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Behavioral and Brain Measures of Morphological Processing in Children With and Without Familial Risk for Dyslexia From Pre-school to First Grade

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School-age reading skills are associated with and predicted by preschool-age cognitive risk factors for dyslexia, such as deficits in phonological awareness, rapid automatized naming, letter knowledge, and verbal short-term memory. In addition, evidence exists that problems in morphological information processing could be considered a risk factor for dyslexia. In the present study, 27 children at pre-school age and the same 27 children at first grade age performed a morphological awareness task while their brain responses were measured with magnetoencephalography. Our aim was to examine how derivational morphology in Finnish language, and concomitant accuracy and reaction times are associated with first grade reading, in addition to the preschool age reading-related cognitive skills. The results replicated earlier findings; we found significant correlations between pre-school phonological skills and first-grade reading, pre-school rapid naming and first-grade reading, and pre-school verbal short-term memory and first-grade reading. The results also revealed a significant correlation between the pre-school children's reaction time for correctly derived words in the morphological task and the first-grade children's performance in rapid automatized naming for letters. No significant correlations were found between brain activation measures of morphological processing and first-grade reading.

Keywords: derivational morphology, pre-school children, at risk for dyslexia, reading development, longitudinal, MEG, first-grade children

INTRODUCTION

The development of reading is a critically, increasingly important skill in our modern society. Learning to read is a continuous process that starts to develop during pre-school and kindergarten, before the starting point of formal education. Previous studies have demonstrated that pre-school linguistic and cognitive skills (such as phonological processing, rapid automatized naming (RAN), letter knowledge and verbal short-term memory) measured behaviorally predict school-age reading skills and/or reading difficulties (Landerl and Wimmer, 2008; Puolakanaho et al., 2008; Ziegler et al., 2010; Melby-Lervåg et al., 2012; Araújo et al., 2015; Clayton et al., 2019). Also, it is evident that morphological information processing is an essential feature of typical reading acquisition

(Carlisle, 2003; Kuo and Anderson, 2006). The aim of the current study was to longitudinally examine whether the neural underpinnings of morphological information processing in pre-school children with and without familial risk for dyslexia can be predictors of reading development in first grade. Moreover, we aimed to examine whether poor morphological processing can be considered a risk factor for reading difficulties (Louleli et al., 2020; Louleli et al., under review), especially in a morphologically rich language such as Finnish.

Characteristics of the Finnish Language

Learning to read in a transparent language requires accurately learning the combinations between graphemes and phonemes—which, in Finnish, are nearly fully transparent (i.e., one grapheme corresponds to one phoneme; Seymour et al., 2003; Lyytinen et al., 2015; Aro, 2017). Learning to read accurately is a relatively fast process for Finnish children since most of them learn to read accurately after 1 year of formal reading instruction (Lerkkanen et al., 2004; Soodla et al., 2015). Despite its very transparent phonological system, the Finnish language has a complex morphological system with rich inflectional morphology and divergent derivational morphology; a significant number of words are produced by derivational operations (Kiefer and Laakso, 2014). Previous behavioral studies conducted in young children have shown that awareness of derivational morphology is correlated with accurate word reading, especially in languages with transparent orthographies and rich morphological systems (i.e., Italian: Burani et al., 2002; Spanish: Ramirez et al., 2010; Greek: Diamanti et al., 2017; Manolitsis et al., 2017).

In the current study, the focus is on Finnish derivational morphology. Derivation is a type of morphological operation used for the creation and production of new words, using from one to multiple morphemes per stem or word. During the derivational operations, the morphemes need to be attached either before the stem (prefix: **un**-happy) or after the stem (suffix: danc-**er**). Usually, the derived new words are somehow semantically connected with the stem (such as the cases of play–player and dance–dancer). There is a variety of derivational suffixes in the Finnish language (almost 140 different suffixes; Kiefer and Laakso, 2014). In the morphological task, we used the derivational suffix /-jA/, which is used to derive highly frequent words only from verbs (e.g., opetta-ja = teacher; Kiefer and Laakso, 2014).

