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The use of the Warnke Method in dyslexia therapy for children

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ABSTRACT

Schools are introducing more and more non-evidence-based methods in dyslexia therapy. The aim of the study is to verify whether the novel method – Warnke Method can be regarded as a useful tool in dyslexia therapy in Polish children. The research group consisted of 37 pupils, between 10 and 12 years, diagnosed with developmental dyslexia. Participants were assessed at pretest on literacy and phonological processing and tasks measuring central auditory and visual processing with Warnke Method tools. Subsequently, each child underwent 20 training sessions of Warnke Method. Afterwards, children were assessed with posttest measures. Results showed that phonological processing served as a mediator in relationship between central auditory and visual processing and reading and writing skills. Significant improvement was observed with regard to central auditory and visual processing, phonological processing, as well as reading and writing skills. Furthermore, improvement was seen in students' grades of Polish language and literature classes.

Introduction

DSM-5 (American Psychiatric Association, 2013) defines dyslexia as an alternative term used to refer to a specific learning disorder concerning reading impairment which often coexists with difficulties in other language skills such as spelling and writing. It is primarily characterized by problems with accuracy or fluency of word recognition, poor decoding and poor spelling abilities.

Despite decades of study and an ongoing search for the causes and mechanisms of developmental dyslexia, there are still no clear answers. Morton and Frith (1995) proposed considering three levels—biological, cognitive and behavioral—when analyzing and understanding the phenomenon of dyslexia. We will refer to the biological level when considering genetic predispositions and the neurobiological characteristics associated with dyslexia; the cognitive level is related to pathological mechanisms. Finally, we will use the behavioral level for discussing the symptoms of dyslexia (for instance difficulties in reading and writing). The use of the above categories allows the organization of a significant amount of knowledge regarding developmental dyslexia (Frith, 2008; Morton & Frith, 1995).

Pathomechanisms for dyslexia

Many current theories look for the causes of dyslexia at the biological level, particularly in genetic predispositions (Anthoni et al., 2012; Galaburda, LoTurco, Ramus, Fitch, & Rosen, 2006; Kere, 2014; Krasowicz-Kupis, Bogdanowicz, & Wiejak, 2014; Mascheretti et al., 2017; Matsson et al., 2015; Neef et al., 2017; Pennington & Olson, 2008; Wilcke et al., 2009). Some neurofunctional and neuroanatomical differences between individuals with dyslexia and those who do not exhibit any learning difficulties have also been reported (Bloom, Garcia-Barrera, Miller, Miller, & Hynd, 2013; Clark et al., 2014; Démonet, Taylor, & Chaix, 2004; Goswami, 2014; Habib, 2000; Jednoróg, Gawron, Marchewka, Heim, & Grabowska, 2014; Norton, Beach, & Gabrieli, 2015; Płoński et al., 2017; Richlan, 2014; Wajuihian, 2012; Xia, Hoeft, Zhang, & Shu, 2016).

Because the diagnostic criteria for developmental dyslexia are various language difficulties—namely, challenges to master accuracy and/or fluency in word recognition, poor spelling, and decoding abilities (Lyon, Shaywitz, & Shaywitz, 2003)—the main approach in studies searching for the pathomechanism of the disorder stresses the role of linguistic processes. The most documented hypotheses which focus on auditory language functioning are: 1) the phonological deficit hypothesis, which examines difficulties with representation, storing, manipulating and retrieving speech sounds (Law, Vandermosten, Ghesquiere, & Wouters, 2014; Peterson, Pennington, Olson, & Wadsworth, 2014; Ramus, 2014; Ramus, Marshall, Rosen, & van der Lely, 2013; Snowling, 2000; Snowling & Hayiou-Thomas, 2006); and 2) the double deficit hypothesis which looks to deficits in both phonological processing and naming speed (Heikkilä, Torppa, Aro, Närhi, & Ahonen, 2016; Norton

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et al., 2014; Torppa et al., 2013; Wolf & Bowers, 1999).

However, in the last 25 years, theories have been put forward which suggest that deficits in dyslexia are more than just phonological in nature and can also include visual deficits. Stein (2001) and other researchers (Gori, Cecchini, Bigoni, Molteni, & Facoetti, 2014; Gori, Seitz, Ronconi, Franceschini, & Facoetti, 2016; Jednoróg, Marchewka, Tacikowski, Heim, & Grabowska, 2011; Stein, 2014) applied magnocellular deficit theory and looked for the causes of dyslexia in anomalies in neural pathways associated with visual analysis. Individuals with dyslexia present deficits in perception organization and in manipulation of visual information (Lipowska, Czaplewska, & Wysocka, 2011; Winner et al., 2001). They experience problems with: the simultaneous processing of multiple pieces of visual information and in visual working memory (Bosse, Tainturier, & Valdois, 2007), visual-motor coordination (Bogdanowicz, 1997; Crispiani, 2015), temporal integration of visual information (Stein, 2014), functional coordination (Lachmann, 2002), and procedural learning (Biotteau et al., 2017; Biotteau, Chaix, & Albaret, 2015; Mariën et al., 2014; Nicolson & Fawcett, 2011; Nicolson, Fawcett, Brookes, & Needle, 2010; Wong & Ho, 2010). There are also theories which point to deficits in temporal processing, which particularly pertain to the processing of short duration auditory and visual elements (Daikhin, Raviv, & Ahissar, 2017; Protopapas, 1634; Szeląg et al., 2014; Tallal, 1980), as well as attention (Borkowska, 2006; Bosse et al., 2007; Dahle & Knivsberg, 2014; Facoetti, Lorusso, Cattaneo, Galli, & Molteni, 2005; Ruffino, Gori, Boccardi, Molteni, & Facoetti, 2014) in the pathomechanism of dyslexia.

Language deficits influencing the clinical picture and therapy of dyslexia

The complex etiology of specific difficulties with reading and writing is mirrored by the variability in clinical pictures of developmental dyslexia exhibited by children and adolescents. Thus, there is a need to employ diverse therapeutic methods, tailored to children's individual needs and initial causes of difficulties (Bogdanowicz & Adryjanek, 2004; Bogdanowicz, Czabaj, & Bućko, 2008; Fletcher, Lyon, Fuchs, & Barnes, 2007; Shaywitz, Morris, & Shaywitz, 2008; Terzi, 2005; Tilanus, Segers, & Verhoeven, 2016). In contrast, the majority of therapeutic methods in many different languages are aimed at directly training phonological awareness and the reading and writing skills of dyslexic pupils. In Morton and Frith's terms (Morton & Frith, 1995), all of these methods are working on the cognitive and behavioral level.

