



## THE ROLE OF PHONOLOGICAL MEMORY IN READING ACQUISITION AND DYSLEXIA: A SYSTEMATIC LITERATURE REVIEW

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### Abstract:

**Purpose:** This paper presents the findings of a systematic literature review regarding the role of phonological memory in reading acquisition and early onset of dyslexia. **Method:** Searching multiple bibliographic databases (PUBMED, HEAL-LINK/Annals of Dyslexia, SCOPUS, SCHOLAR), 254 published studies were identified as potentially relevant with 12 meeting the inclusion criteria. Eight of them refer to the role of phonological memory in reading ability and 4 in dyslexia. **Results:** The findings of the review highlight: (i) the limited range of conducted research regarding the association of phonological memory and reading ability in general and dyslexia in particular among preschool children, (ii) the significant heterogeneity of tools and tasks implemented and (iii) the shared conclusion by the vast majority of the studies suggesting that phonological memory affects reading ability and is an onset predictor of dyslexia. **Conclusions:** As a general conclusion, it was found that a common goal of all studies was to evaluate the contribution of phonological memory to reading ability. However, significant heterogeneity was found in tools and tasks (to a lesser extent) they used in their studies. Also, no clear conclusion emerged on the role of phonological memory in the acquisition of reading skill. More specifically, some studies have found a

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correlation between phonological memory and reading ability and some other non-correlation.

**Keywords:** reading skill; dyslexia; phonological memory; phonological short-term memory; phonological long-term memory

## 1. Introduction

### 1.1 Reading Acquisition

Reading is a skill gradually acquired that is taught based on the coordination of both linguistic and cognitive sub-skills (Gilliver & Byrne, 2009). This acquisition process includes the recognition of graphemes as representative symbols of phonemes on a written level, their correspondence to phonemes, and the storage of these associations in the long-term memory (de Carvalho et al., 2014; Mousiou-Milona, 2004; Porpodas, 2002). Graphemes decoded into sounds during reading, are then stored temporarily in the phonological working memory where they are initially converted into sounds sequence, which allows for the construction of words. Subsequently, the meaning of the constructed words is retrieved from the long-term memory, contributing thus, to understanding, interpreting, and assessing the meaning of everything that is being read (Harrison, 2004).

An essential requirement for learning how to read is the development of a high level, organized brain system, which can integrate orthographic, phonological and lexicosemantic characteristics of written words (Langer et al., 2013; Martin et al., 2015). Typical readers have achieved the skills of automated identification, recognition and grapheme categorisation via the activation of cortical areas, which are responsible for the visual recognition (González et al., 2014).

Specifically, the reading process utilises two distinct neural routes in the left brain hemisphere (Vandermosten et al., 2012; Christodoulou et al., 2014: 1):

- The dorsal phonological route contains the left temporoparietal junction (i.e., posterior superior temporal gyrus, angular gyrus and supramarginal gyrus) as well as the opercular part of Broca's area. The word grapheme-to-phoneme mapping takes place within the dorsal route.
- The ventral orthographic route or 'visual word form area' is found in the left occipitotemporal region close the fusiform gyrus. The activation of the occipitotemporal and semantic areas takes place in the triangular part of inferior frontal gyrus and facilitates the direct lexico-semantic route of reading, promoting thus access from word shape to meaning.

Reading development in beginning readers involves the left dorsal temporoparietal circuit, which includes phonology-based reading through serial grapheme-phoneme conversion. Moreover, more involvement of the left ventral occipitotemporal circuit occurs among skilled and efficient readers for rapid and automatic orthographic whole-word recognition (Martin et al., 2015).

## 1.2 Phonological Awareness and Reading Acquisition

The acquisition of semantic skill, pragmatic language, and the ability to process phonological elements are all achieved during preschool age (Panteliadou, 2000). The phonological processes that are related to acquiring reading are the phonological awareness and the phonological memory (Anthony et al., 2007; Bowman et al., 2004; Lonigan et al., 2000; Whitehurst et al., 2001).

The phonological awareness is related to one's ability to perceive, recognise access, discriminate, and manipulate the phonological structure of the sounds of already known words in a spoken language. The aforementioned abilities are fundamental for converting graphemes to phonemes. It has, also, been ascertained that children who have acquired phonological awareness exhibit better reading performance (Anthony & Francis, 2005; Carroll et al., 2003; Lonigan et al., 2000; Stuart, 2005). Researchers confirm that phonological awareness is, also, an essential skill for acquiring reading in Chinese language (Chow et al., 2005; McBride-Chang & Ho, 2005; Perfetti et al., 2013).

It is a specialised skill, which primarily contributes to the awareness that words are composed of phonemic constructs on an oral level and consequently to the manipulation of individual phonemes included in syllables or words. More specifically, phonemic awareness refers to the ability to synthesise phonemic elements in order to generate words and to analyse them in the phonemic structural elements of which they are composed (Scarborough & Brady, 2002).

## 1.3 Phonological Awareness and Early Onset of Developmental Dyslexia

Developmental Dyslexia (DD) is a specific learning difficulty with a neurological basis that is characterised by difficulties in writing, spelling and reading single words fluently and accurately (Caylak, 2010; Christodoulou et al., 2014). The ability to comprehend the content of a text requires the coordination of multiple processes and individuals with DD show limited reading comprehension owing to the deficient decoding and/or the slow reading speed (Christodoulou et al., 2014). The scientific community nowadays tends to move beyond a single-factor theory about the aetiology of DD and it rather adopts a multi-factor one (Elliot & Grigorenko, 2014). The single-factor theory approach suggests that reading difficulty is based solely on one factor, the medical one, which relates to brain functioning (Tzouriadou & Barbas, 2003). According to the multi-factor theory approach, "Phonological deficit" is one of the main theories that was developed aiming to investigate the causes of multifactorial and multidimensional structure of DD (Elliott & Grigorenko, 2015; Zoccolotti et al., 2016).

According to that theory, DD is characterized by deficits, as:

1. Slow progress in the development and production of (a) phonological codes of sounds (deficiency in auditory perception and discrimination of phonemes) (Goswami, 2002; Snowling 2000; Wilson & Lesaux, 2001); (b) phoneme-grapheme correspondence (Spinelli et al., 2009; Ziegler et al., 2010), and (c) semantic

recognition of words and non-words (Lishman, 2003; Puolakanaho et al., 2007; Verhoeven, Reitsma and Siegel, 2011).

2. Deficits in phonological memory (Anthony et al., 2010).

These domains are considered very important for aligning oral and written communication successfully. Snowling (2000) and others (Skeide et al., 2015; Zakopoulou et al., 2013) hypothesised that individuals with DD code the representations of verbal sounds incorrectly. Based on this hypothesis, individuals with DD exhibit difficulties to perceive the phonetic structure of oral language, to decode phonemes and their succession, resulting in later phonological errors during reading and orthography.

### 1.4 Phonological Memory

The most powerful predictor of the early development of phonological awareness by the end of the first year in primary school is considered the working memory (Preßler et al., 2014). Importantly, availability in working memory capacity at school entry has been linked to students' later academic achievement (Catts et al., 2002; Kirby et al., 2003; Schatschneider et al., 2004).

Phonological memory as a specialised system is considered responsible for the short-term storage of sounds and coding of phonological information, during the cognitive processes. It increases between ages of 4 and 12 years and is considered as the basic phonological process that contributes to acquiring letter knowledge, recognising words and so, facilitates readers to recall words they read in order to understand the context of a written text (de Jong & Olson, 2004; Piquard-Kipffer et al., 2013).

Phonological memory is commonly assessed by those cognitive tasks required for processing graphemes, as: tasks related to pseudowords repetition, immediate sequence recall, as well as digit span (Alloway et al., 2005; Anthony et al., 2006). These tasks are found not only to be linked with phonological memory but additionally, with the availability of the short-term and long-term memory, as well as with sequence memory (Gathercole & Adams, 1994).