Reading Difficulties: Dyslexia

Persistent difficulties in typical reading acquisition and reading development are characterized as developmental dyslexia (Ramus et al., 2003; Vellutino et al., 2004). Developmental dyslexia has a strong genetic background, which means that it is passed down from one generation to another; that is why an individual with a genetically inherited risk for dyslexia has a larger probability of developing dyslexia later on in life (Byrne et al., 2006; van Bergen et al., 2011; Olson and Keenan, 2015).

Some studies have reported that children with familial risk for dyslexia tend to have lower performance on phonological awareness tasks (Snowling et al., 2003; Boets et al., 2010; Torppa et al., 2010; van Bergen et al., 2011; Van Bergen et al., 2012) or that people with dyslexia have lower scores in tasks involving phonological short-term memory and speech perception (Ramus et al., 2003; Shaywitz and Shaywitz, 2005; Ziegler and Goswami, 2005; Hämäläinen et al., 2013). However, it is evident that dyslexic individuals also deal with other difficulties—for example, the processing of auditory information (Goswami, 2002), visual attention span (Valdois et al., 2004, 2011; Bosse et al., 2007; Lallier and Valdois, 2012; Lobier et al., 2012) and RAN (de Jong and van der Leij, 2003; Puolakanaho et al., 2007; Torppa et al., 2007; Papadopoulos et al., 2016; Lohvansuu et al., 2018). The comorbidity in dyslexia is illustrated by Pennington's (2006) multiple deficit model—in which, when reading difficulty is not based on a single deficit, dyslexia is typically an outcome of the interaction of multiple risk factors per individual.

Predictors of Reading Difficulties

Early pre-literacy and language skills developed before kindergarten can be strong predictors for later reading skills and reading difficulties. Previous studies have demonstrated that phonological awareness, phonological short-term memory, letter knowledge, and RAN are good early predictors for fluent reading performance across multiple orthographies (Landerl and Wimmer, 2008; Puolakanaho et al., 2008; Ziegler et al., 2010; Melby-Lervåg et al., 2012; meta-analyses: Araújo et al., 2015; Clayton et al., 2019).

Phonological awareness is the ability to consciously identify and manipulate the phonemes and syllables of a language (Goswami and Bryant, 1990). For several years, phonological awareness has been considered the core deficit in developmental dyslexia, and that is why its predictive link with reading skills has been studied extensively (review: Castles and Coltheart, 2004). Letter knowledge is the ability to accurately relate graphemes (letters) with phonemes (sounds), and previous studies have already shown its predictive role in reading acquisition (Puolakanaho et al., 2008; Torppa et al., 2010). A RAN task measures the ability to name accurately and as fast as possible visual items such as objects, letters, colors or digits (Denckla and Rudel, 1976). Many studies have established RAN's important value as a predictive measure of reading skills in many languages (Kirby et al., 2010; Moll et al., 2014; Georgiou et al., 2016), including both opaque and transparent languages (Landerl et al., 2019).

Morphological Information Processing as a Risk Factor

Morphological awareness is the explicit knowledge of morphemes, which are the smallest linguistic items with semantic properties (Carlisle, 2003; Kuo and Anderson, 2006). Morphological awareness has been found to predict later reading skills in first-, second-, and third-grade children (Kirby et al., 2012) and explain the variance in reading comprehension (Müller and Brady, 2001; Kirby et al., 2012). A very recent study by Lyster et al. (2020) longitudinally examined, with behavioral measures, the joint contribution of pre-school linguistic skills (phonological, morphological, and semantic awareness) to the reading comprehension of first-, second-, and ninth-grade children. The results showed that these pre-school linguistic skills together accounted for 69.2% of the variance in reading comprehension in the ninth grade (Lyster et al., 2020). However, it is worth mentioning that the study focused on compounding morphology and did not examine the contribution of morphological awareness as a unique variable in the acquisition of typical reading skills but rather together with phonological and semantic awareness.

