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The effectiveness of reading intervention in adults with developmental dyslexia: A systematic review

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Developmental Dyslexia is a lifelong condition characterized by reading and spelling deficits that persist into adulthood, negatively affecting the individual's academic and professional careers. Although numerous studies have been conducted to assess the effectiveness of reading interventions in children, providing promising results, research on adults is still sparse. The aim of this paper was that of summarizing and extending the current knowledge about the effectiveness of reading intervention programs proposed to adults with dyslexia, providing a systematic review of the available research. The literature search comprised an electronic search in the databases ERIC, PsycINFO, Scopus and ProQuest, and an examination of the references of previous studies. Eight studies met the inclusion criteria and were analyzed in detail, discussing the participants' profile, the main features of the proposed interventions and their effectiveness on different reading components, also including reading comprehension, spelling and phonological abilities. Results indicate that providing a literacy training can produce significant gains also in adults with dyslexia and that further research in this domain is needed, especially in languages with different orthographic and writing systems, to guarantee to struggling readers a concrete opportunity to enhance their reading skills and enjoy a better quality of life.

KEYWORDS: Developmental Dyslexia; adults with dyslexia; literacy intervention; literacy training; reading disorders; dyslexia treatment.

1. Introduction

Literacy is so overwhelmingly present in our everyday life that it seems virtually impossible to conceive an existence without it: apart from granting the opportunity to access higher education and the pleasure of reading for entertainment, the ability of decoding and comprehending written messages is fundamental for a wide variety of activities. Written information, indeed, surrounds us, in newspapers, technology, job applications, work orders and formal agreements, but also product labels, instructions, bills and legislation, among many others. Although the ability to access written messages is felt so natural that it is sometimes taken for granted, there is a not negligible number of adults who struggle in reading, due to the presence of specific developmental or

acquired disorders, or to an insufficient or even absent access to literacy instruction during childhood. Their difficulties, beyond impeding them to extract meaning from print as effectively as unimpaired readers do in everyday activities, can negatively impact on both academic career and job opportunities, as a minimum level of literacy skills is almost always required for productively functioning in the workplace.

Among them, we find people who suffer from developmental dyslexia, a disorder that affects the normal development of reading and spelling abilities and that accompanies individuals across their lifespan, negatively interfering with their education and professional occupation. Although it is often remarked that dyslexia is not a disease, and cannot therefore be cured, different remediation therapies have been developed and tested in the last decades, showing that rehabilitation processes can lead to successful results, yielding notable improvements in both decoding and reading comprehension skills, as will be discussed below (National Institute of Child Health and Human Development 2000; Galuschka *et al.* 2014). Nevertheless, the vast majority of these studies focused on children, whereas research on adults is rather sparse, as if receiving an appropriate intervention could be useful only for children and as if it were too late to propose it to adults. On the contrary, it must be emphasized that adulthood does not represent the final product of human development, which is on the contrary an active and dynamic lifelong process that is constantly modified by environmental demands, and that the challenges that people with dyslexia had to face in their school-years do not abandon them as they leave school, but rather they might become even worse (Gerber 2012).

Therefore, the importance of conducting and evaluating intervention studies designed to enhance literacy skills in older learners and adults should not be ignored. The purpose of this paper is that of casting light on this topic, providing a systematic review of the literature to address specific research questions: (i) Can literacy interventions ameliorate the reading skills of adults with dyslexia? (ii) If so, which kind of interventions are most effective, and which characteristics do they present? The paper is organized as follows: we first briefly present the main manifestations of developmental dyslexia, discussing how it can impact on the individual's school and professional career and illustrating the intervention programs that have been developed to treat this disorder in children. Secondly, we describe the steps that we went through in performing this systematic review aiming to investigate the effectiveness of literacy interventions in adults with dyslexia and we present the results of our analysis. Finally, we provide a synthesis of the main results, discussing their implications and suggestions for future research.

1.1. Developmental Dyslexia: Manifestations and outcomes in adulthood

As indicated in the DSM-5 (American Psychiatric Association 2013), Developmental Dyslexia (dyslexia henceforth) belongs to the overarching category of specific learning disorders, defined as neurodevelopmental disorders that impede a person's ability to learn and use specific academic skills, such as reading, writing and arithmetic, which serve as the foundation for most other academic learning. Dyslexia, in particular, is characterized by a marked impairment in the acquisition of reading skills, affecting reading accuracy, fluency and comprehension, which cannot be accounted for by low intelligence level, visual acuity problems, neurological deficits or poor educational opportunities (Lyon, Shaywitz & Shaywitz 2003).

Beyond the evident reading difficulties, dyslexia is also characterized by marked deficits affecting the individuals' linguistic abilities, including their phonological skills (Ramus & Szenkovits 2008), morphological abilities (Joanisse *et al.* 2000; Vender *et al.* 2017), rapid naming skills (Denckla & Rudel 1976; Nicolson & Fawcett 1994) and grammatical competence (Bar-Shalom, Crain & Shankweiler 1993; Wiseheart *et al.* 2009). Working memory (**WM**) and processing abilities are also significantly impaired, negatively affecting the dyslexics' performance in tasks that are particularly expensive in terms of cognitive resources (McLoughlin & Leather 2013; Vender 2017); automatization of skills is also severely compromised (Nicolson & Fawcett 2008). The presence of these difficulties is reflected by a number of brain anomalies, including an alteration in the anatomy of the temporal lobe and its connectivity, and an insufficient activation of the brain areas deputed to reading (Dehaene 2009).

Incidence of dyslexia is estimated between 5% to 10%, although it must be acknowledged that variation within this range is also related to the characteristics of the orthographic system of the considered language, and in particular to its opacity and granularity (Wydell & Butterworth 1999); the prevalence of reading disorders is indeed sensibly higher in countries whose language has an opaque orthographic system, like English (10%, British Dyslexia Association), than in those whose language has a more transparent orthographic system, like Italian (3-5%, Associazione Italiana Dislessia).

It is worth emphasizing that, although it is much more widely studied in children, dyslexia is a condition that accompanies the individuals across all their lifespan. As reported by Bruck (1990), people with dyslexia continue to display extensive reading deficits during adulthood, performing similarly to grade 6 unimpaired children in both fluency and accuracy. In addition, they show word recognition patterns that

are qualitatively different from those displayed by skilled readers and more similar to those of beginning readers, suggesting that their reading development suffered a sort of arrest; also, they continue to display severe phonological deficits (Bruck 1992) as well as rapid naming deficits (Vukovic, Wilson & Nash 2004). Other studies further confirmed that the difficulties in reading and writing related to dyslexia and diagnosed during primary school are substantially unchanged in adulthood and that learning disabilities, including dyslexia, persist across different cultural, language and economic groups, although they may vary in manifestations and intensity depending on the developmental stage and on the environmental demands (McLoughlin & Leather 2013). The presence of anomalies related to dyslexia in adulthood is evident at the neurological level too, with a decrease in the temporal lobe activity found in school-aged children as well as in adults suffering from lifelong reading difficulties (Dehaene 2009).

These persistent learning difficulties can have negative consequences that interfere with the individual's emotional sphere and social skills as well: people with dyslexia, both children and adults, often display low levels of self-confidence and self-esteem, they may show anger and frustration related to the way they have been treated in the past, when their disability was still unrecognized, and to high levels of anxiety, especially in relation to learning, examinations and testing (Riddick *et al.* 1999; Nelson & Harwood 2011).

Despite having accumulated several years of reading experience, adults with dyslexia still manifest serious literacy deficits, which can also hamper their educational and professional career. Reaching academic success can indeed be very difficult if reading is extremely slow (Ackerman & Dykman 1996), as effortful decoding is often an obstacle to effective reading comprehension; the unfortunate consequence is that the feeling of anxiety and the struggles in academic studies result in an increased dropout rate for individuals with learning disabilities and in a lower access to university studies (Davis *et al.* 2008; Moriña 2017). Nevertheless, possibly thanks to the laws enacted to support students with dyslexia and to a greater awareness raised on these topics, a higher percentage of individuals with dyslexia is nowadays choosing to invest in their school career, with a marked increase in university enrollment and positive outcomes (Shaywitz *et al.* 2020; Moriña 2017; Richardson 2021).

Literacy difficulties can also impact on professional career: adults with dyslexia may indeed face significant challenges when it comes to entering the workforce, which is also related to their low levels of personal resources, including in particular self-efficacy, self-regulation and

coping difficulties (McLoughlin & Leather 2013). Lower employment rates are also reported in this population, often associated with lower earnings, as well as employment in lower-skill positions and lower job satisfaction (Alexander-Passe 2006; Nalavany, Logan & Carawan 2018; Kavale & Forness 1996). Research on disclosure rates indicates that dyslexic adults tend to deny having literacy problems when they enter the labor market, probably because they perceive them to be related only to the school context, or because they judge it not convenient to admit them, based on current dynamics of risk and rewards and on the fear of being penalized (Gerber 2012; Martin & McLoughlin 2012; Gerber, Price & Mulligan 2005). However, it must be said that there is actually huge variability, related to different factors including not only severity of the disorder but also intelligence level and family socioeconomic status, with poor employment rates and occupational achievements being strictly connected to poor academic achievements (Bruck 1987).