Phonological memory is divided into phonological short-term memory and phonological working memory. Phonological short-term memory refers to the temporary storage of information to be processed and is linked with reading performance and the ability to store and reproduce verbal information (Carroll & Snowling, 2004; Catts et al., 2001). Its assessment is determined by tasks including pseudowords repetition, sentence repetition, and mnemonic ability using word lists, digit span, and sentence span (Kobayashi et al., 2005).

Phonological memory contributes significantly to the vocabulary development as it plays an important role in processing and storing new phonological structures (Gathercole, 1995; Michas & Henry, 1994). Vocabulary is developed subsequently facilitating the acquisition of reading as it is suggested that its slow development rate relates to reading difficulties (Alloway et al., 2005; Brunswick et al., 2012; Clark et al., 2012; Gathercole et al., 1991; Gilliver & Byrne, 2009; Piquard-Kipffer et al., 2013).

According to Gathercole et al. (2003), phonological working memory exhibits many structural and functional changes during the first two decades of life. Bowey (2001) reported that 5-year old children are able to identify phonemes and demonstrate better performance in phonological working memory.

Attempting to explain how the reader anchor the phonemic representations of each grapheme that he/she recognizes while reading a word, Baddeley (2003) developed the theory of “phonological loop”.

According to the Baddeley’s theory (1996, 2003), the “phonological loop” a specified sub-system of working memory is considered responsible for the short storage and elaboration of phonological information. In this way, when a sequence of graphemes in a visual form to assess immediate recall is presented, the grapho-phonemic correspondence must be realized, where the retention of the graphs is influenced by their phonological characteristics. Accordingly, as it has been confirmed from other studies (Porpodas, 1993; Steinbrink & Klatte, 2008), when performances in a reading test are below average, the performance in the phonological circuit also shifts to low scores.

### 1.5 Objectives

In summary, the structure as well as the role of phonological awareness in both reading acquisition and relative difficulties have been debated in a multifaceted basis, as follows:

- Is phonological awareness a unitary or a multifaceted process (Anthony & Francis, 2005)?
- Is phonological awareness related to other (cognitive) abilities (Carroll et al., 2014; Gustafsson & Wolf, 2015)?
- Does phonological awareness differ across languages (Papadopoulos et al., 2013)?
- Is phonological awareness measured efficiently, mainly at the preschool age (Wolf & Gustafsson, 2015)?
- Is phonological awareness considered an onset predictor of DD (Willcutt et al., 2010)?
- Is phonological memory causatively linked both with reading acquisition and specific learning difficulties (Carvalho et al., 2014; Gathercole, 2006)?

Almost all the aforementioned research questions are well answered in the literature, stressing the significant role of the multidimensional phenomenon of phonological awareness in understanding the process of learning to read and spell and consequent difficulties (Kjeldsen et al., 2014; Ziegler and Goswami, 2005).

However, examining all the evidence with regard to phonological memory that is considered as a key component of phonological awareness in reading and possible related difficulties (as DD) (Cain et al., 2004; Carvalho et al., 2014), the following hypothesis remains unclear:

Whether and under what prerequisites phonological memory could affect the early acquisition of reading and predict the early onset of DD, at the preschool age.

The main aim of the presented systematic review is to investigate in depth the aforementioned hypothesis through a systematic review of the current literature.

Particular key research questions were addressed, as following:

### 1.6 Key research questions

1. What criteria are met by studies to investigate the effectiveness of phonological memory in the acquisition of reading or early onset of DD at the preschool age?
2. Are the results of the studies investigating the effectiveness of phonological memory in reading and early onset of DD depended on psychometric analysis applied occasionally?

Specifically:

- a. What kind of measures of phonological memory are used to test the effectiveness of phonological memory in reading acquisition and early onset of DD?
- b. What kind of tasks are used to test the effectiveness of phonological memory in reading acquisition and early onset of DD?
3. Do the studies lead to well defined, clear as well as common conclusions about the effectiveness of phonological memory in reading acquisition and early onset of DD even at the preschool age?

## 2. Method

In the current study, the systematic literature review method was adopted in order to scope and review an adequate number of research papers relating to the subject under study (Peters et al., 2015; Moher et al., 2015).

### 2.1 Search Strategy

The following procedure was adopted for the identification of potentially relevant studies, their screening and eligibility as well as their final selection.

Initially, articles were included if they were published in English and no publication date range was applied among the following databases:

- PUBMED
- HEAL-LINK/Annals of Developmental Dyslexia
- SCOPUS
- SCHOLAR

The following keywords were searched: Developmental Dyslexia, phonology, "phonological memory", Developmental Dyslexia AND "phonology", Developmental Dyslexia AND "phonological memory", Developmental Dyslexia AND "phonological working memory", Developmental Dyslexia AND "phonological short-term memory, Developmental Dyslexia AND "phonological long-term memory".