English is a language with an opaque alphabetic orthography, i.e., it has many irregular letter-sound mappings. This creates difficulties both in reading and writing acquisition. It is more consistent at the level of morphological units than phonological units. Therefore more global methods of literacy training supported by phonics instruction aimed at both phonemes and larger onset-rhyme particles are the most efficient when the student is an English speaker (Gottardo, Pasquarella, Chen, & Ramirez, 2016). In contrast, Polish is a morphophonemic, inflectional, and consonantal language with semi-transparent correspondence between phonemes and graphemes (more transparent in terms of reading, less transparent in terms of spelling, although more transparent in both aspects than English; Awramiuk & Krasowicz-Kupis, 2014; Łockiewicz & Ciecholewska, 2017; Pawlicka, Lipowska, & Jurek, 2018). Therefore reading acquisition in Polish develops based on analytical and phonological strategies focusing on phonemes and syllables at the initial stage, developing in to global word- and phrase-based reading.

When working with a Polish-speaking child affected by developmental dyslexia, training focuses on grapheme-phoneme correspondences, word decoding, phoneme and/or syllable segmentation, and blending skills. In particular, the following methods are commonly used: reading words, sentences, and text excerpts in syllables; alternate reading of syllables, words, and sentences; loud and subvocal reading, quiet selective reading, and syllable reading; reading using an eye-level reading ruler; and group reading (Bogdanowicz, Adryjanek, & Rożyńska, 2014; Skibska, 2016; Trypuć, 2014). Writing acquisition evolves from partial representation of speech units, through a dominant phonetic strategy, to the stage where orthographic and morphological awareness develop and are central to writing (Awramiuk & Krasowicz-Kupis, 2014). Furthermore, when practicing writing skills, therapists employ the following exercises: drawing big letters with one's hand in the air; writing large letters on a blackboard; tracing letter templates; writing letters on sheets of paper of varying sizes; writing letters using a stencil; and copying letters using carbon paper. These exercises are often supplemented by art classes, exercises aimed at improving seeing shapes and backgrounds, as well as tasks related to spatial relationships (Bogdanowicz et al., 2014; Skibska, 2016; Trypuć, 2014). Therapeutic interventions used with children in other countries are similar (Abegg & Gentile, 2016; Alexander & Slinger-Constant, 2004; Denton & Madsen, 2016; Facoetti, Lorusso, Paganoni, Umiltà, & Mascetti, 2003; Snowling & Hulme, 2012; van der Leij, 2013), with some differences reflecting the specifics of the language (e.g. orthography transparency representing the level of grapheme-phoneme correspondence).

The Warnke Method in the treatment of dyslexia

To date, specialists who apply empirical research to clinical practice have been mostly interested in detecting symptoms of developmental dyslexia. The application of research to practice has resulted in the development of an effective system of diagnosing specific learning disorders and the creation of reliable diagnostic tools (Bogdanowicz, Kalka, Karpińska, Sajewicz-Radtke, & Radtke, 2012; Fawcett, Singleton, & Peer, 1998; Feifer, 2015; Flanagan, Ortiz, & Alfonso, 2013; Hook, Macaruso, & Jones, 2001; Jaworowska, Matczak, & Stańczak, 2010; Krasowicz-Kupis, 2009; Nayton, Hettrich, Samar, & Wilkinson, 2017; Nicolson & Fawcett, 1997; Reynolds & Caravolas, 2016; Wagner, Torgesen, Rashotte, & Pearson, 2013; Wiederhold & Bryant, 2012; Wolf & Denckla, 2005). However, few evidence-based effective approaches are available for developmental dyslexia that align with the research-based diagnostic tools. Thus, creating a comprehensive system of intervention as well as diagnostic assessment for children with developmental dyslexia has become a priority (Nayton et al., 2017; Reynolds, Nicolson, & Hambly, 2003).

In order to ensure that children with specific learning difficulties can benefit from effective, evidence-based forms of therapy, the current study attempts to provide data on whether the Warnke Method—a fairly new therapeutic approach which has generated significant interest among Polish teachers and therapists—is a valid and efficient therapeutic or supportive method, or at least one that does not lower children's phonological awareness and reading/writing skills when used in the therapy of developmental dyslexia.

The method was developed by Fred Warnke (2000) for individuals who experience difficulties with reading, writing, and speaking. It assumes that difficulties in learning the complex skills of reading, writing, and speaking result from deficits in the processing of auditory, visual, and motor stimuli—mainly due to a decreased level of automaticity of these processes (Warnke, 2014). This method requires the use of special equipment. Diagnostic and therapeutic equipment allows the assessment of functioning in eight tasks: visual and auditory order threshold, spatial hearing, pitch discrimination, auditory motor timing, auditory choice reaction time, frequency pattern recognition, and tone duration recognition. The exercises are performed while wearing headphones (Odowska-Szlachcic & Mierzejewska, 2013). According to Warnke (2014), the method is aimed at training central auditory and visual processing with emphasis on auditory motor timing, automatic balance retainment, and auditory choice reaction time as particularly important in reading and writing.

The Warnke Method differs from other well-established methods focusing on fluency (e.g. RAVE-O; Wolf et al., 2009). Above all, the main difference is that it does not directly employ typical linguistic exercises—syllable and phoneme manipulation tasks, learning about

words in context, etc. The method can be therefore grounded in Tallal's (1980) 'rapid temporal processing' theory, which identifies basic perceptual processing as a possible cause of dyslexia, especially the apprehension of temporal auditory and visual patterns. Studies report deficits in perceptual sequence learning in dyslexics, either with use of visual (Bennett, Romano, Howard, & Howard, 2008; Howard, Howard, Japikse, & Eden, 2006) or auditory stimuli (Helenius, Uutela, & Hari, 1999; Tallal, 1980). The lower results of poorer readers on rapid naming tasks (RAN; Wolf & Bowers, 2000) may point to a sequence learning deficit, as sequential processing is also involved in RAN tasks (Bennett et al., 2008). Furthermore, the cerebellar theory (Nicolson, Fawcett, & Dean, 2001) stresses the contribution of the cerebellum to central-auditory functions, speech perception, speech timing, and, hence, phonological awareness (Stoodley & Stein, 2011).