Importantly, some studies suggest that psychosocial resources like self-efficacy, self-confidence and resiliency are malleable and can be enhanced with specific interventions: although research on this topic is still very limited, there is initial evidence indicating that such personal resources can indeed be enhanced through a proper training (see Costantini, Ceschi & Sartori 2020 for a systematic review on the effectiveness of psychosocial interventions for adults with dyslexia).

In spite of the marked difficulties displayed by individuals with dyslexia also in adulthood and of the impact that they can have on their quality of life, research on the effectiveness of literacy training on adults with reading disorders is also still very sparse (Swanson 2012). Since a wealth of studies shows that considerable improvements can be achieved if the proper reading intervention is proposed to children (Snowling, Hulme & Nation 2020), it seems paramount to conduct more research on the effectiveness of a specific training also for adults with dyslexia. Before discussing the types of literacy intervention that have proven to be more successful for children, we will briefly illustrate the main aspects of reading development and of the components involved in this process.

1.2. Theoretical perspective on reading

Being able to read is the result of a long and complex learning process enabled by a constellation of perceptual, cognitive and linguistic skills that must be integrated and coordinated to build meaning out of printed signs. Intensive formal instruction is then required to achieve good proficiency in reading, which involves two principal

components: decoding, that is the ability to correctly pronounce written strings, either overtly or covertly, by applying grapheme-phoneme conversion rules, and comprehension, that is the ability to understand the meaning of the words and the sentences composing the text (Hoover & Gough 1990). Decoding skills are typically measured by considering fluency and accuracy in real word and nonword reading, which are in turn processed in a different way and activating different mechanisms; according to the Dual-Route Cascaded Model (Coltheart *et al.* 2001), two routes are normally activated in reading, depending on the nature of the stimulus to be read. In the sublexical route, the string is decomposed in its minimal units (letters at first, followed by letter clusters and morphemes afterwards) and letter-sound correspondences are applied; in the lexical route, instead, the string is considered as a whole, it is recognized as familiar based on visual cues and it is associated to the corresponding phonological form stored in the individual's orthographic lexicon. Familiar words are thus generally read by activating the lexical route, whereas unfamiliar words and nonwords are necessarily read through the sublexical route, since no memorized form is available in the store. Irregular words, which cannot be correctly pronounced resorting to conversion rules, are instead read through the lexical route (see Ehri *et al.* 2001 for a model of learning to read and Dehaene 2009 for a discussion of the brain networks activated in reading).

Reading comprehension, instead, is built on a number of skills including word reading, text reading fluency, but also listening comprehension, linguistic competence, ranging from phonology, morphology, grammar and orthography, background knowledge, higher order cognition (drawing inferences, reasoning and comprehension monitoring) and domain-general cognition, comprising working memory and attentional control (see for instance Kim 2020 and her proposal for an integrative model of reading).

While language competence *tout court* is thus necessary in the complex process of understanding a text, good phonological skills play the most critical role in the first stages of reading acquisition and in particular in the learning, application and automatization of conversion rules. There is indeed robust evidence indicating the strong predictive role of phonological skills, measured by tasks like phoneme segmentation and blending, in literacy acquisition (Ehri *et al.* 2001; Wagner & Torgesen 1987) and indicating that phonological awareness can in turn be enhanced by reading instruction (Blachman 2000), as also confirmed by studies indicating lack of sensitivity to phonemes in illiterate adults (Morais *et al.* 1979; Morais *et al.* 1986). Poor phonological competence, which is unsurprisingly identified as a hallmark of dyslexia, can thus

drastically reduce the chances to learn and automatize the conversion rules that are fundamental in order to decode words.

More recently, it has been shown that morphological skills play a crucial and predictive role in literacy acquisition as well, especially at higher developmental stages: being able to identify the morphemes of a word and to associate them to their sound consistently speeds up the process of decoding, increasing reading accuracy, while also boosting comprehension, even independently from the phonological abilities (Vender *et al.* 2017; Apel & Lawrence 2011; Kirby *et al.* 2012). Morphological instruction can be particularly effective in later grades (end of the primary school), when there is a shift in the main focus of development from decoding, which is typical of the first grades, to reading comprehension (Chall 1983): at this stage, in fact, the impact of phonological awareness in reading decreases and is replaced by an increased influence of morphological awareness (Singson, Mahony & Mann 2000).

According to the Lexical Quality Hypothesis (Perfetti & Hart 2001; Perfetti & Hart 2002; Perfetti 2007) successful reading comprehension is made possible when lexical representations have a high quality, that is when all of their constituting features, i.e. phonology, morphology, grammar and meaning, are identified and linked together in an orthographic image that is linguistically multidimensional but stored as a single spelling entry in the mental lexicon (Cain, Oakhill & Bryant 2004). This guarantees greater word analysis and reading skills, higher morphological awareness and also better vocabulary knowledge, which is essential for academic success and, more in general, for an optimal reading comprehension.

Working memory also plays an important role in reading, both on the side of decoding and of reading comprehension: higher WM resources allow indeed to speed up the application of conversion rules and word recognition, the maintenance and manipulation of information for enabling connections with already processed materials and the building of an overall representation of the text (Cain, Oakhill & Bryant 2004; Kim 2020).

Depending on their decoding and comprehension skills, the individual's reading abilities can be classified in different levels: professional, technical, vocational and functional (McLoughlin & Leather 2013). Professional reading skills, which are normally achieved in grade 11-12, are required for understanding sophisticated material necessary for high school and university studies, but also for work related activities. To complete secondary education studies, reading at the technical level, normally achieved at junior high school, should be required, whereas it could be more difficult with reading skills at the vocational level, typical

of the primary school. Reading at the functional level instead guarantees only reading survival skills for adults, who could not be able to deal with jobs in which even a small amount of reading is demanded.

In fact, huge variation is possible within each reading level, also depending on the nature of the text and on the percentage of known words contained: at the independent stage people know approximately more than 97% of the words of the text and can reach excellent proficiency without assistance, whereas at the instructional stage the material contains 93-97% of known words, suggesting that they could need help to understand the text. Finally, at the frustrational level known words are fewer than 93% and comprehension could be seriously hindered (Treptow, Burns & McComas 2007). If the individuals' reading abilities are not adequately developed, indeed, they could be unable to properly comprehend written texts and therefore to reach success in learning across all academic domains, crucially including math, science and social sciences, as well as at work.

Summarizing, the literacy difficulties experienced by people with dyslexia can hinder both their academic and their professional career, rendering it essential to promote research on intervention strategies that can guarantee them an enhancement of their reading abilities and, as a consequence, access to equal opportunities. On the other side, the complexity of the process underlying reading skills which has been briefly hinted at in this paragraph, emphasizes the importance of identifying the real sources of difficulties for each individual. This is also the reason why it is important to provide dyslexics with an intervention specifically suited to the peculiarities characterizing their disorder, while enrolling them in a general program directed to adults with low literacy skills may not be entirely appropriate. This is a qualification that is worth making as there is a higher number of studies focusing on literacy intervention in adults who are defined as functionally-illiterate (see Torgerson, Porthouse & Brooks 2005 for a systematic review), while only a very limited number of studies addressed adults with dyslexia or with a history of reading disorders specifically. Although displaying a lower-than-normal reading ability certainly represents a shared commonality between the two populations, it cannot be ignored that in the case of dyslexics poor literacy skills do not depend on external conditions, including inadequate opportunities for learning and poor socioeconomic background, but are related to congenital deficits. This said, it seems correct to acknowledge that adults with dyslexia might need a more specific intervention, tailored on their peculiar difficulties and needs. For this reason, a successful reading treatment program should be first able to identify the specific learning and linguistic profile of the

individuals with dyslexia, in order to detect their strengths and weaknesses and, even more importantly, to isolate the loci of impairment on which to build the whole rehabilitation program.

1.3. Effectiveness of literacy interventions for children with dyslexia

A wealth of studies conducted on children suffering from dyslexia showed that reading difficulties can be attenuated by appropriate interventions and that considerable gains can be observed if specific training is provided. As suggested by a number of systematic reviews conducted in this field (National Institute of Child Health and Human Development 2000; Galuschka *et al.* 2014; McArthur *et al.* 2018), the most effective treatments for children are those that focus on a systematic instruction of letter-sound relations and on sound blending, as the phonics treatment, whose major aim is that of helping students acquiring the alphabetic code and speeding up the automatization of grapheme-phoneme correspondences, integrating elements of reading fluency training, which focus on repeated word or text reading practice, and on phonemic awareness training. The strength of this treatment lies in the combination of these two components, which considered separately are indeed not sufficient to guarantee sensible gains (Galuschka *et al.* 2014), and in its broad effects that can enhance the application not only of conversion rules, but also of morphological and orthographical spelling rules (Castles, Rastle & Nation 2018).

As discussed above, morphology-sensitive procedures are in fact particularly helpful in the development of reading skills. Although morphological awareness has received a more limited attention in dyslexia intervention, results are promising, as it has been found that treatments focusing on morphological instruction can improve both decoding and comprehension (Reed 2008). Positive effects of this type of training are generally found in all readers, but benefits appear to be even stronger in older students, who can exploit morphological cues in reading in order to compensate for their markedly impaired phonological skills (see for instance the systematic review by Bowers, Kirby & Deacon 2010, who provided evidence for the effectiveness of morphological training for younger and older children up to grade 7).