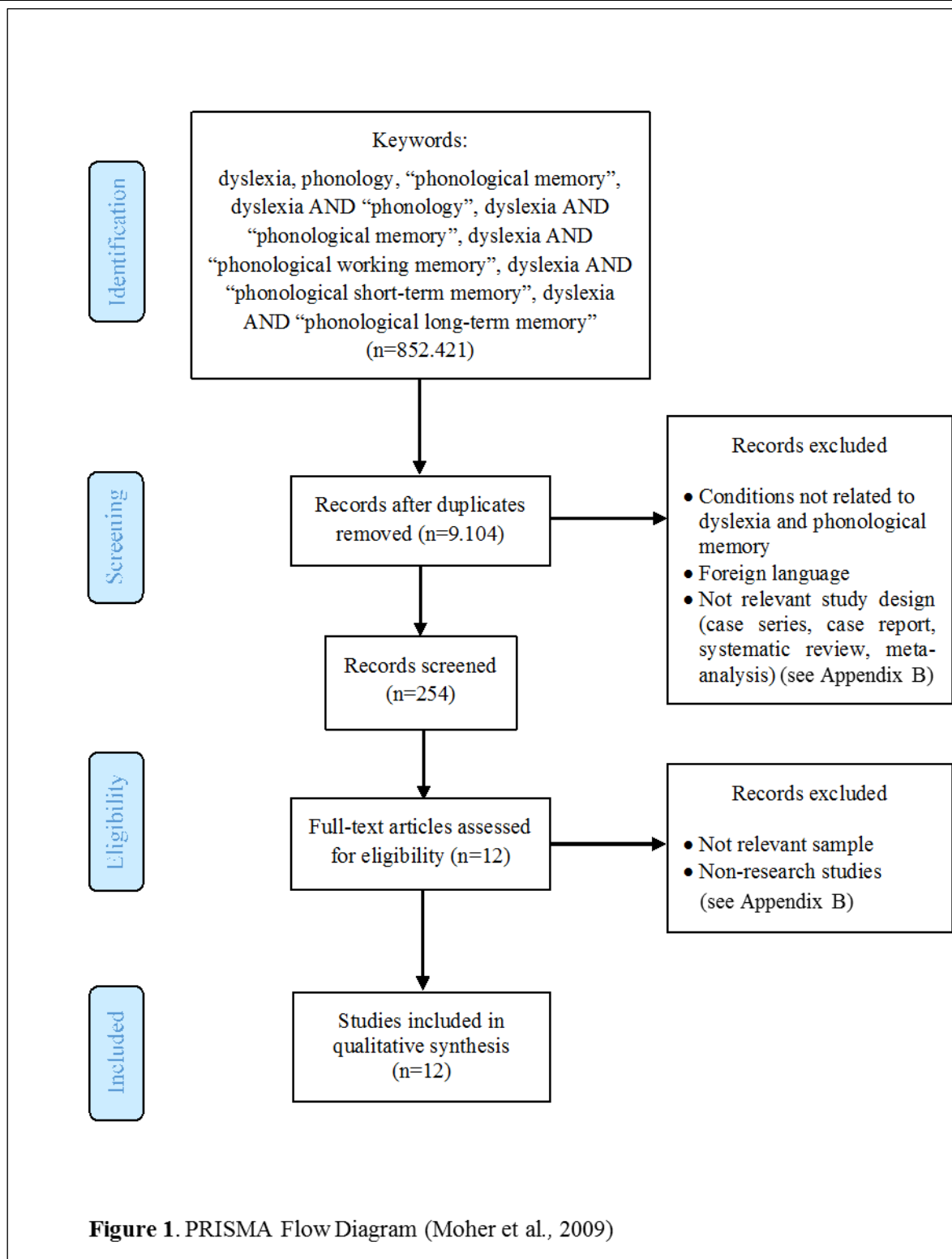
## **2.2 Study Design**

The study screening process (Moher et al., 2009) was done in two stages, as follows: (a) in stage 1, studies referring to reading skills or learning difficulties but not explicitly investigating the association between phonological memory and reading and DD were excluded. Similarly, studies were excluded on the basis of methodological criteria including: (a) studies not written in English; (b) studies reporting on adult samples; (c) non-research studies. In stage 2, those studies that initially included as referring to phonological memory and reading were excluded, in case the sample type was beyond the scope of interest as above or the type of studies was non-research (See S. Appendix A).

## **3. Results**

### **3.1 Selection of Studies**

The studies were selected based on inclusion and exclusion criteria developed for each key question determined by the PICOTS (Schardt et al., 2007) approach for identifying populations, interventions, comparators, outcomes, timing, settings and study designs (Figure 1).



The included studies were considered to allow for a common methodological analysis of their results related to the role of phonological memory in reading and the early onset of DD during preschool age. The main characteristics of all the included studies were (a) the type of the study (longitudinal or cross sectional); (b) the language in which tasks were administered; (c) the participants exclusion criteria in the studies; (d) the tools and assessment tasks for phonological memory; (e) the tools and



assessment tasks for reading; (f) the reported results; (g) the discussion and implications of the results.

Furthermore, the current systematic review included studies with an explicit focus on the preschool age children and on the role of phonological memory regarding reading's acquisition and early onset of DD. Longitudinal studies with a wider participants' age range were included but only data referring to children of the aforementioned age were taken into consideration (See S. Tables 1 & 2).

**Table 1:** Type of studies applied testing the effectiveness of phonological memory in reading acquisition and early onset of DD

<b>Reading acquisition</b>		
<b>N</b>	<b>Type of study</b>	<b>Studies</b>
6	Longitudinal	Bar-Kochva, 2013; Brunswick et al., 2012; Gathercole et al., 1991; Gathercole, 1995; Nithart et al., 2011; Piquard-Kipffer et al., 2013
2	Cross-sectional	Kidd et al., 2015; Kobayashi et al., 2005
<b>Early onset of dyslexia</b>		
3	Longitudinal	Ho, 2014; Moll et al., 2016; Torppa et al., 2006
1	Cross-sectional	Gilliver & Byrne, 2009

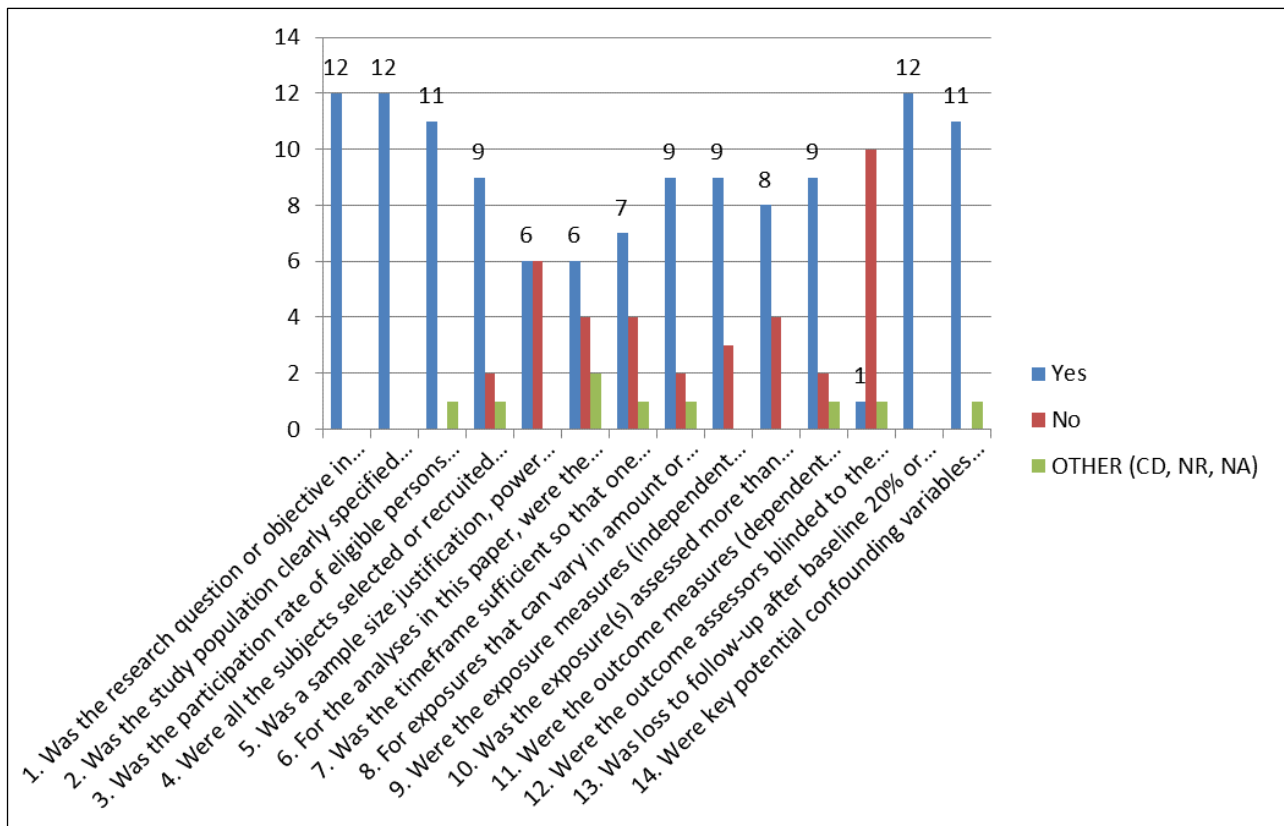
The quality of the included studies was assessed using the Quality Assessment Tool for Observational Cohort and Cross-Sectional Studies developed by the US department of the NIH (Moher, et al., 2009; National Heart, Lung, and Blood Institute, 2014). The assessment scale consists of 14 items that can be answered with a "Yes" a "No" or with an "other" that contain: "Cannot Determine", "Not recorded" and "Not applicable" (National Heart, Lung, and Blood Institute, 2014) (See S. Appendix B).

**Table 2:** Language of the sample recruited in the studies with regard to reading acquisition and early onset of DD

<b>Reading acquisition</b>		
<b>N</b>	<b>Mother tongue</b>	<b>Studies</b>
4	English-speaking children	Brunswick et al., 2012; Gathercole et al., 1991; Gathercole, 1995; Nithart et al., 2011
1	French-speaking children	Piquard-Kipffer et al., 2013
1	Native Hebrew speakers	Bar-Kochva, 2013
1	Cantonese-speaking children	Kidd et al., 2015
1	Monolingual Japanese speakers	Kobayashi et al., 2005
<b>Early onset of dyslexia</b>		
1	Finish native speakers	Torppa et al., 2006
1	Chinese participants	Ho, 2014
1	Australian participants	Gilliver & Byrne, 2009
1	Slavic-speaking children (Slovak & Czech)	Moll et al., 2016

For the most of the items (9/14) the positive answers are 9 (out of 12 studies) or more, indicating a good methodological plan and implementation. For the remaining 4 items the positive answers do not drop below 6 and only in the case of blinding the number is

low, but this is an item that we would not expect to be different considering the nature of the studies included (Figure 2).