However, the question arises as to whether performing compensatory work using this procedural learning system but with the use of non-linguistic material might be beneficial for literacy development in dyslexics. Stoodley (2016) acknowledges the potential benefits. On the other hand, Kearns and Fuchs (2013) question the effectiveness of training of underlying cognitive processes in dyslexia therapy.

The present study

Since the Warnke Method may be regarded as being based on scientific theories related to the pathomechanism of dyslexia and is generating interest among practitioners working with dyslexic children, we examined its efficacy in the context of its potential implementation (in terms of the number and frequency of training sessions) in public schools in Poland.

The goal of the current study was to investigate the effectiveness of the eight tasks (visual and auditory order threshold, spatial hearing, pitch discrimination, auditory motor timing, auditory choice reaction time, frequency pattern recognition, and tone duration recognition) of the Warnke Method in the therapy of developmental dyslexia in children. Some necessary modifications (regarding the frequency of the sessions) were made so that the Warnke Method could be used in a school setting.

In summary, we examined the following three research questions

First, we examined the relationships between the variables—in particular, we were interested in whether the impact of central auditory and visual processing on reading and writing skills was direct or indirect, through phonological processing.

1. Does phonological processing mediate the relationship between central auditory and visual processing and reading and writing skills?

Furthermore, we examined two questions about the efficiency of the Warnke Method in developmental dyslexia therapy in children:

2. Does a course of 20 sessions of training with the Warnke Method improve the functioning of children with developmental dyslexia in terms of the central auditory and visual processing?
3. Does training of central auditory and visual processing with the Warnke Method improve phonological processing in children with developmental dyslexia as well as their reading and writing skills, decreasing the severity of their dyslexic deficits?

Method

Participants

Forty students from the fourth and fifth grade of primary schools in northern and central Poland with a formal diagnosis of developmental dyslexia took part in the study (19 children presented severe reading problems, 15 moderate problems, and three children mild problems). The age of the study group is a result of regulations from the Polish Ministry of Education (2010) stating that developmental dyslexia can be diagnosed after the third year of primary school education, when a child is expected to have mastered reading and writing skills. Participants were recruited through contact with teachers and psychologists working in public and non-public schools. The children who took part in the study did not regularly engage in any other therapeutic intervention aimed at difficulties in reading and writing. They also did not exhibit any other types of learning difficulties (e.g. developmental dyscalculia), nor did they have any other clinical diagnoses (e.g. attention deficit hyperactivity disorder, conduct disorder, or autism spectrum disorder). Throughout the course of the intervention, three children were excluded. Two of them began to exhibit neurological symptoms (headaches, nausea) and one was excluded because of long-term hospitalization which resulted in absence from school and lack of regularity in therapeutic training. As a result, the final group comprised 37 children: 17 girls (45.95% of the sample) and 20 boys (54.05% of the sample) aged between 10 and 12 ($M = 11.23$; $SD = 0.63$).

Measures

Three research tools were used in the study: *The Battery of Methods for Diagnosing the Causes of Failure at School 10/12 (Polish: Bateria Metod Diagnozy Przyczyn Niepowodzeń Szkolnych 10/12;* Bogdanowicz et al., 2012) was used to assess phonological processing and reading and writing skills; the *Brain-Boy Universal Professional* device was used to assess central auditory and visual processing at the beginning of the project and after 20 training sessions; and the *Brain-Boy Universal* device was used during the 20 training sessions.

The Battery of Methods for Diagnosing the Causes of Failure at School 10/12 (Polish: Bateria Metod Diagnozy Przyczyn Niepowodzeń Szkolnych 10/12; Bogdanowicz et al., 2012) is a tool used for the initial diagnosis of specific learning disorders in children aged 10–12. The tool is comprised of tests diagnosing visuospatial functions (visuospatial perception and the speed of visual perception when working with visual material) and phonological processing (phoneme differentiation, phonological memory, phoneme analysis skills, phoneme isolation, phoneme synthesis, and attention span). The battery is characterized by good content validity and satisfactory construct validity. The internal consistency of the tool (Cronbach's α) was 0.77. The validity of the tool was determined based on the factor structure and its correspondence with the psychological concept of developmental dyslexia symptoms. A relationship between battery scores and school achievement has also been confirmed (see Bogdanowicz et al., 2012). The current research used the sub-tests investigating phonological processing and reading and writing skills, as the Warnke Method is theoretically addresses children's functioning in these areas.

Phonological processing

Phonological awareness

1. *Phonemic Differentiation Task*: assessing whether two non-words are identical or different. Consists of 25 pairs of non-words, of which six are identical and 19 pairs include non-words differing from each other by one phoneme. The task measures the ability to analyze the phonemic structure of a pair of nonsense words.
2. *Phonemic Analysis*: the subject hears a nonsense word and breaks it into phonemes. Consists of 7 non-words ranging between four and ten phonemes.
3. *Phonemic Synthesis*: the subject composes a nonsense word out of phonemes vocally produced by the researcher. The task consists of seven non-words ranging between four and ten phonemes.
4. *Phoneme Deletion*: the child is asked to repeat a word produced by

the researcher while skipping its third phoneme. The task consists of ten one- or two-syllable words. The task requires phonemic analysis, phoneme isolation, phonemic synthesis, as well as phonological memory skills.

5. *Spoonerisms*: comprised of two parts:
   A. *Spoonerisms – production*: the subject is asked to exchange the first syllables in both words of a two-word phrase, creating a two-nonwords phrase. Consists of five two-word phrases.
   B. *Spoonerisms – recognition:* this task involves the same activity but starting with the non-word phrase and resulting in the meaningful phrase—i.e. the child is asked to swap the first syllables in a phrase composed of two nonsense words, resulting in the creation of two real words (a meaningful phrase). Consists of four non-word phrases. The score on the Spoonerisms task is the total score obtained on the production and recognition part.

Phonological memory

1. *Repeating non-words*: the child listens to a number of nonsense words (from three to six non-words consisting of between one and three syllables) and is required to recall as many of them as possible (in any order). Assessment of short-term phonological memory.