Another intervention which has been used for children is the Repeated Reading (National Institute of Child Health and Human Development 2000): in this methodology, which relies on the assumption that rehearsing a text boosts automaticity and fluency, teachers read aloud short text passages to the class, then students and teacher reread it orally in unison and after that students individually read it orally

up to three times in the same session to improve fluency and accuracy (Rasinski *et al.* 1994). Notice however that the efficacy of this kind of intervention has been questioned by the review provided by Galuschka *et al.* (2014) and described as ineffective.

Integrating the different levels of visual and linguistic competence is instead the principal aim of the RAVE-O program (Retrieval, Automaticity, Vocabulary, Elaboration-Orthography; Wolf *et al.* 2009; Morris *et al.* 2012) which has been found particularly suitable for children with dyslexia presenting naming deficits who struggle in connecting visual and linguistic processes, as in rapid naming tasks. This program focuses on building linguistic skills across the board, targeting phonology in conversion rules, morphology in the internal analysis of words, semantics and syntax in the access to the meaning of words in the sentence context.

A different approach has instead been adopted by the Reading Acceleration paradigm, which aims at speeding up the decoding process, focusing on fluency and providing a time-constrained reading in which students are forced to read faster than their habitual reading rate by means of computerized training (Breznitz 1997; Breznitz & Share 1992; Breznitz 2001). Accelerated reading interventions have been less investigated but results seem to be promising, indicating improvement in fluency in children, with no decrease, noticeably, in reading comprehension (Irausquin, Drent & Verhoeven 2005). Interestingly, this type of intervention has been found effective independently of the opaqueness of the orthographic system, as shown by Horowitz-Kraus *et al.* (2014), who reported similar positive effects in children tested in English, representative of deep writing systems, and in children tested in the diacritic form of Hebrew, representative of a shallow orthography.

Finally, a more limited number of studies proposed non-linguistic trainings, like the auditory training, in which children are instructed to identify non-linguistic auditory stimuli, or the visual training, in which they are invited to read with colored filters or colored overlays; results were however much less effective, indicating that interventions should focus directly on literacy skills and not on underlying auditory or visual causes in order to remediate spelling and reading skills (Galuschka *et al.* 2014). Similarly, only minor gains were obtained by studies assessing a medical treatment with the administration of drugs. More recently, there has been some evidence showing that action video games can improve reading efficiency in children with dyslexia (Franceschini *et al.* 2017; Franceschini *et al.* 2013), although they do not seem to be more effective than traditional approaches (Toffalini *et al.* 2021).

Crucially, the vast majority of these studies evaluated the intervention's effectiveness on children (Galuschka *et al.* 2014; Toffalini *et al.* 2021; McArthur *et al.* 2018). The few available studies conducted on adolescent struggling readers (up to age 14; in the review by McArthur *et al.* 2018 on the effectiveness of the phonics intervention only one study focused on adolescents, and no studies on adults) reveal that appropriate interventions focusing on phonological and orthographic training and on comprehension strategies can have positive outcomes on both phonological processing skills, literacy abilities and reading comprehension of older students (Lovett *et al.* 2012; Joseph & Schisler 2008; Forness *et al.* 1997). Studies on adults are much less numerous, which contributes to the unfortunately widespread prejudice that an intervention for the improvement of reading skills in adulthood is not worth pursuing and that older dyslexics will just need to live with their reading difficulty.

The aim of our systematic review is that of shedding light on this aspect, locating and summarizing findings from rigorous, scientifically based studies on the effectiveness of treatments for enhancing reading skills in adults with dyslexia.

2. Method

We conducted a systematic review of the literature following the recommendations of the Cochrane Group (Higgins & Altman 2008) and the PRISMA guidelines (Moher *et al.* 2009).

2.1. Effectiveness of literacy interventions for adults with dyslexia

We conducted an extensive literature search, looking for linguistic intervention studies administered to young adults (older than 16 years old) and adults with a diagnosis of dyslexia and published until July 2020, with no restrictions concerning the starting period, in the following databases: Scopus, ERIC and PsycINFO. In order to take into account also unpublished studies we searched the database ProQuest. The literature search began in June 2020 and was conducted using the following search terms in Title, Keywords and Abstract:

> (Dyslexia OR reading disorder OR reading disability) AND (adults OR adolescents) AND (intervention OR treatment OR training OR remediation).

In addition to the papers identified through the aforementioned databases, we examined the bibliographic references contained in the literature reviews conducted on this topic.

2.2. Study selection criteria

In order to be eligible for this systematic review, studies had to meet the following criteria:

(i) Participants had to be adults or young adults (older than 16 years old) with a diagnosis of developmental dyslexia or a severe impairment in reading, occurring in absence of additional cognitive, physiological or language deficits. Studies on individuals with acquired dyslexia, aphasia, mental retardation or comorbidity with other disorders as ADHD were excluded. Studies on low-literate adults and on adult beginning readers were also excluded since they have a different profile from individuals with dyslexia.

(ii) Reading abilities had to be independently assessed before the treatment to confirm the presence of a reading disorder in the dyslexic group.

(iii) A linguistic literacy treatment had to be administered with the aim of enhancing the participants' reading skills and it had to be described with sufficient detail in the paper. Non-linguistic, auditory or visual treatments as well as neuropsychological and medical treatments were not included as they fall outside the scope of the present study.

(iv) Pre- and post-testing measures directly assessing the individual's reading abilities had to be included in order to evaluate the effects of the intervention.

(v) A control group of age-matched unimpaired individuals or of age-matched individuals with dyslexia who had not received the experimental treatment had to be included in the study in order to evaluate the intervention's efficacy.

(vi) The outcome of the intervention had to be focused on reading abilities. We considered as primary outcome any gains in reading abilities, both in fluency and in accuracy, and as secondary outcomes improvements in any other domain, including spelling, reading comprehension and language abilities.

3. Results

The literature search yielded 4210 results. After removal of obviously irrelevant studies and duplicates, we analyzed 110 full-text articles, only 6 of which met all the inclusion criteria discussed above and were considered eligible for the present systematic review. Two further studies were added through examination of the references included in the other literature reviews as they were compatible with the purposes of this research and the established inclusion criteria.

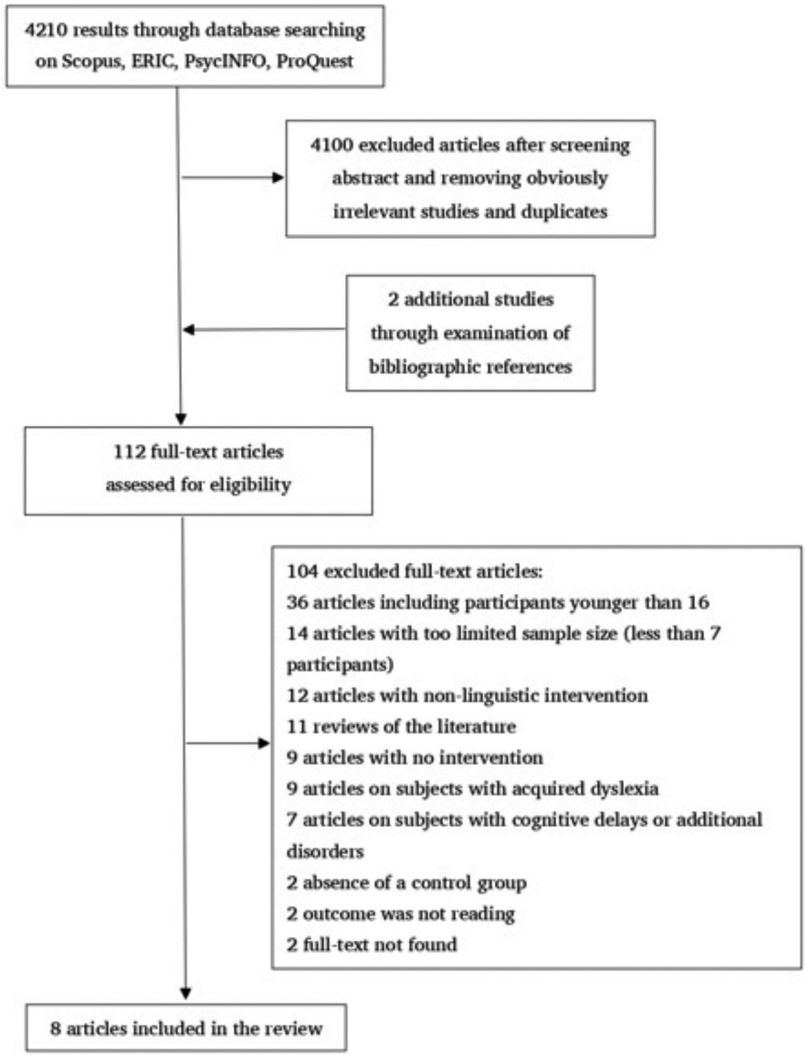

Figure 1. Flowchart of the study's selection process.

