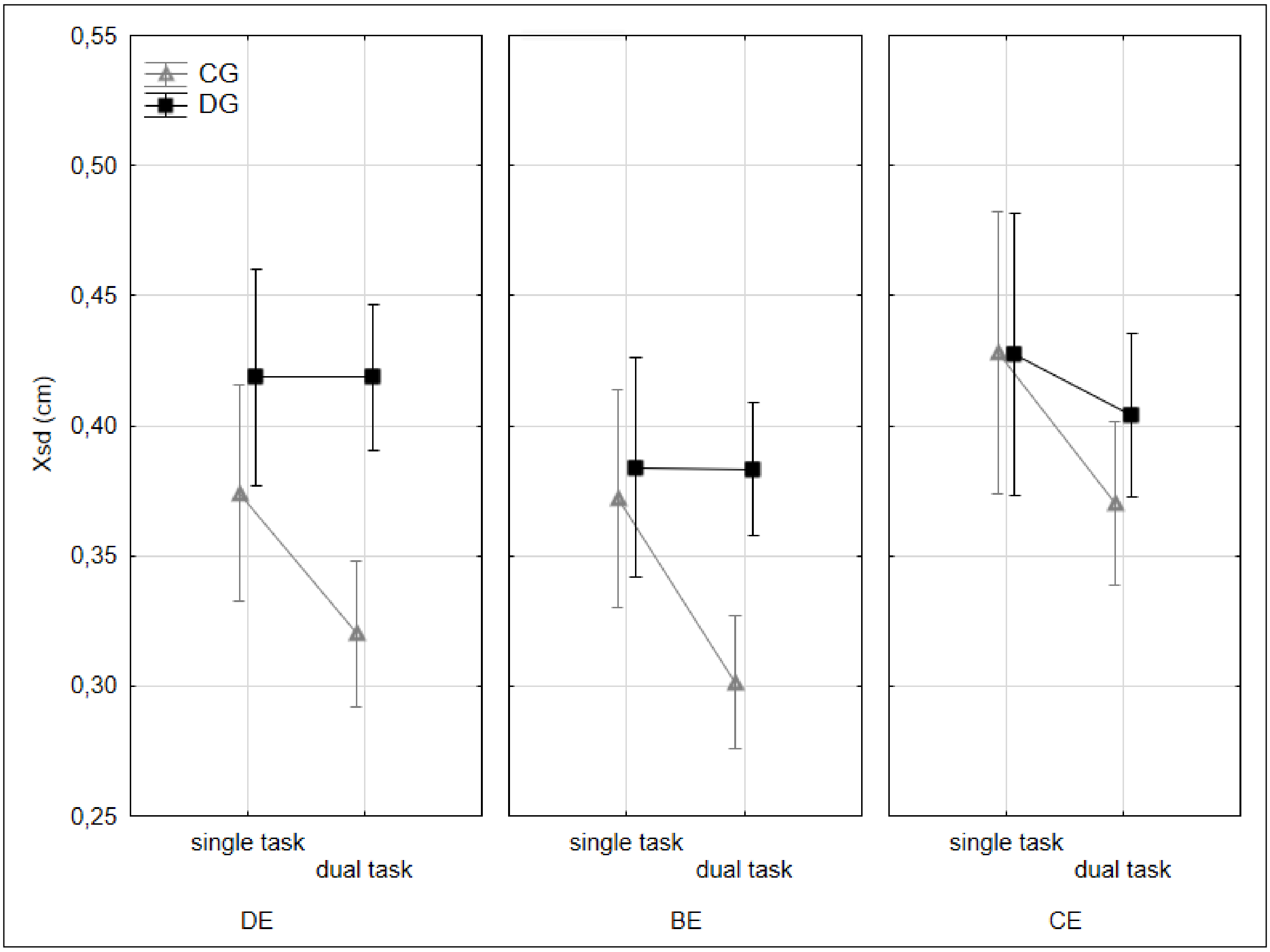

Fig. 1. The mean values of X_{SD} parameter. Dyslexic group (DG – dark lines) and the control group (CG – light lines), ST – single task, DT – dual task, DE – viewing with the dominant eye, BE – viewing with both eyes, CE – closed eyes, the error bars stand for the mean standard error.

cated by insignificant interaction between group and observation condition ($F_{2,56}$=0.18, P=0.838, η^2=0.01) and between group, observation condition and task factors ($F_{2,56}$=0.22, P=0.800, η^2=0.01).