Two of the above subtests (Spoonerisms and Phonological Memory) were used to build a latent variable: *phonological processing*. The reliability measured by the omega internal consistency coefficient for this variable in the current study was 0.67. The Spoonerisms task is the most complex, requiring a high level of phonological awareness (including phoneme differentiation, phonemic synthesis, and analysis and deletion skills) in order to obtain a high score (from seven to nine points in this task). On the other hand, repeating non-words is considered an important indirect measure of phonological working memory. One of the most important functions of phonological memory is temporary storage of incoming linguistic information. It also supports the subvocal rehearsal process. These functions have significant meaning for vocabulary acquisition, acquiring reading skills as well as reading and oral language comprehension (Baddeley, 2012; Marini, Ruffino, Sali, & Molteni, 2017; Nicolielo-Carrilho, Crenitte, Lopes-Herrera, & Hage, 2018).

Reading and writing skills

1. *Reading Aloud*: reading a meaningful text out loud. The text consists of 11 phrases with difficulty level adjusted to the reading skills of fourth and fifth graders (different texts for the fourth and fifth grades). The task measures reading skills in terms of speed and accuracy.
2. *Reading Aloud – Comprehension*: after the child reads the text, they are asked to answer 4 questions regarding the text.
3. *Reading Nonsense Words:* the child is asked to read aloud 71 nonsense words, ranging from two to four syllables. The task is aimed at the assessment of decoding without reference to meaning, i.e. excluding compensation mechanisms associated with word memory.
4. *Dictation:* the child is asked to accurately write down a text dictated by the researcher on a sheet of paper. The text consists of 11 sentences (96 words) in the fourth grade and 13 sentences (104 words) in the fifth grade. Afterwards, the child is asked to write down 24 short phrases dictated to her/him. The task measures the skill of writing from hearing, accurate spelling, and the efficiency of direct auditory memory. The score is the number of errors (both spelling and punctuation) made by the child (the higher the score, the lower the writing skills). The following kinds of errors are taken into account in the score: 1) spelling mistakes (regarding orthography, but also omission/addition of letters, letter/syllable repetition, word distortions) and 2) punctuation errors.

We used two of the above measured skills (reading words aloud measuring the reading speed and accuracy and dictation—number of errors—measuring the writing skill – writing accuracy) to build a latent variable named *reading and writing skills*. Reliability measured by the omega internal consistency coefficient for the created variable in the current study was 0.69.

Central auditory and visual processing measured using Warnke Method tasks

The Warnke Method (Warnke, 2000, 2014) requires the use of specialist devices, namely headphones and the following equipment:

1. The *Brain-Boy Universal Professional (BUP)* device allows the accurate assessment and training of central auditory and visual processing in the tasks listed below. All tasks are performed by the child while wearing headphones. Based on the results of the initial assessment, a training program tailored to the individual needs and abilities of the child is proposed.
2. The *Brain-Boy Universal* device is used mainly for training the skills listed below. The plan for its use (the sort and number of games played in each session together with the difficulty level) is based on the results of the assessment with the BUP device. The device is equipped with eight games and has options for adjusting the level of difficulty based on the user's performance.

The name of the device (*Brain-Boy) is intended to associate* it with the *Game Boy*—in order the decrease the anxiety related to undergoing training with a specialized device and make children eager to train.

Both the assessment and the training in the Warnke Method are administered in the form of eight different games:

1. The *Visual Brain-Boy* game – visual order threshold: the child sees one flash of light on the left and one on the right side. The task is to decide on which side it appeared first; pairs of flashes of light appear with progressively shorter time intervals between them (from 400 to 5 ms).
2. The *Auditory Brain-Boy* game – auditory order threshold: the child hears one click in the left ear and one in the right ear. The child needs to decide in which ear the stimulus appeared first; the pairs of sounds appear with progressively shorter time intervals between them (from 400 to 5 ms).
3. The *Klik-Boy* game – spatial hearing: the child hears one click and has to decide on which side of their head it appeared.
4. The *Sound-Boy* game – pitch discrimination: the child hears two sounds of different tones and has to decide in which order they appeared.
5. The *Sync-Boy* game – auditory motor-timing: the child hears a regular sequence of sounds (clicks) which appear in the left and the right ear, alternately. The child needs to synchronously press buttons to the rhythm of the heard clicks.
6. The *Speed-Boy* game – auditory choice reaction time: the child hears two sounds of different tones in the left and right ears. The child has to press a button as fast as possible on the side from which the lower tone came.
7. The *Trio-Boy* game – frequency pattern recognition: the child hears three sounds, one of which differs from the two others in terms of the tone. The child has to identify which sound was different from the other two.
8. The *Long-Boy* game – tone duration recognition: the child hears three sounds, one of which lasts longer than the other two sounds. The child needs to assess which sound differed in duration from the other two.

Finally, five of the eight tasks (visual and auditory order threshold, pitch discrimination, frequency pattern recognition, and tone duration recognition) constituted the latent variable named *central auditory and*

visual processing. Reliability measured by the omega internal consistency coefficient for this variable in the current study was 0.77.

Procedure

Before conducting this research, consent was obtained from the parents of students recruited to participate in the project. The parents were informed about the anonymity of the collected data and about their use for an empirical study. Research was conducted throughout the 2015/2016 school-year (approximately eight months) in primary schools in northern and central Poland.

In the first stage of the research (time one), which took place after the beginning of the school year (September–October), parents filled-in a questionnaire regarding the life and medical history of the child as well as the socio-economic status of the family. In the second stage, the researcher met each child during an initial assessment at the beginning of the school year. The initial assessment included phonological processing and reading/writing skills *using the Battery of Methods for Diagnosing the Causes of Failure at School 10/12 (Polish: Bateria Metod Diagnozy Przyczyn Niepowodzeń Szkolnych 10/12;*Bogdanowicz et al., 2012), as well as assessment of the child's central auditory and visual processing using the *Brain-Boy Universal Professional* device.