As can be noted form the flowchart of the selection process displayed in Figure 1, a substantial number of studies found in the considered databases (36) included children or adolescents younger than age 16, which were excluded since the aim of this review was that of addressing intervention on older individuals with a more mature brain development. In addition, we removed articles reporting interventions

on people with acquired dyslexia (9), cognitive delays or other neurological disorders, as aphasia, or comorbidity with other disorders, as ADHD (7), since we wanted to focus on people with developmental dyslexia or a history of undiagnosed severe reading disability, a condition that is inherently different from acquired dyslexia in terms of additional and congenital language deficits, requiring a specific treatment. As for the type of intervention, we excluded articles reporting the results of neurological interventions, or involving drug administration (11) or motor interventions aimed at stimulating the vestibular system (1), as well as papers where no real intervention was proposed (9), as in the case of questionnaires, and literature reviews (11).[1] To guarantee a quality standard of the intervention we did not take into consideration studies conducted on a too limited sample of participants (less than 7; 14 studies) or lacking a control group (2); as will be discussed below, after a first examination of the searched papers we decided not to limit our selection to randomized studies, as only three papers had a proper randomization (see section 3.6.). In the following sections we will describe the main features of these studies, focusing on the participants' profile, the type of intervention administered and its effectiveness on first and secondary outcomes.

3.1. Profile of the participants

The participants involved in the eight selected studies were in total 727 and their age range varied from 16 to 78 years old; specific information about age, gender and language of the participants of each study are reported in Table 1.

Reference	Country	Language	Participants	Age	Gender	Diagnosis
Bar-Kochva (2016)	Israel	Hebrew L1	78 participants, 4 groups: 1) 21 dyslexics, morpheme-based training 2) 20 dyslexics, control training 3) 17 dyslexics, no intervention 4) 20 normal readers, no intervention	Age-Range: N/A Mean age morpheme training: 24.85 y.o. Mean age control training: 25.30 y.o.	Dyslexics: 30% males	Yes, diagnosis of Developmental Dyslexia

Breznitz *et al.* (2013)	Israel	Hebrew L1	110 participants, 4 groups: 1) 40 dyslexics, reading acceleration 2) 15 dyslexics, self-paced reading 3) 40 normal readers, reading acceleration 4) 15 normal readers, self-paced reading	Age range: 22-29 Mean age: N/A	35% males	Yes, diagnosis of Developmental Dyslexia
Eden *et al.* (2004)	USA	English L1	38 participants, 3 groups: 1) 9 dyslexics, phonological intervention 2) 10 dyslexics, no intervention 3) 19 normal readers, no intervention	Age range: N/A Mean age dyslexics: 44.0 y.o. Mean age controls: 41.1 y.o.	Dyslexics: 74% males Normal readers: 68% males	Yes, diagnosis of Developmental Dyslexia
Gray *et al.* (2018)	USA	English L1 and English L2	34 poor readers, 2 groups: 1) 17 morpho-phonemic intervention 2) 17 control whole-word intervention	Age range: 18-31 Mean age: 24 y.o.	Group 1: 58% males Group 2: 29% males	No, 6 grade equivalency
Guyer & Sabatino (1989)	USA	English L1	30 dyslexics, 3 groups: 1) 10 morphophonemic intervention 2) 10 whole-word intervention 3) 10 no intervention	Age range: 17-24 Mean age: 20.3 y.o.	N/A	Yes, diagnosis of Learning Disability

Greenberg *et al.* (2011)	USA	English L1 and English L2	198 poor readers, 5 groups: 1) 49 DCEF intervention 2) 46 DF intervention 3) 41 DCF intervention 4) 22 ER intervention 5) 40 Generic literacy intervention	Age range: 16-78 Mean age: 36.76 y.o.	67.2% female	No, 3 to 5.9 grade equivalency levels
Sabatini *et al.* (2011)	USA	English L1	148 participants, 3 groups: 1) 48 Corrective Reading 2) 50 RAVE-O intervention 3) 50 Guided Repeated Reading	Age range: 17-76 Mean age: 36 y.o.	67% female	No, 3 to 4 grade equivalency levels
Shiran & Breznitz (2011)	Israel	Hebrew L1	91 participants, 4 groups: 1) 26 dyslexics, WM training 2) 35 skilled readers, WM training 3) 15 dyslexics, self-paced reading 4) 15 normal readers, self-paced reading	Age range: N/A Mean age dyslexics: 24.84 y.o. Mean age controls: 25.11 y.o.	N/A	Yes, diagnosis of Developmental Dyslexia

Table 1. Demographic characteristics of the participants.

Five of the selected studies were conducted on participants who had a formal diagnosis of developmental dyslexia (Breznitz 2013; Eden *et al.* 2004; Bar-Kochva 2016; Shiran & Breznitz 2011) or of learning disabilities with a particularly marked deficit in reading (Guyer & Sabatino 1989). Participants of the remaining three studies had no formal diagnosis but were instead people with a history of severe reading disabilities who were recruited from those who searched for literacy service in adult education centers (Greenberg *et al.* 2011; Sabatini *et al.* 2011) or were enrolled in adult learning programs (Gray, Ehri & Locke 2018) or they had markedly impaired reading, determined as a 3-4 grade equivalency in Sabatini *et al.* (2011), 3-5.9 equivalency in Greenberg *et al.* (2011) and 6 grade equivalency in Gray, Ehri & Locke (2018).

In all the studies included in this review, participants were further administered a comprehensive battery of standardized tests assessing their literacy and language competence. Specifically, all studies assessed accuracy in word and nonword reading of participants, reporting severe deficits; all measures of reading abilities were judged as having adequate reliability and validity. The participants' nonverbal intelligence was assessed by 6 studies reporting normal or above than normal levels; this parameter was not considered by Sabatini *et al.* (2011), who argued however that none of the subjects had a history of mental retardation, and by Greenberg *et al.* (2011). We decided not to exclude these two studies as there was a careful assessment of the literacy and linguistic profile of the participants.

As shown in Table 2, additional measures were considered to provide a better characterization of the participants' profile.

Study	General Cognitive abilities	reading (general)	Nonword decoding	Real Word Reading	Passage Reading Rate	Passage Reading Accuracy	Reading Comprehension	Spelling	Phonology	Vocabulary	Rapid Naming	Working memory
Bar-Kochva (2016)	Yes	No	Yes (impaired)	Yes (impaired)	Yes (only intervention groups)	Yes (only intervention groups)	Yes (only intervention groups)	Yes (only intervention groups)	Yes (impaired)	No	Yes (impaired)	No
Breznitz *et al.* (2013)	Yes	No	No	Yes (impaired)	Yes (impaired)	No	Yes (impaired)	Yes (impaired)	Yes (impaired)	No	Yes (impaired)	Yes (impaired)
Eden *et al.* (2004)	Yes	No	Yes (impaired)	Yes (impaired)	Yes (impaired)	Yes (impaired)	Yes (impaired)	No	No	No	No	No
Gray *et al.* (2018)	Yes	No	Yes	Yes	No	No	Yes	Yes	No	Yes	No	No
Greenberg *et al.* (2011)	No	No	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	No
Guyer & Sabatino (1989)	Yes	Yes (impaired)	N/A	N/A	N/A	N/A	No	No	No	No	No	No
Sabatini *et al.* (2011)	No	No	Yes	Yes	No	No	Yes	No	No	Yes	No	No
Shiran & Breznitz (2011)	Yes	No	Yes (impaired)	Yes (impaired)	Yes (impaired)	No	Yes (normal)	Yes (impaired)	Yes (impaired)	No	No	Yes (impaired)

Table 2. Literacy and language tests administered to determine the participants' profile. (Yes = measure included in the pretest session. No = measures not included in the pretest session. Impaired: score reported as significantly impaired in participants with dyslexia/struggling readers.)

Spelling performance and/or orthographic processing was assessed by 6 studies (Breznitz 2013; Bar-Kochva 2016; Shiran & Breznitz 2011; Guyer & Sabatino 1989; Greenberg *et al.* 2011; Gray, Ehri & Locke 2018) while reading comprehension was tested by all studies, except from Guyer & Sabatino (1989). Lexical competence was assessed by 5 studies, focusing on vocabulary (Eden *et al.* 2004; Greenberg *et al.* 2011; Sabatini *et al.* 2011; Gray, Ehri & Locke 2018) or on lexical access (i.e. rapid naming, Breznitz 2013; Bar-Kochva 2016; Greenberg *et al.* 2011). Finally, four studies assessed phonological competence (Breznitz *et al.* 2013; Shiran & Breznitz 2011; Greenberg *et al.* 2011; Bar-Kochva 2016).

As for the language spoken by the participants, which was also the one adopted for the intervention, it was English for 5 studies and Hebrew for the remaining 3 (Bar-Kochva 2016; Shiran & Breznitz 2011; Breznitz *et al.* 2013); participants were native speakers of that language, except for some of the subjects involved in Greenberg *et al.*'s (2011) and in Gray, Ehri & Locke's (2018) studies, who had an adequate to high proficiency in English as a L2 and were thus enrolled in adult programs designed for native speakers.

3.2. Characteristics and effectiveness of the interventions

In spite of the small number of studies considered in this review, there was a significant diversification of the interventions proposed, which ranged from phonological-based trainings, the most traditional one, adopted by five studies, to programs integrating different linguistic levels, with a special emphasis on morphological analysis, to more modern computerized treatments focusing on reading acceleration and on working memory. The relevant features of the studies reviewed here, including effectiveness of the interventions on both primary and secondary outcomes, language, duration, group size, implementer, presence of a follow up and randomization are reported in Table 3.