Sway area (Area of 95% confidence ellipse)

The mean results for the Area95 parameter are presented in Fig. 3.

In general, DG indicated higher value of Area95 parameter than CG (4.11 *vs.* 2.96 cm^2, for DG and CG, respectively, $F_{1,28}$=4.61, P=0.041, η^2=0.14). This parameter had also higher values in the single task than in the dual task (3.77 *vs.* 3.29 cm^2; $F_{1,28}$=4.76, P=0.038, η^2=0.15). Significant interaction was found between the task and group factors ($F_{1,28}$=3.82, P=0.043, η^2=0.09). As can be seen in Fig. 3, and proved by the *post-hoc* test, in the CG body stabilization reflected in Area95 parameter was better in the dual task than in the single one (P=0.048), however, in the DG this effect was not observed (P=0.984). Visual inputs did not influence the value of Area95, what was proved by insignificant main effect of observation condition ($F_{2,56}$=1.69, P=0.194, η^2=0.06), interaction between observation condition and task factors ($F_{2,56}$=2.15, P=0.126, η^2=0.07), or interaction between observation condition, task and group factors ($F_{2,56}$=0.51, P=0.602, η^2=0.02).

Velocity

The results obtained for the CoP parameter, i.e., V_{avg}, are presented in Fig. 4.

In general, V_{avg} parameter was dependent on *observation condition* ($F_{2,56}$=26.47, P<0.001, η^2=0.49) with the smallest value of V_{avg} for BE (1.00 cm/s), higher for DE (1.05 cm/s), and the highest for the CE (1.18 cm/s). *Post-hoc* tests revealed that significant difference in V_{avg} was found between CE and BE (P<0.001) and between CE