During the next stage, which lasted approximately eight months, the subjects underwent a series of 20 training sessions using the Warnke Method and the *Brain-Boy Universal* device. Six training sessions were of a combined auditory-visual character; the remaining 14 were based on auditory stimuli. The duration of a single session was approximately 30 min and as the training progressed it was shortened to about 15 min. Each training session took place in the psychologist's or speech therapist's office at school. We cooperated with the specialized group of school psychologists and speech therapists who completed a specialist course in assessment and training with the Warnke Method.[1] Training sessions with the children took place weekly; however, during Christmas, Easter, and the Winter school vacation, two-week long breaks between the training sessions took place (resulting in an average of three sessions per month). In the last stage, after completing 20 therapy sessions, the children underwent a final post-test assessment (time two) using the same assessment battery as at first stage of the study.

Statistical analyses

Statistical analyses were conducted in two stages: in the first stage, a theoretical model describing the relations between the variables was tested; in the second stage, participants' mean scores were compared at baseline and after completing the intervention, in order to assess the effectiveness of the Warnke Method. The model of the relationship between the variables was tested using structural equation modelling (SEM). The model incorporated three latent variables: Central auditory and visual processing (indicators: Other threshold – visual, Order threshold – auditory, Pitch discrimination, Frequency pattern recognition, Tone duration recognition), Phological processing (indicators: Phonological memory and Phonological awareness), and Reading and writing skills (representing by Reading speed and accuracy and Writing accuracy). In order to estimate the parameters of the model, a maximal likelihood estimator (ML) was used. When assessing the fit of the model to data, the following measures were used: χ^2, root mean square error of approximation (RMSEA), and comparative fit index (CFI; Kline, 2016).

The mediating role of *phonological processing* was examined by testing the indirect effect of *central auditory and visual processing* on reading and writing skills. Following the recommendations of Cheung and Lau (2007)—especially in the context of a very small sample—we implemented a bootstrapping procedure in which 1000 bootstrap samples were created at a 95% confidence interval. In order to assess whether the indirect effects are significant, we used the bias-corrected percentile method.

Calculations were conducted in an R environment using the lavaan package (Rosseel, 2012). A paired *t*-test was used to test differences in mean scores of the subjects at baseline and after the completion of 20 training sessions. For the *central auditory and visual processing* indices, results were normalized in a way such that the subjects' developmental performance change due to age was taken into account (norms for the eight tasks trained with use of the *Brain-Boy Universal include* ages five to twelve). In the case of *phonological processing* and *reading and writing skills*, raw scores were used for comparison.

Results

Table 1 Presents means, standard deviations, and correlation coefficients of the analyzed variables.

In line with the hypotheses, phonological memory was highly correlated with producing and recognizing Spoonerisms ($r = 0.51$), which supports the idea that these skills should be treated as indicators of phonological processing of the first category.[2] Importantly, only *phonological processing* (as a latent variable) was significantly correlated with reading and writing skills. Furthermore, analysis of correlation indicates a significant positive association between *central auditory and visual processing* with *reading and writing skills* (as latent variable), as well as with *phonological processing* (Figs. 1 and 2).

Relationship between central auditory and visual processing and reading and writing skills—the mediating role of phonological processing

In the first step of statistical analysis, a theoretical model describing relations between the investigated variables was tested. This model (see Fig. 3) includes three latent variables: 1) *central auditory and visual processing*, with the results of five of the eight measured tasks in the Warnke Method as indicators; 2) *phonological processing*, whose indicators are phonological memory (repeating nonwords) and phonological awareness (producing and recognizing Spoonerisms); and 3) *reading and writing skills*, whose indicators are the speed of reading and accuracy of writing (dictation). It was assumed that the relationship of *central auditory and visual processing* with *reading and writing skills* is mediated by *phonological processing*. The model was tested using data from the baseline measurement. The results of path analysis are presented in Fig. 3. The model fit the data well [$\chi^2 = 29.43$ ($df = 25$; $p = .25$); CFI = 0.95; RMSEA = 0.069].

Effects of training central auditory and visual processing using the Warnke Method

In order to analyze the effectiveness of the Warnke Method in the development of *central auditory and visual processing*, *phonological processing,* and *reading and writing skills*, we compared the mean scores for the investigated variables before and after training (see Table 2).

In line with expectations, mean scores obtained by the participants were significantly higher after 20 sessions of training, with the

[1] The specialist training course of the Warnke Method includes both lectures and practical exercises. In Poland trainings are conducted only by certified educators from BioMed Neurotechnologie, with approval from MediTech Electronic GmbH. Participants receives a certificate entitling to conduct diagnostics and training using the Warnke Method. The training is intended for psychologists, teachers and therapists working with both, children and adults.

[2] The second category of phonological processing, is composed of phonemic analysis and phonemic synthesis: both variables were highly correlated ($r = 0.50$). At the same time, no significant relationship was observed between variables from the separate categories.

Table 1
Descriptive statistics and correlation coefficients between tested variables.

Variable	*M*	*SD*	*1*	*1.1.*	*1.2.*	*1.3.*	*1.4.*	*1.5*	*2*	*2.1.*	*2.2.*	*3*	*3.1.*	*3.2.*
1. Central auditory and visual processing (latent variable)	–	–	–											
1.1. Order threshold – visual	27.46	27.37	0.71**	–										
1.2. Order threshold – auditory	44.78	26.07	0.68**	0.30	–									
1.3. Pitch discrimination	22.89	26.07	0.48**	0.17	0.08	–								
1.4. Frequency pattern recognition	37.32	25.91	0.84**	0.47**	0.48**	0.41*	–							
1.5. Tone duration recognition	45.59	27.55	0.75**	0.48**	0.47**	0.04	0.57**	–						
2. Phonological processing (latent variable)	–	–	0.38*	0.06	0.16	0.28	0.52**	0.29	–					
2.1. Phonological memory (Repeating nonwords)	7.43	2.24	0.39*	0.00	0.24	0.27	0.50**	0.34*	0.87**	–				
2.2. Phonological awareness (Spoonerisms)	1.86	2.06	0.29	0.10	0.04	0.22	0.42*	0.16	0.87**	0.51**	–			
3. Reading and writing skills (latent variable)	–	–	0.33*	0.03	0.22	0.13	0.33	0.43**	0.64**	0.68**	0.43**	–		
3.1. Reading speed and accuracy (Reading aloud)	61.05	27.88	0.26	−0.04	0.19	0.07	0.30	0.39*	0.63**	0.61**	0.48**	0.20	–	
3.2. Writing accuracy (Dictation)	42.51	20.36	−0.32	−0.13	−0.19	−0.18	−0.27	−0.36*	−0.46**	−0.56**	−0.24	−0.31	−0.52**	–

Note: N = 37.
* p < .05.
** p < .01.