Study	Interventions	Language	Duration	Training group size	Implementer	Measure	Randomization	Follow up
Bar-Kochva (2016)	1) Morpheme-based training 2) Non-morphological control training	Hebrew	• 2 training sessions (25 min each) • **Total**: 50 minutes	Individual	Computer	Behavioral	Yes (random assignment of participants to the training groups)	No

Breznitz *et al.* (2013)	1) Computerized reading acceleration training 2) Self-paced reading control intervention	Hebrew	• 24 practice sessions (15-20 min each) • 3 sessions per week • **Total**: 6-8 hours	Individual	Computer	Behavioral	No	Yes (gains retained after 6 months interval)
Eden *et al.* (2004)	1) Phonological multisensory intervention 2) No Intervention (control)	English	• 3-hour sessions daily for 8 weeks • **Total**: 112.5 hours	Small groups	Human	Behavioral and neurological (fMRI)	No	No
Gray *et al.* (2018)	1) Morpho-phonemic intervention 2) Whole word control intervention	English	• 2-hour sessions, once a week for 4 weeks • **Total**: 8 hours	Individual	Human: trained teachers	Behavioral	No	No
Greenberg *et al.* (2011)	1) Decoding and fluency 2) Decoding, comprehension and fluency 3) Decoding, comprehension, extensive reading and fluency 4) Extensive reading 5) Generic literacy control intervention	English	• 2-hour session, 4 sessions a week • **Total**: 100 hours	Mixed	Human: trained research teachers	Behavioral	Yes (random assignment of participants and teachers to intervention)	Yes: no gains retained after 6-month interval
Guyer & Sabatino (1989)	1) Phonetic multisensory intervention 2) Nonphonetic intervention 3) No intervention	English	• 5-week program • **Total**: N/A	N/A	Human: trained teachers	Behavioral	Yes (blinded teachers, random assignment of the participants)	No

Sabatini *et al.* (2011)	1) Phonics intervention 2) Vocabulary elaboration orthography intervention 3) Guided repeated reading intervention	English	• 10-18 weeks • 45 75-min sessions • **Total**: 56 hours	Individual	Human: trained expert tutors	Behavioral	No	No
Shiran & Breznitz (2011)	1) Working memory training 2) Self-paced reading control intervention	Hebrew	• 24 15-min sessions • 6 weeks, 4 sessions a week • **Total**: 6 hours	Individual	Computer	Behavioral and electrophysiological (ERP)	No	No

Table 3. Characteristics of the reviewed studies.

Consistently with the inclusion criteria that we have established, all the studies are characterized by at least two groups of participants with comparable reading disorders: the first group was administered the experimental intervention, whereas the other group(s) were administered a distinct control intervention (4 studies: Shiran & Breznitz 2011; Greenberg *et al.* 2011; Gray, Ehri & Locke 2018; Breznitz *et al.* 2013) or no intervention at all (2 studies: Eden *et al.* 2004; Guyer & Sabatino 1989); in one case three different interventions were compared without a real control intervention (Sabatini *et al.* 2011).

In this section we will review the main characteristics of each intervention, discussing their general effectiveness; a more specific discussion of their efficacy on each of the primary and secondary outcomes considered (see Table 4) will be provided in the following section.

Guyer & Sabatino (1989) randomly assigned their 30 English L1 participants with dyslexia to three groups: 10 received a multisensory phonetic approach, 10 a nonphonetic intervention, while the remaining 10 did not receive training. The phonetic training was designed using an adaptation of the Orton-Gillingham approach, an alphabetic synthetic method specifically developed for students with dyslexia focusing on phonics instruction using multisensorial techniques (Gillingham & Stillman 1960). A special emphasis was put in reducing the language to the symbols which are used to write it, by establishing relations between the sound of a letter and the form of the grapheme and associating a concrete object to specific letter combinations which are not familiar to

the reader (e.g. <ph> to *phone*). In the spirit of multisensoriality, reading, spelling and handwriting are taught simultaneously, so that people who had difficulties in establishing solid connections between symbols and sounds could benefit from the kinesthetic component involved in handwriting. Students were encouraged in subvocalizing during writing and in discovering the sensory channels which were more effective for their learning. The nonphonetic approach instead aimed at improving the participants' critical and practical reading skills, focusing on the teaching of comprehension strategies, with no attention on decoding processes: students were instructed about how to identify the main ideas of a text, how to learn new words in the reading contexts, while promoting comprehension improvement and literature appreciation. Both interventions lasted five weeks, but no details were provided about the number and length of the training sessions nor about the group size of the participants; the intervention was carried out by trained teachers with a master's degree in learning disabilities. The authors found that the phonetic intervention was the most effective, since only students of the first group showed an improvement in reading, as measured by the two standardized tasks administered; unfortunately, no further details were provided to specify in which area of reading the positive outcomes were found, as only a general reading score was provided.

More details were instead reported by Eden *et al.* (2004), who conducted a fMRI study aiming at assessing the effectiveness of a phonological intervention based on the commercial program designed by the Lindamood-Bell Corporation, which was administered to 9 of their 18 participants with dyslexia. In this case as well, training was centered on a specific, multisensorial instruction in sound awareness and in the establishment of conversion rules by means of sensory stimulation, imagery strategies used to visualize and manipulate written symbols and articulatory feedback. The intervention was delivered to small groups in 3-hour sessions for eight weeks, for an average total of 112.5 of tutoring. Significant gains of the intervention group were found in nonword decoding and passage reading, but limited to accuracy; phonological abilities were also improved, whereas no benefits were found in reading rate and comprehension, arguably suggesting that these abilities could be more resistant to a phonological training. In addition to the positive effects on decoding, the dyslexics who received the intervention showed an enhancement in the use of the brain areas of the left hemisphere parietal cortex and of the right hemisphere which are typically involved in phonological processing, providing a further confirmation of the training's effectiveness.

Gray, Ehri & Locke (2018) aimed at testing the effectiveness of a morpho-phonemic training in reading; in their study, the authors taught the same 40 morphologically complex words to two groups of adults with reading difficulties receiving different instruction programs. In the morpho-phonemic intervention the 40 words were taught through a sub-lexical, within word analysis, promoting the identification of root and affixes, of their function and of related words with the same root; syllable division and primary stress assignment were also considered. In the control whole-word training, participants received a traditional vocabulary instruction based on the teaching of whole words without analyzing their phonological and morphological structure. Both groups displayed significant and comparable gains in learning to read and spell the target words, but only the morpho-phonemic training led to a learning transfer on standardized measures of word reading, including nonword reading and word recognition.

Another study confirming the effectiveness of morphological training is provided by Bar-Kochva (2016) on Hebrew L1 adults with dyslexia and normal readers. Training in this case was particularly short, consisting of just two 25-minute sessions of a lexical decision task in which participants were required to decide whether a given stimulus was a word or not. Half students received a morpheme-based training in which the presentation of the root of words and pseudowords was restricted in time, whereas the letters of morphological patterns remained on the screen until an answer was provided. For the other half, receiving a control training, the procedure was identical but the letters remaining on the screen did not belong to a morphological unit. Interestingly, despite the implicitness and the short duration of the training, for the first group of participants significant gains were reported in passage reading accuracy (medium effect size) and especially in word reading accuracy (large effect size) and near significant gains in spelling (small effect size). No gains were instead found in reading rate.

Other studies proposed an integration of different linguistic levels in the intervention. Sabatini *et al.* (2011) compared three more integrated interventions differing in the amount of time spent on decoding and fluency processes. In a phonics based intervention, the Corrective Reading Program (CR; Engelmann 1999), focusing on both strengthening of grapheme-phoneme conversion rules and word recognition skills, was proposed to 48 English adult struggling readers: importantly, students progressively moved from the phonological level to the word-level, and were guided to process words more rapidly by recognizing word patterns and reading words within a context. They were also given the opportunity to train fluency (80-90% of the time focused on phon-

ics, 10-20% on fluency), reading controlled, i.e. decodable texts. In the RAVE-O, as discussed above, different linguistic levels, including beyond phonology also morphology, syntax and semantics, were simultaneously trained in the 50 participants, with a higher emphasis on fluency (65-75% fluency, 25-35% phonics). Finally, in the Guided Repeated Reading (Shore 2003), administered to 50 poor readers, there was a greater emphasis on fluency associated to a minor phonics component (10-20% phonics, 80-90% fluency) and students were invited to repeatedly read the same text after it was modeled by the teacher. Results revealed that all programs were relatively effective on reading abilities, despite having small to medium effect sizes; although there were no statistically significant differences amongst the programs, the strongest (medium) effect sizes were reported for the Corrective Reading and the RAVE-O on nonword decoding. Unfortunately, the major limitation of this study was the absence of a real control intervention, which could have been useful to evaluate the effectiveness of the three approaches used.