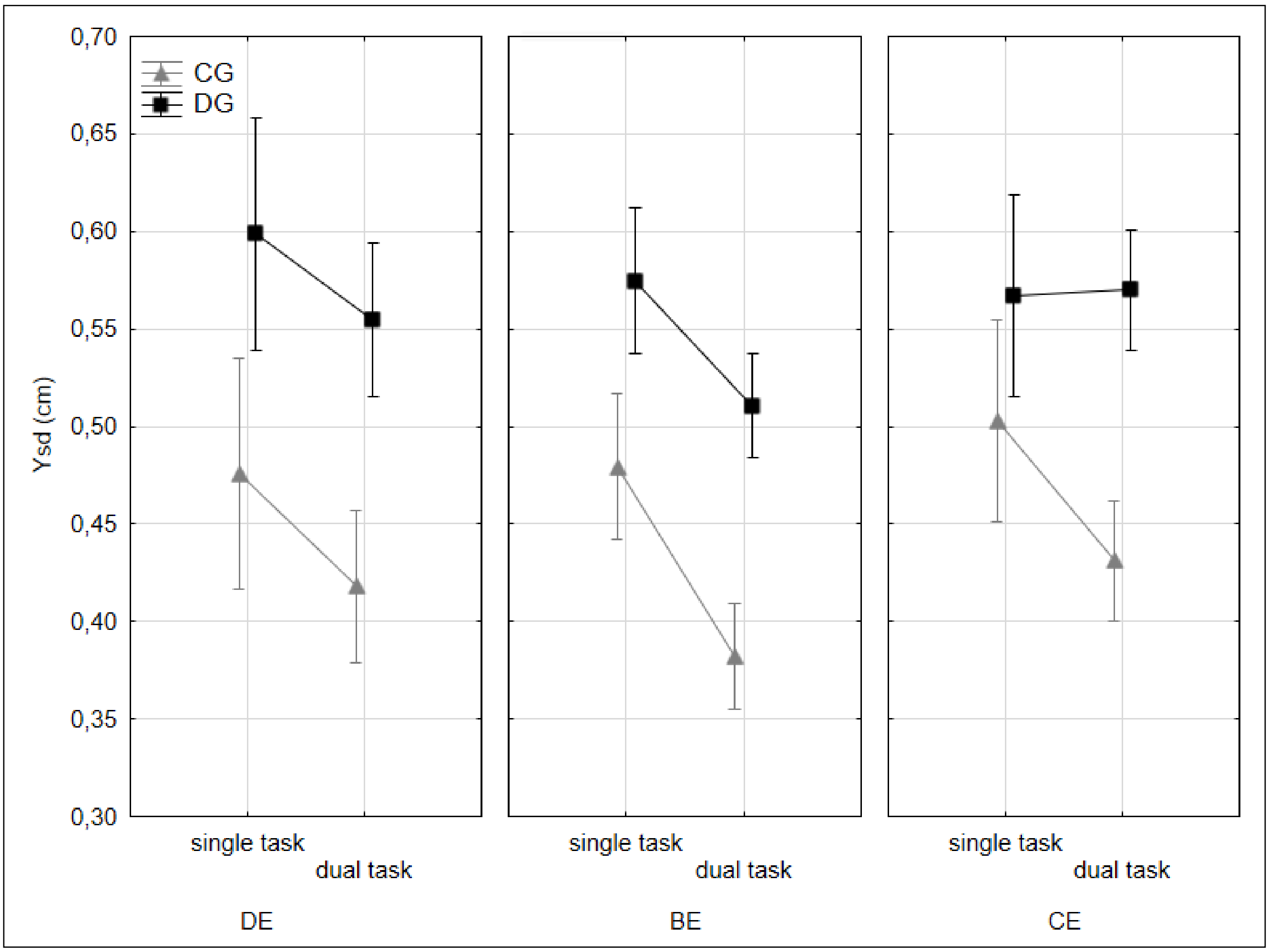

Fig. 2. The mean values of Y_{SD} parameter. The dyslexic group (DG – dark lines) and the control group (CG – light lines), ST – single task, DT – dual task, DE – viewing with the dominant eye, BE – viewing with both eyes, CE – closed eyes, the error bars stand for the mean standard error.

and DE (P<0.001) but not between DE and BE (*P*=0.181). This effect occurred in both groups, what was confirmed by the insignificant interaction between observation condition and group factors ($F_{2,56}$=26.47, P<0.001, η^2=0.49). Dual task did not significantly change the V_{avg} parameter, what was reflected by insignificant task and group interaction ($F_{1,28}$=0.15, P=0.710, η^2=0.01) or task and observation condition interaction ($F_{2,56}$=1.58, P=0.215, η^2=0.05). Three factor interaction was also insignificant (task x observation condition x group interaction: $F_{2,56}$=0.17, P=0.842, η^2=0.01).

DISCUSSION

The aim of the present research was to investigate whether impaired binocular fixation in dyslexic subjects may contribute to body balance impairments in adults. The results confirmed that dyslexic subject demonstrate problems with binocular coordination (related to binocular instability), which was manifested by the presence of FD on the Wesson card in all the subjects (as compared to only two non-dyslexic subjects) with the average FD values in dyslexics being significantly higher than in the controls (5 min of arc *vs.* 0.1 min of arc). In the Mallett test, FD had lower incidence than in the Wesson card but was still more common than in the control group (6 subjects out of 15 in the DG and none of the subjects in the CG). The results are consistent with the previous findings (Brenk-Krakowska et al., 2012), where binocular instability in the Wesson card was found in almost 70% of the study participants with dyslexia, and 56% of dyslexics had FD. Similarly, Przekoracka-Krawczyk et al. (2017), found fixation instability in 66% of dyslexic study subjects in the Mallett test (FD occurred in 41%) and in 76% of cases in the Wesson card (FD occurred in 72%). Moreover, the authors have shown that the binocular instability