**Figure 2:** Quality Assessment Tool for Observational Cohort and Cross-Sectional Studies developed by the US department of the NIH (Moher, et al., 2009; National Heart, Lung, and Blood Institute, 2014).

Following the inclusion and quality criteria that the studies should fulfil in order to answer the key research questions, the evidence of all the reviewed studies is presented below, respectively:

Testing the effectiveness of phonological memory in the acquisition of reading, the main criteria posed in the studies were established according to the mother tongue, the absence of any reading or developmental disorders, and the absence of following any speech therapy, as follows:

- Mother tongue was French (Piquard-Kipffer et al., 2013)
- Children were native speakers of Hebrew (Bar-Kochva, 2013)
- Children had not been diagnosed with mental, physical, or sensory (visual & auditory), linguistic, articulatory, neurological - cognitive difficulties (Gathercole et al., 1991; Kidd et al., 2015; Nithart et al., 2011; Piquard-Kipffer et al., 2013)
- Children had not been diagnosed with developmental difficulties at the preschool age (Bar-Kochva, 2013; Kobayashi et al., 2005)
- Children had not been diagnosed with hyperactivity and other emotional or behavioural problems (Kidd et al., 2015)

- Children had not been identified as non-readers at the beginning of the study (Brunswick et al., 2012)
- Children had not received speech therapy (Gathercole et al., 1991)

In reference to the criteria posed for the effectiveness of phonological memory in the early onset of DD, three main criteria were set: the absence of specific developmental disorders, monolingual participants, and the level of parental education, as follows:

- Children had not been diagnosed with mental, physical, or sensory disorders (visual & auditory), linguistic, articulatory, neurological - cognitive deficits: (Gilliver & Byrne, 2009; Torppa et al., 2006)
- All participants were monolingual (Gilliver & Byrne, 2009; Moll et al., 2016)
- The level of parental education was representative of the Finnish population (Torppa et al., 2006)
- No criterion specified: 1 study (Ho, 2014)

With regard to the psychometric characteristics of the studies, initially, the type of the studies applied and the language characteristics of the sample recruited were taken into account, as shown in the tables 1 & 2.

Concerning the measures used to test the effectiveness of phonological memory in reading acquisition, no common tools were administered in the studies while only three (3) of the measures were applied at the preschool age (Table 3).

**Table 3:** Measures used to test the effectiveness of phonological memory in reading acquisition applied at school and preschool age

<b>School age</b>		
<b>N</b>	<b>Phonological Memory Measures for Reading Acquisition</b>	<b>Studies</b>
1	Sub-tests from the AWMA battery (Alloway, 2007)	Bar-Kochva, 2012
2	British Ability Scales (Elliott, 1983)	Gathercole et al., 1991; Brunswick et al., 2012
1	Children's Test of Nonword Repetition (CNRep, Gathercole, Willis, Baddeley, & Emslie, 1994)	Gathercole, 1995
1	Audio-recordings (Ho et al., 2011)	Kidd et al., 2015
1	Non-word Repetition (from Japanese morae)	Kobayashi et al., 2005
1	E-prime (Psychological Software Tools, Pittsburgh, 2000)	Nithart et al., 2011
1	Test one of the ERTL4 test (Épreuve d Repérage des Troubles du Langage chez l'enfant de 4 ans) Roy & Maeder, 1992	Piquard-Kipffer et al., 2013
<b>Preschool age</b>		
1	Chinese reading textbooks for children at the preschool age in Hong Kong	Ho, 2014
1	Pre-Reading Level (Bat-Elem, Savigny, 1974)	Piquard-Kipffer et al., 2013
1	Single Chinese Characters for the preschool age (Ho et al., 2011)	Kidd et al., 2015

Similarly, no common measures were administered in the studies testing the effectiveness of phonological memory in the early onset of DD, while four (4) of them were used at the preschool age (Table 4).

**Table 4:** Measures used to test the effectiveness of phonological memory in the early onset of DD

N	Phonological Memory Measures for the early onset of DD	Studies
1	Developmental Neuropsychological Assessment (NEPSY; Korkman, Kirk, & Kemp, 1998)	Torppa et al., 2006
1	Novel Test	Gilliver & Byrne, 2009
1	Modified version of “Word Repetition Subtest of the Hong Kong Test of Specific Learning Difficulties in Reading and Writing (HKT-SPLD)	Connie Suk-han Ho, 2014
1	TEKOS I, TEKOS II & WESLALEX databases	Moll, 2016

Concerning the tasks used to test the effectiveness of phonological memory in reading acquisition at school age, the tasks commonly administered were “Single or List of Nonword Repetition” and “Digit Recall” while only one study (Bar-Kochva, 2002) used the “Listening Recall” task. Regarding the preschool age the most commonly used tasks were those of “Reading Single/Two Characters Words” while in only one study (Gathercole et al., 1991) the tasks of “Word Recognition” or “Picture-Word Matching” were used. “Oral Reading Fluency” task was used in only one study (Kobayashi et al., 2005) (Table 5).

**Table 5:** Specific phonological memory tasks testing the effectiveness of phonological memory in reading acquisition at school and preschool age

N	Phonological Memory Tasks for Reading Acquisition	Studies
<b>School age</b>		
7	Nonword Repetition Immediate Serial Recall Table 5 <i>Specific phonological memory tasks testing the effectiveness of phonological memory in reading acquisition at school and preschool age</i> (ISR) of Nonword lists. /Single Nonword Repetition Task/Pseudoword Repetition/Recall Test	Bar-Kochva, 2012; Gathercole et al., 1991; Gathercole, 1995; Kidd et al., 2015; Kobayashi et al., 2005; Nithart et al., 2011 Piquard-Kipffer et al., 2013
3	Recall of Digits, Digit Recall Forward & Backward/ Auditory Digit Span	Bar-Kochva, 2012; Brunswick et al., 2012; Gathercole et al., 1991
1	Listening Recall	Bar-Kochva, 2012
1	Recognition of the Serial Order of Digits	Nithart et al., 2011
<b>Preschool age</b>		
2	Reading of Chinese Single-Character Words	Ho, 2014; Kidd et al., 2015
2	Reading of Chinese Two-Character Words	Ho, 2014; Kidd et al., 2015
1	Reading of Simple Vowels	Piquard-Kipffer et al., 2013
1	Single-Word Reading (word decoding) Ability	Gathercole et al., 1991
1	Selection of the Correct Printed Word given its spoken form	Gathercole et al., 1991
1	Picture-Word Matching	Gathercole et al., 1991
1	Single - Word Recognition	Gathercole et al., 1991
1	Oral Reading Fluency (hiragana and katakana character) for at the preschool age children	Kobayashi et al., 2005

Testing the effectiveness of phonological memory in the early onset of DD, the main tasks that were used were of “Nonword Repetition”, “Word/Sentences Repetition”, while in only one study (Gilliver & Byrne, 2009) “Unfamiliar/Newly Learned Phonological Form” was used (Table 6).