Greenberg *et al.* (2011) compared four different types of intervention and a control one to 198 English L1 or L2 struggling readers. The first three programs differed on the time devoted to decoding (i.e. letter-sound combinations) and comprehension (i.e. organization of facts in the text, by means of analogy, inferences, and other comprehension strategies), with an additional part of the lesson focusing on fluency, of the same length for each intervention (13% for each lesson). This final part consisted in an implementation of the corrective reading approach, in which students were asked to practice a passage until they improved their rate of correct words read per minute by 40% of the baseline; it was expected to be particularly effective for improving fluency, due to previous results on children. The fourth intervention featured Extensive Reading (Krashen 1993), in which students were engaged in silent sustained reading and read-aloud activities, whereas the last one was a control intervention employing a general literacy program. Results were quite modest: when pre- and post-test scores were compared independently of the type of instruction, a general improvement in reading skills, although with small effect sizes, was found in word and pseudoword reading accuracy and in fluency; however, when the different interventions were compared, adding also age, number of hours and entry scores as covariate in the model, no gains were detected in any of the measures considered, except for a significant difference in nonword reading, for which lower outcomes were reported in the case of Extensive Reading. Contrary to the expectations, then, there was no clear advantage for the approaches featuring extensive reading on fluency, which was interpreted by the authors as evidence that this strategy

is less efficient for adults than it is for children, perhaps due to the many years of bad habits that fossilized the reading strategies used by adults.

A different type of training, more specifically focused on fluency, was the reading acceleration program proposed by Breznitz *et al.* (2013) in Hebrew L1. 40 adults with dyslexia and 40 normal readers underwent a computerized training with increasing time constraints consisting of 24 sessions (15-20 minutes each): during each session they were presented with the same 50 sentences in which letters disappeared one at a time, based on the individual's reading rate as determined in the pre-test, followed by a comprehension question. The per-letter erasure rate was increased by 2 ms per-character on the basis of the number of consecutive correct answers. Two control groups of 15 dyslexics and 15 normal readers were presented with the same sentences in a self-paced reading modality, with no time constraints. Results on standardized reading tasks revealed robust gains in both reading rate and comprehension for the two groups trained with the reading acceleration protocol, with positive outcomes being even more marked for dyslexics, who reached a performance similar to that of the typical readers. No gains were instead detected in the two groups receiving the self-paced reading training.

Positive outcomes in both behavioral and electrophysiological measures were found also by Shiran & Breznitz (2011), who administered an entirely different intervention targeting the individual's working memory to 26 dyslexics and 35 normal readers, whereas 15 dyslexics and 15 normal readers underwent a control self-paced reading intervention. In this case, too, the language of the interventions was Hebrew, the L1 of all participants. The WM program (Cognifit 2003) aimed at training the individual's memory across different components (i.e. visual, verbal, nonverbal, auditory, visuo-spatial), by asking them to recall sequences of stimuli of different nature with strings of increasing length. There were 24 sessions (4 sessions a week) of approximately 15 minutes each. Beyond confirming the presence of extensive WM deficits in adults with dyslexia, this study showed that the training produced an increase in the individuals' WM skills, accompanied by a significant enhancement of their reading abilities, concerning both words and pseudowords, phonological awareness and reading comprehension skills. These behavioral results were confirmed by the significant changes in the ERP data collected before and after training during a Sternberg task (Sternberg 1966), requiring processing and storage in working memory, and revealing a significant increase in the amplitude of the P300 components, which is associated to updating in working memory (Grune *et al.* 1996; Smith-Spark & Fisk 2007), and a decrease in the latency in both

dyslexic and normal readers, which may reflect in a diminished difficulties in doing the task. These data once again confirm the plasticity of the human brain system and its susceptibility to training also in adulthood.

3.3. Effectiveness of the intervention on primary and secondary outcomes and presence of a follow up

As already mentioned above, all the interventions produced gains in reading; however, they differed with respect to the specific components of reading considered, as shown in Table 4, where the effectiveness of the intervention on primary and secondary outcomes is reported, together with effect sizes (Hedges' *g*) and 95% Confidence Intervals (CI).

Study	Interventions	Gains in Primary Outcomes				Gains in Secondary Outcomes		
		Reading (general)	Nonword decoding	Real word reading	Passage reading	Reading comprehension	Spelling accuracy	Phonological abilities
Bar-Kochva (2016)	1) Morpheme-based training	N/A	N/A	Yes (accuracy: *g* = -0.87; 95% CI [-1.52, -0.22]	Yes (accuracy: *g* = -0.50; 95% CI [-1.14, 0.13])	No	Yes (*g* = - 0.28; 95% CI [0.91, 0.34])	N/A
	2) Non-morphological control intervention	N/A	N/A	No	No	No	No	N/A
Breznitz *et al.* 2013	1) Computerized reading acceleration intervention	N/A	N/A	N/A	Yes*	Yes*	N/A	N/A
	2) Self-paced reading control intervention	N/A	N/A	N/A	N/A	No	N/A	N/A
Eden *et al.* (2004)	1) Phonological intervention with multisensory approach	N/A	Yes*	No	Yes (accuracy)*	No	N/A	Yes*
	2) No intervention (control)	N/A	No	No	No	No	N/A	No
Gray *et al.* (2018)	1) Morpho-phonemic intervention	N/A	Yes (*g* = -0.40; 95% CI [-1.11, 0.31)	Yes (*g* = -0.16; 95%CI [-0.86, 0.54])	N/A	No	No	N/A
	2) Whole-word control intervention	N/A	No	No	N/A	No	No	N/A

Greenberg *et al.* (2011)	1) Decoding and fluency	N/A	Yes (*g* = -0.27, 95% CI [-0.68, 0.13)	No	No	No	N/A	N/A
	2) Decoding, comprehension and fluency	N/A	No	No	No	No	N/A	N/A
	3) Decoding, comprehension, extensive reading and fluency	N/A	Yes (*g* = -0.33, 95% CI [-0.73, -0.07)	No	No	No	N/A	N/A
	4) Extensive Reading	N/A	No	No	No	No	N/A	N/A
	5) Generic literacy control intervention	N/A	Yes (*g* = -0.39, CI [-0.84, 0.06])	No	No	No	N/A	N/A
Guyer & Sabatino (1989)	1) Phonetic multisensory intervention	Yes*	N/A	N/A	N/A	N/A	N/A	N/A
	2) Nonphonetic control intervention	No	N/A	N/A	N/A	N/A	N/A	N/A
	3) No intervention	No	N/A	N/A	N/A	N/A	N/A	N/A
Sabatini *et al.* (2011)	1) Phonics intervention	N/A	Yes (*g* = 0-.57, 95% CI [-0.99, -0.16)	Yes (*g* = -0.23, 95% CI [-0.63, 0.18])	Yes (*g* = -0.39, 95% CI [-0.80, 0.02])	Yes (*g* = -0.18, 95% CI [-0.59, 0.23])	N/A	N/A
	2) Retrieval, Automaticity, Vocabulary Elaboration-Orthography	N/A	Yes (*g* = -0.57, 95% CI [-0.97., -0.16])	Yes (*g* = -0.19, 95% CI [-0.59, 0.21])	Yes (*g* = -0.29, 95% CI [-0.69, 0.11])	Yes (*g* = -0.09, 95% CI [-0.49, -0.31])	N/A	N/A
	3) Guided repeated reading	N/A	Yes (*g* = -0.25, 95% CI [-0.65., 0.14])	Yes (*g* = -0.21, 95% CI [-0.60, 0.19)	Yes (*g* = -0.34, 95% CI [-0.74, .06])	Yes (*g* = -0.32, 95% CI [-0.72, 0.08])	N/A	N/A
Shiran & Breznitz (2011)	1) Working memory intervention	N/A	Yes (*g* = -0.37, 95% CI [-0.93, 0.20])	Yes (*g* = 0.45, 95% CI [-1.01, 0.12])	Yes (*g* = 0.24, 95% CI [-0.31, 0.80])	Yes (*g* = -0.66, 95% CI [-1.23, -0.08])	N/A	Yes (*g* = 0.47, 95% CI [-0.10, 1.03])
	2) Self-paced reading control intervention	N/A	No	No	No	No	N/A	No

Table 4. Effects of the interventions on primary and secondary outcomes. (Yes = significant gains produced by the intervention in primary and secondary outcomes. No = absence of significant gains produced by the intervention in primary and secondary outcomes. Effect sizes: *g* = Hedges' g, with 95% Confidence Intervals, CI, in brackets, reported only for significant improvements of the administered trainings in primary or secondary outcomes. * Reviewers unable to calculate effect sizes due to absence of the relevant data.)

Guyer & Sabatino (1989) reported only a general positive effect on reading, but unfortunately the data provided were insufficient for calculating the effect size. As for NONWORD READING, gains were reported

by the phonological interventions (Eden *et al.* 2004), including the integrated linguistic interventions (Greenberg *et al.* 2011; Sabatini *et al.* 2011), the morphophonemic intervention (Gray, Ehri & Locke 2018) and the WM intervention (Shiran & Breznitz 2011); all effect sizes were low. The most effective is the Corrective Reading phonics intervention and the RAVE-O interventions by Sabatini *et al.* (2011) with a medium effect size (respectively: g = -0.57, 95% CI [-0.99, -0.16] and g = -0.57, 95% CI [-0.97, -0.16]). Extensive reading (Greenberg *et al.* 2011) and self-paced reading were instead not effective. Concerning REAL WORD READING, benefits were produced only by morphological trainings (Bar-Kochva 2016; Gray, Ehri & Locke 2018), by Sabatini *et al.*'s (2011) integrated interventions and by the WM training, whereas the phonological interventions were not effective. The morphological intervention by Bar-Kochva was the most effective, with a large effect size (g = 0.87, 95% CI [-1.52, -0.22]), followed by the WM memory training with a medium effect size (g =- 0.45, 95% CI [-1.01, 0.12]); the effect size of the other trainings was small or lower than small. PASSAGE READING was successfully improved by the reading acceleration training, the WM training, the integrated interventions by Sabatini *et al.* (2011); positive effects, although limited to accuracy, were reported by the phonological intervention of Eden *et al.* (2004) and the morpheme-based intervention of Bar-Kochva (2016). All effect sizes were small.