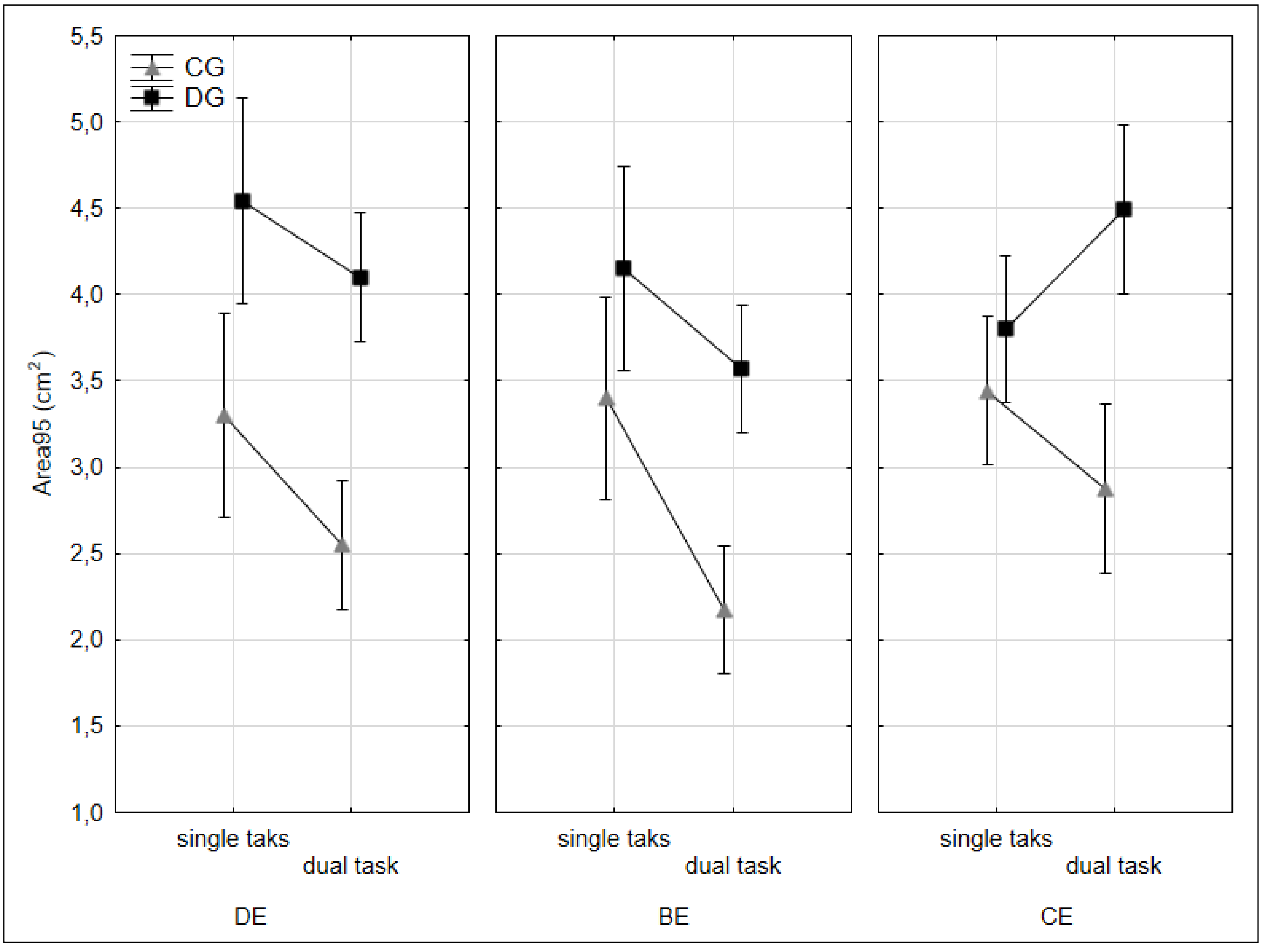

Fig. 3. The mean values of Area95 parameter. The dyslexic group (DG – dark lines) and the control group (CG – light lines), ST – single task, DT – dual task, DE – viewing with the dominant eye, BE – viewing with both eyes, CE – closed eyes, the error bars stand for the mean standard error.

impacts serial reaction time task, i.e., when the RT test was performed binocularly, the time taken to complete the task was significantly longer, as compared to monocular viewing (Przekoracka-Krawczyk et al., 2017). Therefore, research presented in the current study confirms that binocular fixation problem is a co-existing condition in dyslexia (Kapoula & Bucci, 2007; Bucci et al., 2008; Jainta & Kapoula, 2011), which may have an impact on reading difficulties.