**Table 6:** Specific phonological memory tasks testing the effectiveness of phonological memory in the early onset of DD

N	Phonological Memory Tasks for the early onset of DD	Studies
3	Nonword Repetition Immediate Serial Recall (ISR) of nonword lists. /Single Nonword Repetition Task/ Pseudoword Repetition	Moll et al., 2016; Torppa et al., 2006
1	Word Repetition/Recall Test	Moll et al., 2016
1	Sentence Repetition Task	Torppa et al., 2006
1	Syllable Repetition	Ho, 2014
1	Immediate Recall of Unfamiliar Phonological item in isolation	Gilliver & Byrne, 2009
1	Recognition Memory of the Newly Learned Phonological Form	Gilliver & Byrne, 2009

With regard to the conclusions of the studies, whether a significant effectiveness of phonological memory is causatively linked with reading acquisition or not, mostly at the preschool age, their findings were documented as follows:

Four (4) studies (Brunswick et al., 2012; Gathercole et al., 1991; Gathercole, 1995; Piquard-Kipffer et al., 2013) agree that phonological memory plays a significant role in the acquisition of reading, and for the most of the part, even from the preschool age. Four (4) studies (Bar-Kochva, 2012; Kidd et al., 2015; Kobayashi et al., 2005; Nithart et al., 2011) agree that phonological memory does not play a significant role in the acquisition of reading, at the preschool age.

However, concerning the effectiveness of phonological memory in the early onset of DD, three (3) studies (Gilliver & Byrne, 2009; Moll et al., 2016; Torppa et al., 2006) agree that phonological memory has a significant correlation with the early onset of DD at the preschool age. However, in one (1) study (Ho, 2014) no correlations were found between phonological memory and early onset of DD.

### 3.2 Discussion

The main aim of the presented systematic review was to investigate whether and under which prerequisites phonological memory, as distinctive component of phonological awareness, could affect the early acquisition of reading and predict the early onset of DD.

The results of the current review showed that the majority of the included studies proposed phonological memory as a significant predictor for the acquisition (or not) of reading. Moreover, the scrutiny of the studies’ characteristics facilitated a constructive comparison of their methodological aspects which were then reflected on the established key research questions, as following:

**Q1. What criteria are met by studies to investigate the effectiveness of phonological memory in reading acquisition or early onset of DD at the preschool age?**

The majority of the studies (apart from Ho, 2014) applied inclusion criteria for the participating children. Some of them excluded studies with children diagnosed with mental, physical, sensory (visual and auditory), linguistic, articulatory, neurological – cognitive, and developmental difficulties (Bar-Kochva, 2013; Gathercole et al., 1991; Gilliver & Byrne, 2009; Kidd et al., 2015; Kobayashi et al., 2005; Nithart et al., 2011; Piquard-Kipffer et al., 2013; Torppa et al., 2006).

It becomes obvious that any correlation founded between phonological memory and reading or early onset of DD regards only the process of reading or the occurrence of any symptom of the clinical profile of DD

This criterion is in line with Caylak (2010) and Horowitz-Krauz et al. (2014) who suggested that DD is not related to sensory deficits, low IQ, lack of educational opportunities or psychiatric disorders.

**Q2. Are the results of the studies investigating the effectiveness of phonological memory in reading and early onset of DD depended on psychometric analysis applied occasionally?**

The included longitudinal studies (Bar-Kochva, 2013; Brunswick et al., 2012; Gathercole et al., 1991; Gathercole, 1995; Ho, 2014; Moll et al., 2016; Nithart et al., 2011; Piquard-Kipffer et al., 2013; Torppa et al., 2006) provided more in-depth presentation of the results compared to cross-sectional studies (Gilliver & Byrne, 2009; Kidd et al., 2015; Kobayashi et al., 2005). Monitoring and assessing a sample more than once, as in the case of longitudinal studies, more comparisons across different timelines can be made. Consequently, this results in more thorough analysis of, and reflection on the findings. In those cases where the performance of a sample is examined only at a specific point in time, as in the case of cross sectional studies, important conclusions can be made but not of a high significance as in the case of longitudinal studies. Similarly, in those studies where significant associations are identified, the assessment of reading takes place at primary school whereas the assessment of phonological memory at preschool age.

As a result, it becomes obvious that based on the design of cross-sectional studies the identification of statistically significant associations is rendered rather challenging and possibly this study design might not be appropriate for the exploration of the relationship between phonological memory and reading.

**a.** What kind of measures of phonological memory are used to test the effectiveness of phonological memory in reading acquisition and early onset of DD?

Heterogeneity was evident among the studies concerning the tools used to assess phonological memory.

However, some of the studies used partially common tools, ascertaining that the important factors for assessing phonological memory are memory of words, memory of sentences, and nonword repetition (Gilliver et al., 2008; Ho, 2014; Moll et al., 2016;

Torppa et al., 2006). Other studies concluded that phonological memory is associated with phonological awareness to a moderate degree, as the participants are required to operationalise the memory capacity to engage with the phonological awareness tasks. In addition, the retention of auditory information in phonological short-term memory is essential for the processing of information through working memory (Anthony et al., (2006; Clark et al., 2012; Preßler et al., 2014).

Proportionally, Banai et al. (2012) explored the phenomenon of anchoring in relation to a short-term implicit process that allows individuals to better comprehend information. Using a syllable span task they concluded that anchoring, which contributes significantly to the achievement of reading, is indeed associated with phonological memory.

Similarly, phonological memory, digit span, literacy rate, and mother training were considered as the most important predictors of delay in the development of literacy. In addition, the high risk of occurring DD was found to be related to the slow learning of the names of the letters and hence to poor phonological memory, poor vocabulary and poor reading.

It was found that the capacity of phonological working memory is associated significantly with literacy achievement and constitutes the most powerful predictor of the development of phonological awareness both at preschool and at Grade 2 of primary school.

Regarding the tasks used for assessing phonological memory most of the included studies administered the “Nonword Repetition/Pseudoword Repetition” task (Bar-Kochva, 2013; Gathercole et al., 1991; Gathercole, 1995; Kidd et al., 2015; Kobayashi et al., 2005; Moll et al., 2016; Nithart et al., 2011; Piquard-Kipffer et al., 2013; Torppa et al., 2006). According to Anthony et al (2006) and Clark et al (2012), this particular task was considered as reliable for assessing phonological memory, as valid to be applied at the pre-school, pre-literacy level.

In contrast, Baddeley et al. (1998) suggested that “Nonword Repetition” is not an appropriate task, as children cannot access the stored mental lexicon. In addition, Bowey (2001) stated that “Nonword Repetition” is a complex task because apart from the capacity of memory other phonological processing skills are required, such as phonological awareness.

Other tasks found as reliable enough to assess phonological memory were targeted to the ability of recalling (sequence of) digits in order, such as:

- i. “Recall of Digits/Digit Recall Forward & Backward” (Bar-Kochva, 2013; Brunswick et al., 2012; Preßler et al., 2014; Torppa et al., 2006), “Word Recall” (Bar-Kochva, 2013)
- ii. “Digit Span” (Bar-Kochva, 2013; Brunswick et al., 2012; Gathercole et al., 1991)
- iii. “Digit Span Forward Task-Recall of a Series of Digits in a Correct Order” (Preßler et al., 2014)
- iv. “Recognition of the Serial Order of Digits” (Nithart et al., 2011).

Taking into consideration the above observations, it is obvious that the assessment of the ability of recalling non-words, digits and the order of digits and digits span repetition could lead to more reliable and comparable outcomes.

With regard to the tools and tasks used for predicting reading during preschool age were even more heterogeneous and there was higher disagreement as to their suitability amongst researchers. More specifically, only the 'Primary Reading Test' (France, 1981) was used in more than one study as it was reported by Gathercole et al. (1991) and Gathercole (1995). Amongst the remaining studies, no other reading assessment tool was used in more than one study.

Despite the fact that preschool children were the focus of the current review it is worth mentioning that some studies (Bar-Kochva, 2013; Brunswick et al., 2012; Nithart et al., 2011; Piquard-Kipffer et al., 2013; Kidd et al., 2015; Kobayashi et al., 2005) administered reading tasks amongst primary school children. The related results provide important information regarding the main objective of the current review that is the predictive role of phonological awareness in reading and DD especially via reading performance in the first years of primary school. Once again, based on the above, the use of a commonly agreed and accepted tool for assessing reading has been deemed necessary. Lending further support to this proposition is the fact that only two studies (Nithart et al., 2011; Piquard-Kipffer et al., 2013) administered the 'Standardised French Reading Test L' allouette' tool (Lefavrais, 1967).