Fig. 1. The Brain-Boy Universal Professional device.

(a)

(b)

Fig. 2. a. The Brain-Boy Universal device. b. The Brain-Boy Universal device.

exception of the tone duration recognition task results. For this variable, a statistically significant difference was only observed in pupils whose baseline level of *central auditory and visual processing* was below the median ($M_{\text{Before training}} = 25.00$, $SD = 21.64$, $M_{\text{After training}} = 41.16$, $SD = 25.77$, $t = -2.10$, $p = .05$).

The results of children with developmental dyslexia in terms of *phonological processing* as well as *reading and writing skills* were also compared to developmental norms provided with *the Battery of Methods for Diagnosing the Causes of Failure at School 10/12 (Polish: Bateria Metod Diagnozy Przyczyn Niepowodzeń Szkolnych 10/12*; Bogdanowicz et al., 2012). The norm group was composed of children aged 10–12 years with no dyslexia diagnosis. The standardized scores represented level of skills expected at the specific developmental age and they were set every three months. On this basis, profiles of the severity of dyslexic difficulties exhibited by the children were created. Low scores (0–7 for Phonological memory, 0–3 for Phonological awareness, 0–65 for Reading speed and accuracy and more than 28 mistakes for Writing accuracy) indicate a high severity of difficulties. The aim of this was to verify whether the effects obtained through the Warnke Method training were due to the natural process of development over the course of the ten months of the school year or whether they were the result of the intervention. The analyses indicated a decrease in the dyslexic difficulties in the group of children studied. The percentage of low scores decreased and average and high scores increased in the group, as shown in Fig. 4.

The number of children who scored high on *Phonological Memory* (the first of the phonological processing indicators in our study) increased (from three to eight children), while the number of children who scored low dropped (from 15 to 10). However, the distribution of scores in comparison to developmental norms changed most with regards to the *Spoonerisms* subtest (the second of the phonological processing indicators in our study). During the final assessment, only seven out of 37 children obtained low scores, which is about 20% of the group. During the initial assessment, 23 children (60% of subjects) scored low in this task. During the primary assessment, only one child

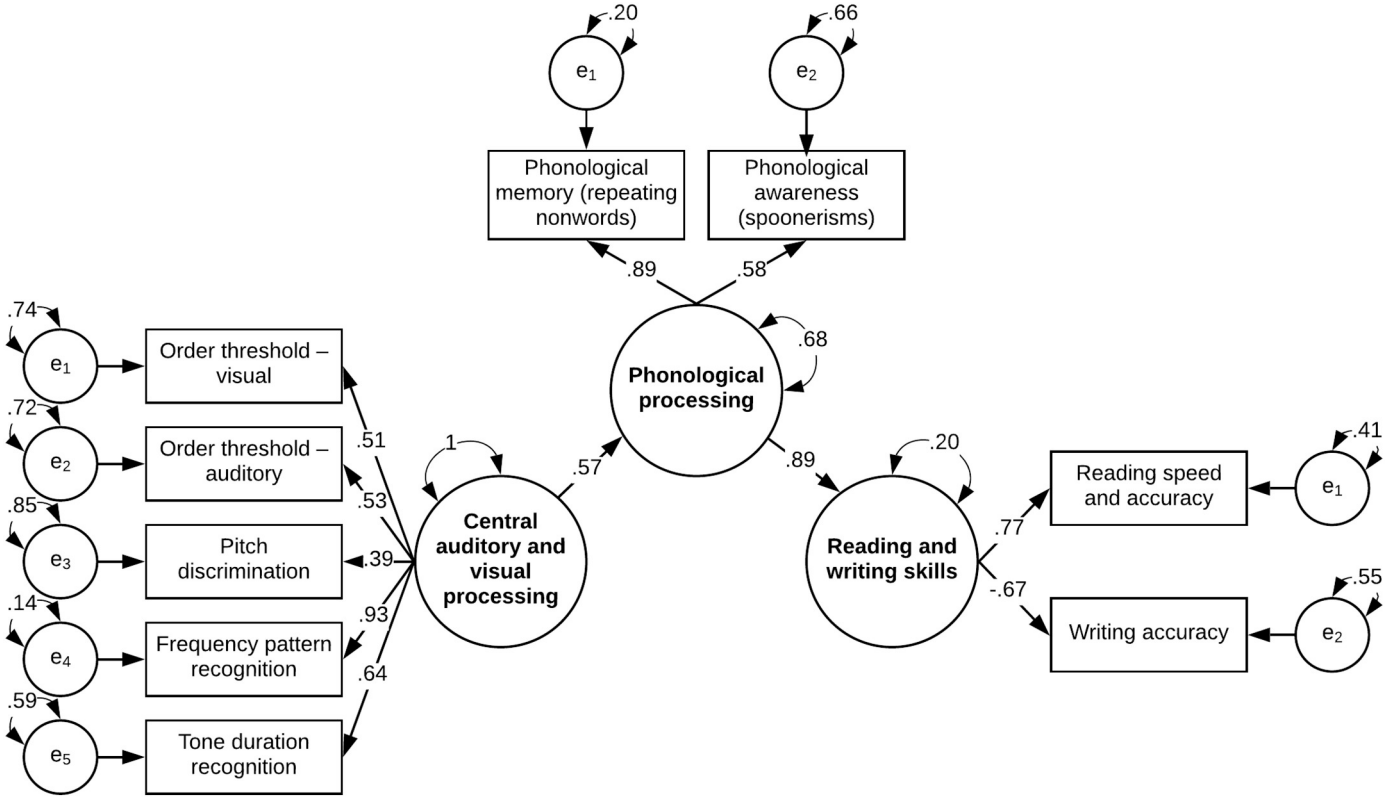

Fig. 3. Model of the relationship between central auditory and visual processing, phonological processing, and reading/writing skills.

Table 2
Comparison of mean scores for central auditory and visual processing, phonological processing, and reading and writing skills before and after training with the Warnke Method.