However, binocular fixation did not have a destabilizing effect on balance in the dyslexic group (DG), despite the higher occurrence of FD. In both groups of subjects, body stability improved with binocular fixation compared to closed eyes, which was evident in the medio-lateral sway (parameter X_{SD}) and in the assessment of CoP speed (parameter V_{avg}). When looking with both eyes, the value of X_{SD} and CoP velocity was the lowest. When the eyes were closed, the values of both parameters increased, which was related to the loss of an important postural cue, which is vision. Under open eyes conditions, information coming from the retina such as retinal slip and motion parallax stabilizes the posture (Guerraz et al., 2000). Additionally, when both eyes are fixating on a target, proprioceptive signals from the extra-ocular muscles and vergence effort significantly improve posture (Kapoula & Le, 2006; Le & Kapoula, 2006; Kapoula & Bucci, 2007; Przekoracka-Krawczyk et al., 2014).The increase of CoP velocity with eyes closed could be explained as intensified activity of the muscles in the lower extremities when vision is eliminated (Amiridis et al., 2003; Kapoula & Le, 2006), forced the subjects to take increased effort (i.e., tense the leg muscles) in order to maintain an upright posture. Importantly, in the current study stabilizing impact of binocular viewing on the V_{avg} and X_{SD} parameters has been noted in both study groups, which indicates that the increased incidence of FD did not influence body balance in dyslexic adult subjects.

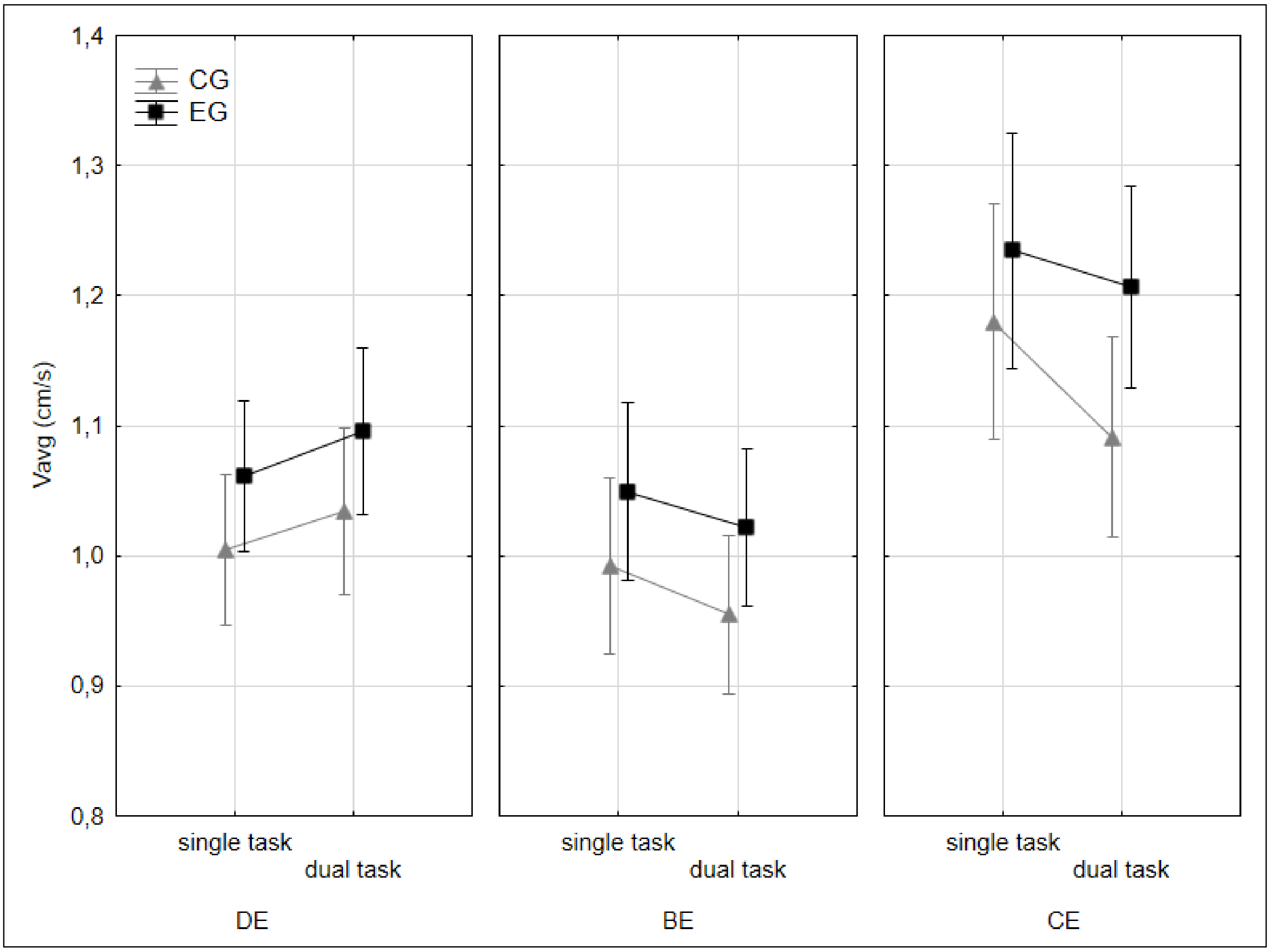

Fig. 4. The mean values of V_{avg} parameter. The dyslexic group (DG – dark lines) and the control group (CG – light lines), ST – single task, DT – dual task, DE – viewing with the dominant eye, BE – viewing with both eyes, CE – closed eyes, the error bars stand for the mean standard error.