Regarding the administered tasks there was a higher degree of convergence in the tools reported. More specifically, Gathercole et al. (1991) as well as Gathercole (1995) administered "Word Recognition" task amongst preschool children, and Nithart et al. (2011), amongst primary school children, respectively.

Similarly, the task of "Oral Reading Fluency/Reading Aloud/Word Reading" task was considered widely accepted to be administered amongst preschool children (Gathercole et al., 1991; Ho, 2014), amongst both preschool and primary school children (Kidd et al., 2015; Kobayashi et al., 2005; Piquard-Kipffer et al. 2013), and amongst primary school children (Brunswick et al., 2012). Less accepted was considered the "Comprehension of Reading" task, as it was administered only in Bar-Kochva's (2013) study.

### **Q3. Do the studies lead to well defined, clear as well as common conclusions about the effectiveness of phonological memory in reading acquisition and early onset of DD even at the preschool age?**

Based on the studies' findings, it seems that rather there is an agreement about the statistically significant association between phonological memory and reading (Brunswick et al., 2012; Gathercole et al., 1991; Gathercole, 1995; Piquard-Kipffer et al., 2013) at the preschool as well as the primary school children.

Particularly, the researchers stress that the role of phonological memory is related to reading in every stage of reading acquisition and mediates in the relationship between reading and phonological awareness (Brunswick et al., 2012). Moreover, they



conclude that phonological short-term memory is associated with future reading and early phonological short-term memory skills from the age of 5 can reliably predict future reading at the age of 8 (Piquard-Kipffer et al., 2013)

Gathercole et al. (1991) concluded that the role of phonological memory is important for acquiring reading at the age of 5 years, but not at the age of 4 years, while Gathercole (1995) came to the opposite conclusion suggesting that phonological memory is important at the age of 4 and not 5 years for acquiring reading. The main factor for arriving at the latter conclusion was the diminished role of phonological memory within one year into learning how to read, resulting in the importance of phonological memory at the age of 4 and not 5 years.

However, it has been suggested that phonological memory does not have a statistically significant association with reading among at the preschool age (Bar-Kochva, 2012; Kidd et al., 2015; Kobayashi et al., 2005; Nithart et al., 2011). Kobayashi et al. (2005) further extended this assertion suggesting that the aforementioned association is present among primary school children only. On the other hand, Nithart et al. (2011) did not identify such an association neither among preschool nor primary school children. According to the authors, this absence might be explained by the design of the administered tasks, as they included one-syllable and multi-syllable pseudowords. The majority of pseudoword tasks usually contain items of more than 5 syllables each even if administered at 5 year-old children (Gathercole, 1995). Finally, Brunswick et al. (2012) highlighted that phonological memory is associated overall with reading at every stage of reading acquisition and mediates the relationship between reading and phonological awareness.

The studies that focused on the role of phonological memory in the early onset of DD agreed, across the board, that phonological memory affects the onset of DD among at risk children. They suggested that children at high risk of developing DD exhibited low performance when recalling non-words (Moll et al., 2016; Torppa et al., 2006).

Specifically, they found that preschool verbal expression and phonological memory, the ability of recalling digits (digit span), the teaching of the letters' names at home, and mothers' educational level are important predictors of the delayed learning of letters (Ho et al., 2014; Moll et al., 2016). The high risk of DD's onset was associated with the slow learning of the letters' names and therefore with poor phonological memory, poor vocabulary and poor reading.

On the other hand, Gilliver and Byrne (2009) focused explicitly on phonological memory proposing that vocabulary (word learning) affects primarily reading and subsequently the phonological sub-system of phonological working memory. They, also, suggest that children at high risk of DD can be affected by phonological memory, but only in relation to recall and not recognition performance. Apart from Gilliver and Byrne (2009), Torppa et al. (2006) highlighted that letter knowledge affects reading which in turn is affected by phonological memory. Even in this case, phonological memory indirectly influences reading. As de Jong and Olson (2004) mention, the letter

knowledge is influenced by phonological short-term memory with nonword repetition being a predictor of letter knowledge achievement.

It is important to note that despite the plethora of potentially relevant studies initially identified in the databases, we ended up with a limited number of them fulfilling the inclusion criteria as the concepts explored in this systematic review have not been the explicit focus of research yet. Hence, the emergent research gap related to the association of phonological memory with reading and DD requires further elucidation.

### **3.3 Limitations**

The current review included studies published up until March 2017. Therefore, it is possible that potentially relevant studies published after that time was not screened. Another limitation is that only studies written in English were eligible for inclusion.

## **4. Conclusions**

All the reviewed studies concluded that phonological memory has indeed a prominent role in the development of reading and the early onset of DD. However, it seems increasingly necessary to construct more measures and tasks that meet criteria commonly accepted by the research community. We believe that moving towards this direction, divergent outcomes amongst research studies and findings will constantly be minimized, thus making possible their analysis in light of a common basis.

Specifically, future studies should target to the following:

- Confirmation from as many studies as possible that the role of phonological memory is undeniably related to the acquisition of reading and is considered a strong predictor for early reading acquisition.
- Conduction of longitudinal studies as they monitor the development of children from infancy, thus ensuring more in-depth results.
- Development of a comprehensive phonological memory assessment tool, consisting of specific measurement criteria, which will be widely accepted. As mentioned above, there was considerable heterogeneity in the choice of tools to assess phonological memory and a smaller but equally significant deviation in its measurement tests.
- Conceptual clarification of the effectiveness of the phonological memory in reading and early onset of DD, as a separate phonological processing skill or a phonological awareness.
- Specification from a larger number of studies whether phonological memory is one of or the strongest predictor in reading acquisition and early onset of DD.
- Development of intervention methods that will enhance phonological memory in cases where reading difficulties are detected, preferably at the preschool age.

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**S. Table 1.** Extraction table with characteristics of included studies for phonological memory (PM) and reading ability.

Author (Year)	Study design	Children's age	Language	Criteria	PM tool	PM task	Reading tool at preschool children	Reading Task at preschool children	Reading tool in elementary	Reading Task in elementary	Outcome
Nithart et al. (2011)	Longitudinal study	N= 44 Kindergarten	English-speaking children	The children had no noticeable visual, auditory, articulatory or neurological deficit	E-prime (Psychological Software Tools, Pittsburgh, 2000).	1. Immediate serial recall (ISR) of nonword lists. 2. Single nonword repetition task. 3. Recognition of the serial order of digits	French version of the Peabody test (Dunn, The 'riault-Whalen and Dunn,1993)		Standardised French reading test L'allouette (Lefavrais,1967) /decoding abilities & word recognition was assessed by means of a word- to - picture matching task (Chomsi,1990)	Decoding abilities and word recognition	The correlations between phonological memory and reading skills were not significant
Brunswick et al., 2012	Longitudinal study	N= 142 Kindergarten (72 girls & 70 boys). M: 45,4 months, SD= 4,6	English-speaking children	All children were identified as non-readers at the beginning of the study	British Ability Scales (Elliott, 1983).	Recall of digits (digit span)			British Ability Scales (Elliott, 1983) in elementary school	Reading aloud words of increasing difficulty	Digit span at each stage correlated significantly with subsequent reading ability
Piquard-Kipffer et al., 2013	Longitudinal study	N=85 (39 at - risk /24 boys & 16 girls) & 46 not-at risk/ (28 boys & 18 girls)	French-speaking children	Children : a)without sensory, linguistic or cognitive deficits b)Mother tongue was French	Test one of the ERTL4 test (Épreuve de Repérage des Troubles du Langage chez l'enfant de 4 ans) Roy & Maeder, 1992	Repetition of 7 pseudowords	Pre-Reading Level (Bat- Elem, Savigny, 1974)	Reading of simple vowels	Alouette test (Lefavrais, 1967)	Reading aloud word text	Phonological STM (short term memory)was significantly correlated with future reading skills
Bar-Kochva, 2013	Longitudinal study	N= 74, ages: 4 -7 (33 boys & 41 girls)	Native speakers of Hebrew	Without diagnoses of developmental difficulties at Kindergarten age	Sub-tests from the AWMA battery (Alloway, 2007).	1. Word and pseudoword recall (phonological short-term memory) 2. Forward digit recall (phonological short-term memory) 3. Listening recall (phonological working memory) 4.Backwards digit recall (phonological working memory)			Sub-tests of (ELUL, Shatil, Nevo, & Breznitz, 2007) for G1 and G2.	Silent semantic decision of words Silent semantic decision of pseudo-homophones. Reading comprehension (reading of sentences, a short text and a	Phonological memory scores not explained any significant amount of variance in the reading fluency measures and were therefore excluded from the final regression equations. In