Variable	Before training		After training		*t*
	M	*SD*	*M*	*SD*	
Order threshold – visual (standard score)	27.46	27.37	48.78	34.54	−3.14**
Order threshold – auditory (standard score)	44.78	26.07	59.19	29.75	−3.26**
Pitch discrimination (standard score)	22.89	26.07	41.27	31.45	−4.85**
Frequency pattern recognition (standard score)	37.32	25.91	49.95	26.76	−3.16**
Tone duration recognition (standard score)	45.59	27.55	46.57	28.31	−0.17
Phonological memory (Repeating non-words; raw score)	7.43	2.24	8.76	2.58	−3.68**
Phonological awareness (Spoonerisms; raw score)	1.86	2.06	4.51	2.63	−6.34**
Reading speed and accuracy (Reading aloud; raw score)	61.05	27.88	70.38	28.61	−4.13**
Writing accuracy (Dictation; raw score, number of errors)	42.51	20.36	30.89	14.48	5.53**

Note: N = 37.
** $p < .01$.

scored in the range that qualified as high, while nine children obtained high scores on the final assessment. The children's reading skills (speed and accuracy of reading aloud—the first of the reading and writing skills indicators in our study) also improved in comparison to norms. The number of pupils who scored average on the final measurement did not change, however the number of persons scoring high increased (from one to three) and the number of pupils with low scores decreased (from 23 to 21). One might observe that this change affected two individuals, however the children were about ten months older at this point than during the primary assessment and thus also more was demanded of them. Significant differences in results compared to developmental norms were observed in the *Dictation* task (the second of the reading and writing skills indicators in our study), aimed at assessing writing skills in terms of accuracy of spelling, punctuation, and writing speed. Average and high scores constituted 60% of all scores during the final assessment, while at baseline they only constituted about 40%. None of the subjects scored high in their initial assessment, and at final measurement three subjects obtained such a result. The majority of scores were average at final measurement, while at baseline a considerable majority of scores were low.

This improvement was also visible in the students' grades obtained during the Polish language classes (where a substantial amount of time is spent on reading, reading comprehension, and dictation). At baseline (the previous year's grade from the Polish language course), students' grades were $M = 3.1$, while grades at the end of the school year (after completion of the 20 training sessions) were significantly higher $M = 3.92$ ($p < .05$; with the 1–6 grading system in Poland).

Discussion

The primary goal of this study was to verify whether implementing the Warnke Method in the therapy of children with developmental dyslexia for a period of approximately eight months (20 training sessions) is an effective form of improving phonological awareness,

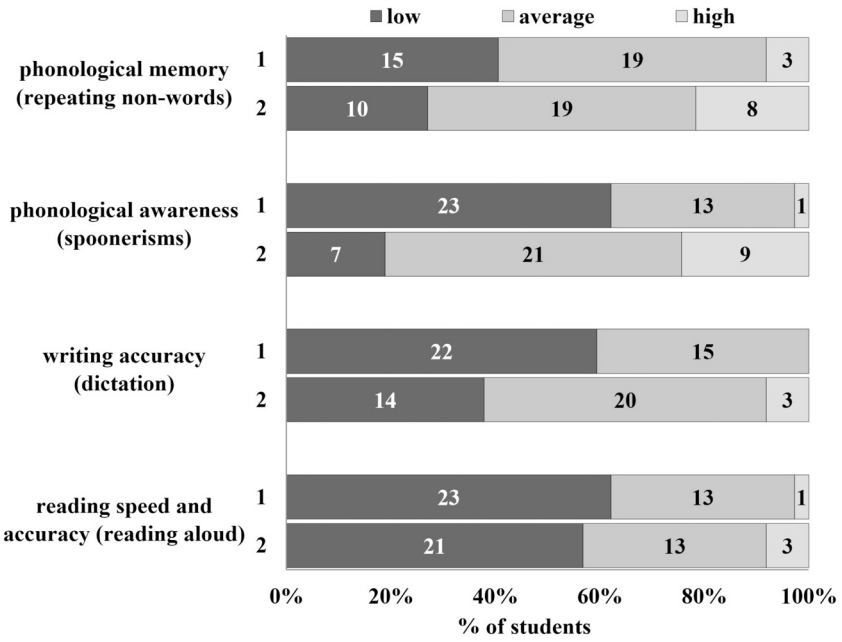

Fig. 4. Severity of dyslexic difficulties in comparison to developmental norms during the first and the second assessment (before and after the Warnke Method training).

phonological memory, and, most importantly, reading and writing skills. We were also interested in the role of *phonological processing* in the relationship between *central auditory and visual processing* and *reading and writing skills*.

The results showed that after the 20 training sessions, children's scores improved for *central auditory and visual processing skills*. Both visual and auditory differentiation thresholds improved as well as pitch discrimination of non-speech sounds, most probably as the result of training (since standardized scores were compared). Moreover an improvement in *phonological processing* was also observed at the final assessment, in terms of both phonological memory (repeating non-words) and phonological awareness (the Spoonerisms task). Comparison of the profiles of the studied pupils, before and after the intervention—in particular on tests from *The Battery of Methods for Diagnosing the Causes of Failure at School 10/12 (Polish: Bateria Metod Diagnozy Przyczyn Niepowodzeń Szkolnych 10/12*; Bogdanowicz et al., 2012)— indicated a decrease in dyslexic difficulties in children who participated in the intervention. The distribution of the scores with regard to developmental norms changed most on the Spoonerisms subtest. This task requires a high level of phonological awareness, syllable isolation, syllable synthesis, as well as phonological memory; therefore, it is difficult for children. It has proven to be effective at 'spotting' children with learning difficulties (Bogdanowicz et al., 2012). The quality of reading non-words aloud also improved in terms of the speed and accuracy in children with dyslexia in comparison to developmental norms, as well as their accuracy of writing. The number of errors with respect to spelling and punctuation was significantly lower from time one to time two both in raw and standardized scores.

However the question arises as to what extent the aforementioned improved scores are due to the Warnke Method training rather than other possible factors (e.g. the education process or the home environment). Since our study was not a randomized control trial, conclusions must be drawn very cautiously. There was no control group in our study, which is a significant limitation. However the studied group comprised of children who were diagnosed with developmental dyslexia and were not undergoing other forms of therapy aimed at learning disorders (including dyslexia) during the period of the Warnke Method training. The exposure to only one type of therapeutic intervention and also comparing the obtained results to the standard scores (referring to the specific developmental age) suggest that observed changes might be attributed as an effect of the Warnke Method training.