As for the secondary outcomes, READING COMPREHENSION was assessed by all studies with the exception of Guyer & Sabatino (1989), but significant gains were produced only by reading acceleration and by Sabatini *et al.*'s (2011) integrated training, with small effect sizes and by the WM training, which was the most effective, with a large effect size (g = -0.66, 95% CI [-1.23, -0.08]).

SPELLING was instead considered only by Bar-Kochva (2016), who reported gains (small effect size) for the morpheme-based intervention and by Gray, Ehri & Locke (2018), who did not report gains. Finally, an improvement in phonological abilities was reported by Eden *et al.* (2004) and Shiran & Breznitz (2011, small effect size), whereas it was not accounted for by the other studies.

A follow-up was performed only by two studies: Breznitz *et al.* (2013), who reported that gains were maintained after a 6-month interval and by Greenberg *et al.* (2011) who instead found no gains, with the loss after 6 months of the only significant effect that they had reported immediately after the training in nonword reading.

3.4. Language of the intervention

As argued above, the language of the intervention was English for the majority of the studies, and Hebrew for the remaining three. Among those on English, two papers included both L1 and L2 participants displaying severe literacy deficits and a good proficiency in English: interestingly, it was found that the intervention's effectiveness was not limited to L1 people, but significantly extended to L2 speakers, who showed similar gains as the L1 speakers in Gray, Ehri & Locke (2018) and even greater benefits in Greenberg *et al.*'s (2011) study.

3.5. Training intensity, group size and implementer

There was considerable variation in the training duration: the longest one was the phonological training by Eden *et al.* (2004) (112.5 hours), followed by the integrated trainings proposed by Greenberg *et al.* (2011; 100 hours) and Sabatini *et al.* (2011; 56 hours). Training was much shorter in the interventions by Breznitz *et al.* (2013; 6-8 hours), Shiran & Breznitz (2011; 6 hours) and Gray, Ehri & Locke (2018; 8 hours), and exceptionally short in Bar-Kochva (2016; 50 minutes). No precise information was available for Guyer & Sabatino (1989), where only a 5-week period is indicated. As for the implementer, a computerized intervention was employed by Bar-Kochva (2016), Shiran & Breznitz (2011), Breznitz *et al.* (2013), whereas it was human (generally a trained teacher or researcher) in the remaining studies. Finally, the intervention was delivered individually in the computerized trainings, in Sabatini *et al.* (2011) and in Gray, Ehri & Locke (2018), and in small groups in (Eden *et al.* 2004); no explicit information was provided by Guyer & Sabatino (1989) and Greenberg *et al.* (2011). As a general observation, the computerized and the morpho-phonemic trainings, which were performed individually, also had a shorter duration.

3.6. Risk of bias

Only two of the considered studies provided information concerning the randomization of participants and teachers and implemented specific procedural safeguards to reduce potential teaching and testing bias; in Greenberg *et al.* (2011) and Gray, Ehri & Locke (2018) it was reported that both participants and teachers were randomly assigned to the different groups. In Bar-Kochva (2016) there was a random assignment of participants; due to the absence of a human implementer, there was no need for teacher randomization. In Gray, Ehri & Locke (2018) post-tests were administered by tutors who were blind to the kind of treatment received by the participants.

As for the attrition bias, in 4 studies (Eden *et al.* 2004; Greenberg *et al.* 2011; Sabatini *et al.* 2011; Gray, Ehri & Locke 2018) it was confirmed that all participants whose data were analyzed in the pre-test post-test comparisons had completed the whole training (participants who did not complete it were excluded from the analyses); no such information was instead explicitly provided in the other studies.

Due to the paucity of this information, risk of bias was judged low as for other 3 studies (Bar-Kochva 2016; Greenberg *et al.* 2011; Gray, Ehri & Locke 2018), whereas it was impossible to determine for the remaining ones.

4. Discussion

The main purpose of this review was that of shifting the attention of intervention studies on dyslexia from children to adults and to verify whether a specific reading training could be profitable also for older struggling readers. Although only 8 studies met the inclusion criteria of this systematic review, evidencing a gap in the literature and the need for more research in this domain, results were promising, confirming that adults can benefit from a reading intervention and that their difficulties in decoding, fluency and comprehension can be successfully compensated for if they are provided with a specific training, yielding an undoubtedly positive effect on their academic and work careers and, more generally, on their quality of life.

There are two aspects that deserve to be emphasized here; the first is that all the studies that we considered reported marked reading deficits in the adult samples that participated in the intervention, thus confirming that the literacy difficulties associated to dyslexia are persistent with age, along with marked phonological, rapid naming and WM deficits. The second is that evidence for remarkable improvements after specific training has been reported as well, together with substantial neurological changes, as confirmed by the fMRI data provided by Eden *et al.* (2004), and the ERP data reported in Shiran & Breznitz (2011), suggesting that the plasticity of the adult brain may be even larger than originally thought. These results are also supported by Horowitz-Kraus (2016), a study that could not be included in this review for the lack of a control intervention and which proposed the very same reading acceleration training administered by Breznitz *et al.* (2013) to adults with dyslexia reporting an improvement in both reading fluency and accuracy associated to significant electrophysiological changes. Although the studies considered suffer some limitations and

the effect sizes are mainly small to moderate (and in some cases looking at the CIs the estimates cannot be considered precise, possibly due to the low number of participants), we believe that they open the way to a fruitful stream of research that should be explored thoroughly and rigorously.

Once observed that training can be effective also in adulthood, which was our first research question, we addressed our second research aim and analyzed in detail the distinct proposals: in spite of the limited number of studies, we found a great diversification and heterogeneity in the approaches developed, which reflects the fact that reading is a complex and composite ability enabled by distinct processes, which can in turn be specifically tackled by different programs. Phonological-based interventions are the most frequently administered, having a longer tradition in the field of developmental dyslexia and of reading training, to the effect that they have been more thoroughly investigated (McArthur *et al.* 2018; Guyer & Sabatino 1989 in this review; see also the multisensoriality phonological intervention tested by Kitz & Nash 1982, excluded from this review for the absence of control group and control intervention). Summarizing the results discussed in this review, it was unanimously showed that these interventions, generally proposed with a multisensoriality instruction, produce gains on those components of reading that require more decoding skills, as in the case of nonword reading, and in particular the application of grapheme-phoneme conversion rules: this is particularly relevant for languages with an opaque orthography like English, which was indeed the language of all the phonics-based approaches reviewed here (Eden *et al.* 2004; Guyer & Sabatino 1989; Greenberg *et al.* 2011; Sabatini *et al.* 2011). The positive outcomes reported in these studies are arguably related to an increased phonological competence of the individual, as independently assessed by Eden *et al.* (2004), both at the behavioral and at the neurological level, which enables a more effective decoding. The fact that the efficacy of these interventions extends to older readers, although it should be observed that the effect sizes are mainly low to medium, is in line with early studies indicating that phonological deficits can be remediated for in adulthood too and that there is actually no critical period for the acquisition of literacy and of segmental analysis in illiterate adults (Morais *et al.* 1986; Morais 1987; Gombert 1994). Nevertheless, real word reading and text reading rates appear to be less susceptible to this kind of training, as suggested by Eden *et al.* (2004), who reported only a significant effect in text reading accuracy, but not in reading rate or in real word reading.

Higher efficacy in real word decoding and text reading accuracy were reported instead by studies integrating the phonological intervention with other linguistic levels, especially morphology. In this respect, the results of Gray, Ehri & Locke's (2018) research provide interesting insights, showing that an intervention integrating phonological and morphological training can positively affect not only nonword but also real word reading. Similarly, Bar-Kochva (2016) showed that even a very short and implicit morpheme-based training can produce positive gains in real word reading and in the accuracy of passage reading (respectively with large and medium effect sizes), which could become even more significant with a higher-intensity intervention. Guiding students in the analysis of the word's morphological structure can indeed improve the readers' linguistic awareness and their autonomy in transferring what learned to new material (Gray 2015), as shown by an increasing number of studies conducted on children and mentioned above. Notice that this can be particularly important for older readers and adults, who are more often exposed to low-frequency and complex words. Moreover, it is interesting to notice that the morpheme-based training was effective not only in a morphologically rich language like Hebrew (Bar-Kochva 2016), but also in a morphologically poorer language with an opaque orthographic system like English (Gray, Ehri & Locke 2018, although with a smaller effect size), which suggests that this type of intervention could be employed in languages with different morphological structures (Tsesmeli & Seymour 2009).