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										long text)	contrast, the phonological working memory score explained a significant amount of variance in G1 reading comprehension
Gathercole et al., 1991	Longitudinal study	N= 108, ages: 4,5 Group of 4= 57 children & mean 4 years 9 months. Group of 5= 51 children & mean age 5 years 9 months	English	Excluded children with: hearing problems or be receiving speech therapy	Undefined means of measure	1. Nonword Repetition 2. Auditory digit span.	1. British Abilities Scales (Elliott, 1983) 2. France Primary Reading Test (1981)	1. Single-word reading (word decoding) ability. 2. Selection of the correct printed word, given its spoken form.			Phonological memory measures (Nonword repetition & digit span) were significant related to reading achievement at age 5, but not at age 4.
Gathercole, 1995	Longitudinal study	N= 70, ages: 4,5 1st wave= mean age 4 years 1 month & 2nd wave=mean age 5 years 3 months	English	Data are reported here only for the core group who completed each of the relevant test at both time of testing	Children's Test of Nonword Repetition (CNRep, Gathercole, Willis, Baddeley, & Emslie, 1994)	Nonword repetition (low- and high-word like nonwords)	1. Level 1 of the Primary Reading Test (France, 1981). 2.The 11 words used by Bryant, Bradley, Maclean, and Crossland (1989)	1. Picture-word matching 2. Single - word recognition			Reading achievement shared significant unique links with the age of 4, but not with the age of 5.
Kidd et al., 2015	Cross sectional	53 children from kindergarten	Cantonese	Participants had all passed an initial screen for visual or hearing impairments based on parental report, as well as hyperactivity and other emotional or behavioral problems, assessed via a parental	audio-recordings (Ho et al., 2011)	Nonword Repetition (nongap).	1. Simple two-character Chinese words (Ho, Leung, & Cheung, 2011). 2. Single Chinese characters for kindergarten	1. One-Minute Word Reading for Kindergarten 2. Chinese Word Reading for Kindergarten	1. Hong Kong Test of Specific Learning Difficulties in Reading and Writing (HKT-SpLD; Ho, Chan, Tsang, & Lee, 2000). 2. The HKT-	1. One-Minute Word Reading for Primary - school children 2. Two-character words for primary-school	Kindergarteners: Non word repetition did not show significant correlations with any of reading tasks. Primary - school: Chinese word

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				questionnaire. Children first took Raven's nonverbal IQ test. Those with an IQ 1 or more standard deviations below age norm average (Raven, 1986) were excluded from further testing.			rs (Ho et al., 2011)		SpLD Chinese Word Reading subtest; Ho et al., 2000).	children	reading correlated significant with all Phonological processing tasks.
Kobayashi et al., 2005	Cross sectional	N= 26 Kindergarten (18 boys, 8 girls. Mean age= 75.0 months, SD = 3.5, with a range of 68 to 80 months)	Japanese speakers	Excluded Children because: global developmental delays reported by their teachers or failed to complete tasks	Nonword Repetition	Nonword Repetition (from Japanese morae)	Unpublished pilot study by Sasaki, Azumi, Ando, Muta, and Yoda (2000)	Administration of oral reading fluency (hiragana and katakana character) for kindergarten children.	1. Unpublished pilot study by Sasaki, Azumi, Ando, Muta, and Yoda (2000) 2. Silent reading comprehension test based on Zoshindo-Jukenkyusy a Publishing Company, 1992, 1998).	1. Advanced text (hiragana, katakana, and kanji character). 2. Reading workbooks for first and second graders	Kindergarteners: No significant correlation between reading and phonological memory (Non word repetition). First Graders: Significant correlation between Reading comprehension and Phonological memory (Non word repetition)

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**S. Table 2.** Extraction table with characteristics of included studies for phonological memory (PM) and Developmental Dyslexia.

Author (year)	Study design	Children's age	Participants	Language	Criteria	Criteria for at risk group	Criteria for at non risk group	PM Tool	PM Task	PM measurement at risk group	PM measurement non risk group	Reading Tool at Preschool children	Reading task at Preschool children	Outcome
Torppa et al., 2006	Longitudinal Study	3,5 to 6,5	96 at-risk children (50 girls, 46 boys) and 90 nonrisk children (40 girls and 50 boys)	All the children are native Finnish speakers	a) The level of parental education is representative of the Finnish population . b) Children have no mental, physical, or sensory difficulties .	At least one of the parents who has been diagnosed with dyslexia & who reports similar problems among immediate relatives	Parents gave no personal or familial report of reading or spelling difficulties	Developmental Neuropsychological Assessment (NEPSY; Korkman, Kirk, & Kemp, 1998)	a)sentence repetition task b) nonword repetition task	Mean: -0.39 SD : 0.89	Mean: -0.03 SD : 0.78			Statistically significant difference between "non risk" and "at risk"
Ho, 2014	Longitudinal Study	4 to 6	High risk N = 75 Low risk N = 39	Chinese population		At least one child or one parent with dyslexia	Low family risk was a lack of this characteristic	Modified version of Word Repetition Subtest of the Hong Kong Test of Specific Learning Difficulties in Reading and Writing (HKT-SPLD)	Syllable repetition task	<b>1st measurement</b> Syllable repetition Mean: 40,06 SD : 1.29	<b>1st measurement</b> Syllable repetition Mean: 42,86 SD : 1.84	Chinese reading textbooks for kindergarten children in Hong Kong/ The alpha coefficients were 0.94, 0.96, and 0.97 for Time 1 to Time 3 respectively.	Chinese word reading (Time 1 to Time3) a) Thirty and 35 Chinese single-character words b) 40 two-character words	Non Statistically significant difference between non-risk and at-risk children
Gilliver & Byrne, 2009	Cross sectional	4 to 5	N=82 (44 males, 38 females) assessed for	Participants were from Australia	All participants were monolingual		Families with a history of reading	Novel Test	a)immediate recall of unfamiliar phonological					Significant correlation with