Conclusions regarding the pathomechanisms for dyslexia

Initially, a theoretical model was tested describing the relations between the variables hypothesized to be underlying deficits for developmental dyslexia. It is worth stressing that this model turned out to appropriately describe the relations between central auditory and visual processing, phonological processing, and reading and writing skills - as previously described in theoretical models of dyslexia (Alt et al., 2017; Christo, Davis, & Brock, 2009; Heikkilä et al., 2016; Nicolson & Fawcett, 2011). The model showed that *phonological processing* mediated the relationship between the other two variables. We can thus say that *central auditory and visual processing* predicted the *phonological processing* of children with developmental dyslexia, which in turn predicted their reading and writing skills. This means that training with the Warnke Method seemed to directly improve phonological processing skills and, through these phonological processing skills (indirectly), reading and writing skills. Specifically, *phonological processing* included: 1) short term phonological memory and 2) phonological awareness including phonemic and syllable differentiation and manipulation.

The obtained results support the theories stressing the importance of basic perceptual processing and automaticity in the pathomechanism for dyslexia. They also support the notions that training of underlying cognitive processes and additionally with use of the non-linguistic material may be beneficial in dyslexia therapy. The role of central auditory and visual processing and its automaticity in the development of reading and writing skills is being emphasized more often in the literature. Nicolson and Fawcett (2011) concluded, based on their own research, that children with dyslexia, apart from difficulties in language functioning, also exhibit deficits in other skills and activities which are ostensibly unrelated to reading or writing (e.g. difficulties in visuo-motor coordination). In this context, auditory-motor coordination seems to play the key role (Needle, Nicolson, & Fawcett, 2015; Nicolson & Fawcett, 2011; Thomson, Fryer, Maltby, & Goswami, 2006). The functions of auditory motor timing and auditory choice reaction time seem to be particularly important (Warnke, 2014). The authors believe that problems with automaticity are the common theme in the various

difficulties exhibited by dyslexic children. This is in line with the conclusions of this study pointing to the role of the more basic, lower-order processes and the importance of training them for the development of higher order processes such as phonological awareness and indirectly reading and writing.

The results of our study pointed to auditory and visual order threshold as well as frequency pattern and tone duration recognition as the aspects of central auditory and visual processing that proved to predict phonological processing and indirectly reading and writing skills. The visual order threshold is proved to be involved in quick visual scanning of written and reading material (Chung et al., 2008; Giovagnoli, Vicari, Tomassetti, & Menghini, 2016) and therefore may be important in reading and writing. The auditory order threshold indicates the smallest time interval which allows one to distinguish between and sequence correctly two auditory stimuli. It is also important for the ability to divide an utterance into segments (Warnke, 2014). Tone differentiation, on the other hand, is crucial for differentiating between similar vowels. Such vowels differ in the structure of their frequency; thus, in order to understand an utterance, the ability to differentiate between tones has to be correctly automatized (Warnke, 2014). Central auditory processing allows a child to receive, memorize, and recognize sounds—in particular, the sounds of speech. Therefore it seems to be significant for phonological awareness and indirectly for reading and writing skills.

Our research suggests that central auditory and visual processing training can influence phonological functioning, as well as reading and writing skills, so it may be a valuable way to decrease dyslexic difficulties. It also should be noticed that to our knowledge this is the first, though preliminary attempt to empirically verify the method which is increasingly used in the treatment of developmental dyslexia. Moreover, presented studies were conducted in accordance with the principles of evidence-based psychological practice (EBPP).

Qualitative impact of the Warnke Method training

It's important to emphasize the emotional and motivational effect of the Warnke Method training. Qualitative observations of children during the intervention training suggested that the children enjoyed the training sessions as they resembled playing a computer game in which certain skills are being improved. Furthermore, children reported a better mood and an increase in their self-esteem, which is of special value to us because the growing body of research indicates that children's mental health is associated with academic achievement (Puskar, Sereika, & Haller, 2003; Schulte-Körne, 2016). Often, before a training session, they would tell us with a smile about their better grades, or praise received from teachers, e.g.: '*Nobody laughed at me today when I read*', '*The teacher praised me today during class', or 'For the first time, I got a better grade than 3* (equivalent to a C) *for reading*'. This was also confirmed by teachers we spoke to after the end of the whole project. They observed an improvement in their pupils, both with regards to reading and writing skills and in their attitude towards studying.

Implications and conclusion

Our study is the first to systematically measure the functioning of dyslexic children before and after the Warnke Method training in terms of both the trained domain and higher level processes and skills (phonological processing and reading and writing skills), which, ultimately, are the goal of the training. This study addresses gaps in the field for evidence-based approaches that align with the theoretical conceptualization of dyslexia, and that can be implemented by trained practitioners in the field and incorporated into practitioners' therapeutic work.

Taking the results of the study into account, we may conclude that the Warnke Method does not hinder the functioning of children in terms of phonological processing and literacy acquisition. After 20 training sessions over approximately eight months, a significant improvement was observed with regards to *central auditory and visual processing*, *phonological processing*, as well as *reading and writing skills*. It is worth stressing that this improvement was visible not only in assessment test scores, but also in the students' grades. More rigorous testing however is needed using randomized control trials to examine the extent to which improvements from the Warnke Method are attributed to the intervention itself.

Since the Warnke Method works on non-linguistic material, it can be used regardless of language. We consider this to be an important benefit of the method. It can be used with bi- or multilingual children—both in diagnosis and in training— influencing all of their language skills. Moreover the method's structure and the game-like approach associate the training with entertainment in the children's minds. This decreases the children's anxiety levels, supports a goal-oriented approach, and increases the children's motivation to participate in other methods of dyslexia therapy. Therefore the method can be also perceived as a supportive tool, enriching the therapy of reading and writing difficulties.

Limitations and future research

Despite the fact that the study was conducted on a relatively large clinical sample of children diagnosed with developmental dyslexia, the sample size somewhat limits the generalization of the results—it would be worthwhile to replicate the study with a larger sample. The research should also be expanded to other countries and languages, which will enable to generalize conclusion about effectiveness of the Warnke Method in dyslexia therapy. Moreover, the quality of the current study would be increased if a randomized control study design were implemented. Another important aspect for further research is assessing the long-term effects of training through a follow-up assessment after the Warnke Method intervention - a year after training and also after the next stage of education (high school).

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