Although majority of dyslexic subjects demonstrated FD on Wesson test, the values were probably not large enough to have any impact on the perception of movement parallax or convergence effort which could destabilize posture.

The other two parameters, antero-posterio sway (Y_{SD}) and sway area (Area95) of CoP, were not dependent on visual conditions. However, in both of them, the dyslexic group performed body stabilization worse than the control group. Area95 and Y_{SD} parameter values were worse in DG than in CG regardless of the viewing conditions as well as of the task (single and dual task). Both parameters were sensitive to the type of the task, such that in the dual task, CoP sway parameters were smaller, i.e., body stabilization was better. This effect was observed in both groups of subjects. The influence of the mental task on body stabilization will be discussed in the next paragraph.

The second objective of the study was to ascertain whether adults with dyslexia exhibit deficits in maintaining body balance in adulthood (Kerr et al., 1985; Nicolson & Fawcett, 1990; Maylor & Wing, 1996; Lang & Bastian, 2002). It is recommended that, in posturographic studies, an additional competing mental task should be introduced with the objective of engaging attentional resources and preventing them from being allocated to the control of posture (Nicolson & Fawcett, 1990). This approach is particularly useful in revealing compensatory mechanisms, as individuals with subtle postural deficits may rely on increased cognitive control to maintain balance under single-task conditions. As mentioned earlier, individuals with dyslexia tend to show poorer postural stability than their peers, especially under cognitively demanding dual-task conditions (Needle et al., 2006; Bucci et al., 2013).

However, dual-task conditions may also have the opposite effect on balance. Earlier studies have shown that introducing a mental task into posturographic testing under moderately challenging postural conditions tends to improve body stability in young healthy adults *via* working memory and attention mechanisms (Dault et al., 2001). An attentional task is thought to stabilize body balance more strongly by getting more general arousal (Hunter & Hoffman, 2001; Yardley et al., 2001). Increased levels of attention can activate the processing of information needed for body balance control (Bouisset & Duchêne, 1994; Maki & McIlroy, 1996).

And in fact, our study showed that after the implementation of the mental task, the body stability of the participants in the control group improved significantly in all three parameters examined describing the CoP sway (X_{SD}, Y_{SD}, and Area95). In addition to healthy adults (Dault et al., 2001), improved body balance in dual task, has been reported in individuals with strabismus, under postural conditions closely resembling those applied in the present study (Przekoracka-Krawczyk et al., 2014). The authors of the study hypothesize that the introduction of a mental task led to the stabilization of their body through an increase in muscle tension/stiffness. The observed improvements in CoP sway parameters may be interpreted as indirect indicators of increased muscle stiffness. It is possible that this form of adaptation enabled the control group to perform the mental task without compromising postural safety, such as the risk of falling.

However, in dyslexics only the antero-posterior sway (Y_{SD}) improved when examined in the dual task compared to the single task. In general, in DG adding the mental task neither significantly changed body sway in the medio-lateral axis (X_{SD}) nor reduced the sway area of CoP (Area95). The X_{SD} parameter in the single task did not differ significantly between groups, but a difference emerged when an additional mental task was added in the dual task condition. This difference was due to the fact that CG subjects stabilized the body in a mental task, an effect that was not present in DG.

It is thought that postural control is not fully automatically regulated, some part of attention is always required for body balance control (Lajoie et al., 1993). Thus, it can be observed that subjects in CG (without reading difficulties) were able to use some of their attentional resources to better control their posture despite performing a mental task. However, this ability was not possessed by the individuals in the dyslexic group studied in this work. While performing the mental task, they did not improve their body stabilization as much as the control group. In contrast to the control group, individuals with dyslexia seem to exhibit an impaired capacity to effectively utilize the strategy of tensing their bodies during challenging tasks.