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			risk in a scale measurement		al, with no reports of hearing problems.		problems, although families of all reading backgrounds were encouraged to participate.		item in isolation b) recognition memory of the newly learned phonological form					risk status, indicated that higher recall scores were associated with lower risk for reading difficulties & no significant correlation for the recognition measure
Moll et al., 2016	Longitudinal Study	5 to 6	Family risk of dyslexia N = 38 (22 boys & 16 girls) Typical development N = 100 (44 boys & 56 girls)	Slavic-speaking children (Slovak & Czech)	Monolingual (zeck & Slavic speaking) children		First-degree relative with dyslexia (parent or older sibling)	TEKOS I, TEKOS II & WESLALEX databases	a)word/pseudo word repetition test b) non-word repetition task	<b>1st measurement</b> Word /PW recall Mean: 84,89 SD : 7.19 NW repetition Mean: 79,15 SD : 11.66	<b>1st measurement</b> Word /PW recall Mean: 77,02 SD : 11.46 NW repetition Mean: 67,89 SD : 15.71			Statistically significant differences in PM with greater values for non risk children
										<b>2nd measurement</b> Word /PW recall Mean: 84,23 SD : 9.71 NW repetition Mean: 77,21 SD : 13.23	<b>2nd measurement</b> Word /PW recall Mean: 74,75 SD : 12.54 NW repetition Mean: 67,11 SD : 15.48			

The following list includes indicative studies that were excluded at the screening stage owing to participants' age out with the scope of this review, studies not written in English and unsuitable study designs:

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## S. Appendix B

Quality assessment of studies exploring the role of phonological memory in relation to reading ability (National Heart, Lung, and Blood Institute, 2014):

- Bar-Kochva I, 2013. What are the underlying skills of silent reading acquisition? A developmental study from kindergarten to the 2nd grade. *Reading and Writing*, 26(9): 1417-1436.

### Quality Assessment Tool for Observational Cohort and Cross-Sectional Studies

Criteria	Yes	No	Other (CD, NR, NA)*
1. Was the research question or objective in this paper clearly stated?	*		
2. Was the study population clearly specified and defined?	*		
3. Was the participation rate of eligible persons at least 50%?	*		
4. Were all the subjects selected or recruited from the same or similar populations (including the same time period)? Were inclusion and exclusion criteria for being in the study prespecified and applied uniformly to all participants?	*		
5. Was a sample size justification, power description, or variance and effect estimates provided?		*	
6. For the analyses in this paper, were the exposure(s) of interest measured prior to the outcome(s) being measured?		*	
7. Was the timeframe sufficient so that one could reasonably expect to see an association between exposure and outcome if it existed?	*		
8. For exposures that can vary in amount or level, did the study examine different levels of the exposure as related to the outcome (e.g., categories of exposure, or exposure measured as continuous variable)?	*		
9. Were the exposure measures (independent variables) clearly defined, valid, reliable, and implemented consistently across all study participants?		*	
10. Was the exposure(s) assessed more than once over time?	*		
11. Were the outcome measures (dependent variables) clearly defined, valid, reliable, and implemented consistently across all study participants?	*		
12. Were the outcome assessors blinded to the exposure status of participants?		*	
13. Was loss to follow-up after baseline 20% or less?	*		
14. Were key potential confounding variables measured and adjusted statistically for their impact on the relationship between exposure(s) and outcome(s)?	*		

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**Quality Assessment Tool for Observational Cohort and Cross-Sectional Studies**

Criteria	Yes	No	Other (CD, NR, NA)*
1. Was the research question or objective in this paper clearly stated?	*		
2. Was the study population clearly specified and defined?	*		
3. Was the participation rate of eligible persons at least 50%?	*		
4. Were all the subjects selected or recruited from the same or similar populations (including the same time period)? Were inclusion and exclusion criteria for being in the study prespecified and applied uniformly to all participants?	*		
5. Was a sample size justification, power description, or variance and effect estimates provided?	*		
6. For the analyses in this paper, were the exposure(s) of interest measured prior to the outcome(s) being measured?	*		
7. Was the timeframe sufficient so that one could reasonably expect to see an association between exposure and outcome if it existed?		*	
8. For exposures that can vary in amount or level, did the study examine different levels of the exposure as related to the outcome (e.g., categories of exposure, or exposure measured as continuous variable)?		*	
9. Were the exposure measures (independent variables) clearly defined, valid, reliable, and implemented consistently across all study participants?		*	
10. Was the exposure(s) assessed more than once over time?		*	
11. Were the outcome measures (dependent variables) clearly defined, valid, reliable, and implemented consistently across all study participants?	*		
12. Were the outcome assessors blinded to the exposure status of participants?		*	
13. Was loss to follow-up after baseline 20% or less?	*		
14. Were key potential confounding variables measured and adjusted statistically for their impact on the relationship between exposure(s) and outcome(s)?	*		

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**Quality Assessment Tool for Observational Cohort and Cross-Sectional Studies**

Criteria	Yes	No	Other (CD, NR, NA)*
1. Was the research question or objective in this paper clearly stated?	*		
2. Was the study population clearly specified and defined?	*		
3. Was the participation rate of eligible persons at least 50%?	*		
4. Were all the subjects selected or recruited from the same or similar populations (including the same time period)? Were inclusion and exclusion criteria for being in the study prespecified and applied uniformly to all participants?			*
5. Was a sample size justification, power description, or variance and effect estimates provided?	*		
6. For the analyses in this paper, were the exposure(s) of interest measured prior to	*		

the outcome(s) being measured?			
7. Was the timeframe sufficient so that one could reasonably expect to see an association between exposure and outcome if it existed?	*		
8. For exposures that can vary in amount or level, did the study examine different levels of the exposure as related to the outcome (e.g., categories of exposure, or exposure measured as continuous variable)?	*		
9. Were the exposure measures (independent variables) clearly defined, valid, reliable, and implemented consistently across all study participants?	*		
10. Was the exposure(s) assessed more than once over time?		*	
11. Were the outcome measures (dependent variables) clearly defined, valid, reliable, and implemented consistently across all study participants?	*		
12. Were the outcome assessors blinded to the exposure status of participants?		*	
13. Was loss to follow-up after baseline 20% or less?	*		
14. Were key potential confounding variables measured and adjusted statistically for their impact on the relationship between exposure(s) and outcome(s)?	*		

- Gathercole S. E, 1995. Is nonword repetition a test of phonological memory or long-term knowledge? It all depends on the nonwords. *Memory & Cognition*, 23(1): 83-94.

#### Quality Assessment Tool for Observational Cohort and Cross-Sectional Studies

Criteria	Yes	No	Other (CD, NR, NA)*
1. Was the research question or objective in this paper clearly stated?	*		
2. Was the study population clearly specified and defined?	*		
3. Was the participation rate of eligible persons at least 50%?	*		
4. Were all the subjects selected or recruited from the same or similar populations (including the same time period)? Were inclusion and exclusion criteria for being in the study prespecified and applied uniformly to all participants?	*		
5. Was a sample size justification, power description, or variance and effect estimates provided?		*	
6. For the analyses in this paper, were the exposure(s) of interest measured prior to the outcome(s) being measured			*
7. Was the timeframe sufficient so that one could reasonably expect to see an association between exposure and outcome if it existed?	*		
8. For exposures that can vary in amount or level, did the study examine different levels of the exposure as related to the outcome (e.g., categories of exposure, or exposure measured as continuous variable)?	*		
9. Were the exposure measures (independent variables) clearly defined, valid, reliable, and implemented consistently across all study participants?	*		
10. Was the exposure(s) assessed more than once over time	*		
11. Were the outcome measures (dependent variables) clearly defined, valid, reliable, and implemented consistently across all study participants?	*		
12. Were the outcome assessors blinded to the exposure status of participants?		*	

13. Was loss to follow-up after baseline 20% or less?	*		
14. Were key potential confounding variables measured and adjusted statistically for their impact on the relationship between exposure(s) and outcome(s)?	*		

- Kidd J. C, Shum K. K. M, Ho C. S. H, & Au T. K. F, 2015. Phonological representations and early literacy in Chinese. *Scientific Studies of Reading*, 19(2): 89-113.

**Quality Assessment Tool for Observational Cohort and Cross-Sectional Studies**

Criteria	Yes	No	Other (CD, NR, NA)*
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2. Was the study population clearly specified and defined?	*		
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5. Was a sample size justification, power description, or variance and effect estimates provided?	*		
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