Although phonological and morphological training can be useful to promote decoding skills, and thus to enhance accurate reading, this seems not to suffice to induce sensible gains in fluency, as suggested by the lack of significant gains reported in text reading rate by the studies reviewed here (see also Breznitz 2006). Among these studies, an improvement in fluency was reported in the three interventions proposed by Sabatini *et al.* (2011), which indeed specifically trained also this component by adopting the repeated reading methodology discussed above. An interesting technique which also attained promising results is the reading acceleration training (Breznitz *et al.* 2013; Horowitz-Kraus 2016), showing that imposing time constraints on reading by means of computerized programs can be very effective for automatizing and speeding up the process of decoding. This indicates that fluent reading relies, at least in part, on rapid information processing and that this in turn is characterized by enough plasticity and flexibility to be susceptible to training even in adults and in people with dyslexia. Interestingly, these results have been confirmed by another study conducted by Horowitz-Kraus *et al.* (2014) on Hebrew L1 and English L1

children, showing gains also in children, independently from the opacity of the orthographic system.

Significant outcomes in fluency, as well as in the other reading measures, have been reported also by the WM training proposed by Shiran & Breznitz (2011), confirming the crucial role played by WM in reading: an intervention tackling the verbal (i.e. phonological) and visuo-spatial WM can lead to improvements in phonological competence, in reading abilities, including accuracy and fluency of nonword, word and passage reading, and in reading comprehension. Having higher WM skills entails indeed having higher processing resources, which in turn permits to elaborate written information more rapidly and accurately and to construct a more precise overall representation of the text: lower WM skills, instead, mean lower resources available for decoding and thus for understanding, as confirmed by studies showing that reading comprehension is strongly related to WM (Cain, Oakhill & Bryant 2004; Swanson & O'Connor 2009). It is also worth observing that in this review gains in comprehension have been reported only by studies who found an improvement in fluency, confirming the tight relationship between the two (Shiran & Breznitz 2011; Sabatini *et al.* 2011; Breznitz *et al.* 2013): reading accurately but too slowly can indeed hinder the comprehension process.

The diversification of the trainings proposed and their effectiveness on different reading components seem thus to suggest that an intervention should tackle different aspects to be maximally effective: on the basis of the individual's weaknesses and strengths, it should aim at improving decoding skills, by focusing on phonological and morphological processes and on the single word in a larger context to activate syntactic and semantic competence (as in Perfetti 2007), but also fluency and reading rate, which can be trained with computerized programs aiming to enhance fluency by means of reading acceleration and working memory programs. This would permit to enhance reading abilities more broadly, thus enabling better comprehension.

Besides providing initial evidence suggesting which interventions can be effective for adults with reading disorders, this review also indicates which types of training are not effective: this is the case of programs proposing direct and focused reading only, as provided in extensive reading programs (Greenberg *et al.* 2011) and in self-paced reading programs (Shiran & Breznitz 2011; Breznitz *et al.* 2013), which is not enough to produce significant gains in reading. We believe that this is something that should be emphasized, as it is often erroneously believed that engaging in a continuous and constant exercise of reading can in itself improve the individual's literacy skills, as it happens for

typically developing children acquiring literacy. This is not the case for people with dyslexia, who even after many years of exposure to written materials still struggle in literacy, showing reading abilities comparable to those of a school-aged child.

As for the practical aspects of the intervention, group size, type of implementer and training duration have been found to vary sensibly depending on the program adopted: as a general observation based on the studies reviewed here, the duration of the intervention can be significantly reduced when the training is computerized and individual. One-to-one and small-group interventions have also been reported in the literature as the most effective options, since they permit to tailor the training on the subject's real needs (Wanzek & Vaughn 2008; Wanzek *et al.* 2016). This is valid also for spelling interventions, as reported in the meta-analysis conducted by Galuschka *et al.* (2020), who found that individual settings showed the largest effect size, as opposed to the moderate effect size of small-group interventions; classroom interventions are instead not sufficiently specific for the learner's needs. In this spirit, a successful training should always be preceded by an accurate identification of the specific profile of each individual and of their strengths and weaknesses (Lorusso, Facoetti & Bakker 2011), which is the only way to predispose an intervention really tailored on the individual's peculiarity and thus maximally effective. In the studies we reviewed, there actually was a quite extensive evaluation of the poor readers linguistic and cognitive abilities, although the information provided were not really accounted for in shaping the intervention: it could be interesting, for instance, to compare different interventions on the basis of the individual's weaknesses, focusing more on phonology for people with evident impairments in this domain and thus in the area of decoding, and on reading acceleration paradigms for slow readers with impaired lexical access.

The importance of making interventions flexible, and adapted to the individual's needs, was also at the basis of our choice to review studies conducted on adults: it can be indeed risky to blindly rely on child-based assumptions when designing interventions for adults and it is essential to conduct research on older learners to develop effective strategies (Nanda, Greenberg & Morris 2010). In this review, we found that most programs that are effective for children are generally useful for adults too, as it is the case for phonics and morphological training, but also for reading acceleration and WM training; conversely, extensive reading programs seem to be less effective for adults than they are for children, perhaps due to a higher fossilization of the reading strategies adopted by older readers.

It must indeed be observed that, although one of the major differences between learning in childhood and in adulthood lies in the greater degree of autonomy of adult learners, who are generally able to control their learning and to self-regulate their behavior, this may not be the case for adults with dyslexia, who tend to replicate in reading the old habits and strategies that they had learnt at school even when they were not effective for them. However, as repeatedly emphasized here, adulthood is not too late for starting an appropriate reading intervention and a specific treatment can be very helpful in changing ineffective strategies, by replacing them with more successful ones, and in enhancing the linguistic and cognitive skills that are deployed in reading.

Some considerations on the language of the intervention and in particular the transparency of the orthographic system are also appropriate here: this review has evidenced a marked unbalance in the research conducted in this field, with the well-known hegemony of English and the presence of Hebrew. Although there is some preliminary evidence that the same treatment can be effective across different languages for the reading acceleration paradigm (see Horowitz-Kraus *et al.* 2014) for a study reporting similar efficacy for children tested in English and in pointed Hebrew, respectively representative of opaque and transparent orthographies) and for the morphological training (Bar-Kochva 2016; Gray, Ehri & Locke 2018), we believe that more research targeting different languages, and crucially also different writing systems, is needed. As for the distinction between L1 and L2 speakers, the same training seems to be effective both for L1 and for L2 speakers with a good proficiency in that language, indicating that positive outcomes extend to or can be even more pronounced in the second language (Greenberg *et al.* 2011; Gray, Ehri & Locke 2018).

To conclude, although the studies reviewed here have the merit to indicate that reading interventions can be effective also for adults, which was our main research question, it must be acknowledged that research in this domain is still in its infancy, and that the few studies proposing a literacy intervention to adults provided results that, although being promising, were in some cases difficult to evaluate due to the lack of important details not reported in the papers and to a potential risk of bias. More research is therefore needed to provide more precise answers about reading interventions in adults with dyslexia, while further studies, especially addressing different languages and different writing systems, should definitely be encouraged.

5. Conclusion

While aiming to fill a gap in the literature on reading intervention for adult individuals with dyslexia, this review enlightened the paucity of studies to date conducted on older people with reading disorders, unveiling the fact that research on this topic remains neglected. Keeping in mind that dyslexia accompanies individuals across all their lifespan and that access to literacy is vital to cope with the daily requests of an information-based society, it appears imperative for future research to address possible interventions that can be enacted to support older dyslexics and impaired readers in enhancing their literacy skills and offering them concrete opportunities for a higher gratification and personal satisfaction, not just on the workplace, but, more in general, in their cultural and intellectual environment and in all those daily activities that require access to literacy.

As shown by this review, only a few studies concretely addressed this issue: results, although still sparse, are however encouraging and indicate that it is never too late to pursue an improvement in reading abilities, which can certainly have positive outcomes not only on literacy and reading comprehension skills, but also on the individuals' quality of life. This is particularly relevant for teachers and health professionals who may be reluctant in proposing literacy interventions to adults. The results reported in this review confirm that the methodologies that are helpful and effective for children are generally equally effective for adults too, who should definitively be given the opportunity to enhance their reading skills, to pursue higher education and professional satisfaction and to fully enjoy social and cultural opportunities.

Notes

[1] We screened all the references contained in the systematic reviews found in our the literature search, and in particular those by Torgerson, Porthouse & Brooks (2005), Hock (2012) and Swanson (1999). The remaining reviews we found were instead not considered relevant for the purposes of our study, since either they focused only on children (Scuccimarra & Olivo 2013), or on students with emotional and behavioral problems (Burke *et al.* 2015; Roberts *et al.* 2015), or they proposed a brain stimulation intervention (Cancer & Antonietti 2018), or they provided just general considerations about definition and treatment of dyslexia (Gersons-Wolfensberger & Ruijssenaars 1997; Lerner 1989). The review by Galuschka *et al.* (2020) was also not considered as it focused on spelling, and not on reading interventions.

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Conceptualization, MV, DD and CM; Methodology, MV; Supervision, DD; Writing – Original Draft Preparation, MV; Writing – Review and Editing, MV, DD and CM.

Abbreviations

CI = Confidence Intervals; DCEF = Decoding, Comprehension, Extensive Reading and Fluency; DCF = Decoding, Comprehension and Fluency; DF = Decoding and Fluency; ER = Extensive Reading; N/A = not available (information not reported in the study); RAVE-O = Retrieval, Automaticity, Vocabulary, Elaboration-Orthography; WM = Working Memory.

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