The results not only show that dyslexic adults do not fully develop compensatory mechanisms for their porturographic deficits in a single task, but they also show impaired abilities to divide attentional resources between mental and motor tasks.

In summary, worse stabilization parameters for dyslexic individuals were observed despite visual conditions (fixation monocularly with dominant eye, binocularly and with eyes closed), what suggests that deficits in body balance were not related to unstable binocular fixation, but rather express general motor control deficits (Fawcett et al., 1996; Fawcett & Nicolson, 1999; Nicolson et al., 1999; Stoodley et al., 2005).What's more, for some posturographic parameters, vision, especially binocular fixation, helped stabilize the body balance, which was the case in both study groups. It seems possible that poor body balance, together with impaired motor learning and unstable binocular fixation combined with motor coordination deficits in dyslexia, co-occur as a consequence of impaired control on the cerebello-cortical level (Fawcett & Nicolson, 1999; Eckert, 2003; Menghini et al., 2006; Przekoracka-Krawczyk et al., 2017). This hypothesis seems to be supported by the results of research on subjects with binocular disorders or vergence deficits who also showed motor deficits, such as poor body balance (Bucci et al., 2009; Lions et al., 2013; Lions et al., 2014; Przekoracka-Krawczyk et al., 2014), impaired implicit motor learning (Przekoracka-Krawczyk et al., 2015) or improper walking strategy (Aprile et al., 2014).

Moreover, it was shown that patients suffering from diseases which affect the cerebellar region, in parallel with the typical cerebellar deficits (Ito, 1990; Molinari et al., 1997; Fulbright et al., 1999; Schmahmann, 2004; Folia et al., 2008), experience oculomotor coordination defects (Hain & Luebke, 1990; Rabiah et al., 1997; Kono et al., 2002).

The results obtained confirm that dyslexic individuals apart from reading and writing problems also exhibit motor deficits related to body balance. Moreover, they experience oculomotor deficits (fixation disparity which is related to binocular instability).

Both of these functions (body balance and binocular stability) are controlled by the cerebello-cortical network (Kapoula & Le, 2006; Bucci et al., 2009). Dysfunctions in this network may contribute to the weak postural control and binocular instability observed in dyslexic adults in our study. Since dyslexic individuals exhibit disturbances in body balance and binocular stabilization, one could argue that introducing techniques that improve cerebellar function (Reynolds et al., 2003; Reynolds & Nicolson, 2007) and binocular vision stability (Alvarez et al., 2010; Nawrot et al., 2013; Peachey & Peachey, 2015; Przekoracka-Krawczyk et al., 2018; Przekoracka-Krawczyk & Wojtczak-Kwaśniewska, 2018) into traditional reading and writing therapy methods (Werth, 2019) might improve the effect of the traditional therapeutic approach. However, this issue requires further research.

To our knowledge, it is the first study to test whether unstable binocular fixation in dyslexics could increase deficits in maintaining body balance, as previous studies have only been conducted with both eyes open or with the eyes closed. By comparing the results of monocular fixation with those of binocular fixation, we were able to assess its influence on body balance in dyslexics. This study evaluated the effect of binocular instability on body stabilization in adults. Of interest is also, whether this process occurs in a similar way in children with developmental dyslexia? In children, the nervous system is not yet fully mature, and it is possible that binocular instability could disrupt body balance at a very young age due to the lack of developed at least some compensation mechanisms. This issue seems very interesting and could be the subject of further research.

CONCLUSIONS

The study confirmed earlier reports of body balance impairment in subjects with developmental dyslexia, indicating that it also occurs in adults with dyslexia.

Importantly, the posturographic deficits observed in the dyslexic group occurred across all viewing conditions (monocular, binocular, and eyes closed), suggesting that binocular fixation itself did not exacerbate postural instability, despite the fact that fixation disparity was more prevalent in this group.

The adult subject with dyslexia in this study did not demonstrate an improvement in body balance in challenging cognitive task (presumably due to an inability to employ a strategy of increased body stiffness to avoid falling), in contrast to the control group.

Deficits in the stabilisation of binocular fixation might affect the reading process, but do not burden body balance scores in adults. Both, poor control of body balance as well as binocular instability, could be symptoms of cerebellar deficits.

Further research is needed to determine whether training in motor coordination, body balance, and binocular fixation stability may have a beneficial effect on individuals with developmental dyslexia.

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