Many behavioral studies have shown that morphological awareness is associated with reading development across many languages (French: Casalis and Louis-Alexandre, 2000; Dutch: Rispens et al., 2008; English: Kirby et al., 2012; Greek: Diamanti et al., 2017; Japanese: Muroya et al., 2017; and Arabic: Tibi and Kirby, 2017). Moreover, previous studies have focused their interest on examining morphological awareness and morphological processing skills in children with and without risk for dyslexia either behaviorally (Casalis et al., 2004; Egan and Price, 2004; Law et al., 2016) or by using neuroimaging techniques (Louleli et al., 2020; Louleli et al., under review). In the behavioral studies, the link between phonological and morphological awareness was examined. Specifically, morphological awareness skills of first-grade students were found to be predicted by phonological processing measured at pre-school age (Cunningham and Carroll, 2015). Similarly, pre-school children with familial risk for dyslexia were found to have both phonological and morphological awareness deficits (Law et al., 2017). These results indicate that phonological and morphological awareness are interlinked and that the pre-reading deficit in morphological awareness is a consequence of the deficit in phonological awareness (Law and Ghesquière, 2017; Law et al., 2017).

To our knowledge, no studies have examined the brain basis of morphological information processing in pre-school and first-grade children and its predictive association with the acquisition of typical reading skills. Our previous studies have demonstrated awareness of derivational morphology in the brain responses of six- to seven-year-old pre-school children with and without risk for dyslexia (Louleli et al., 2020) and 7–8 year-old first-grade children with and without risk for dyslexia (Louleli et al., under review). Specifically, we created a morphological task with correctly and incorrectly derived words and pseudowords, and we measured the brain responses of children with magnetoencephalography (MEG) recordings in two phases: pre-school age and first-grade age (Louleli et al., 2020; Louleli et al., under review). The results showed that both groups were sensitive to correct and incorrect morphological constructs for real words and pseudowords in both ages. However, the at-risk group in both ages exhibited differences in brain activation patterns for derived morphology, compared to the typically developing group, presumably due to their familial risk for dyslexia. Specifically, there were differences in the temporal and spatial distributions of brain activation at the pre-school age between typically developing children and children at risk for dyslexia (Louleli et al., 2020), and differences were found in the timing of brain activation at first-grade age between typically developing children and children at risk for dyslexia (Louleli et al., under review).

Goal of the Study

The aim of our study was to examine, using a longitudinal design, the morphological information processing skills from pre-school age to first-grade age and the relationship between morphological information processing and reading skills in children with and without risk for dyslexia. Specifically, we aimed to test the relationship of brain responses measured with MEG, with accuracy and reaction time scores to auditorily presented correctly and incorrectly derived morphological constructs for real words and pseudowords at pre-school age, with reading measures at first-grade age (see Louleli et al., 2020). To gain a comprehensive understanding of the role of morphological processing, we also measured cognitive skills (phonological processing, rapid naming, and verbal short-term memory) at both pre-school age and first-grade age and examined the relationship between morphological skills and them, as well as their intercorrelations. Further, we examined whether derivational morphological skills at the first-grade age would be related to reading skills, when the children have been taught how to read during the first school year.

METHODS

Participants

A longitudinal sample of native Finnish-speaking children was tested at pre-school age (6.5–7 years) and again the same children were tested at first-grade age (7.5–8 years). The participants are the same as the ones at pre-school age (Louleli et al., 2020) and first-grade age (Louleli et al., under review) MEG data we reported previously. The number of participants at the pre-school age was 40 (22 typically developing and 18 at risk for dyslexia) for real words and 34 (17 typically developing and 17 at risk for dyslexia) for pseudowords (**Table 1**). The number of participants at first-grade age was 34 participants (21 typically developing and 13 at risk for dyslexia) for real words and 29 participants (20 typically developing and 9 at risk for dyslexia) for pseudowords. All of them were native Finnish speakers with normal or corrected-to-normal vision. The participants were screened with a questionnaire filled out by the parents for the following exclusion criteria: hearing problems, head injuries, neurological problems or medication that could affect the central nervous system. As in our previous studies (Louleli et al., 2020; Louleli et al., under review), at both ages, we included children with familial risk for dyslexia. The risk for dyslexia was defined by having one parent and/or sibling with diagnosed dyslexia and/or a parent with reading problems reported in the questionnaire.

For the longitudinal analyses, we used the data of 27 pre-school children (16 typically developing children and 11 children with familial risk for dyslexia) and the same children in first grade, who all participated in the behavioral assessments and the MEG measurements (**Table 1**).

This study was approved by the Ethical Committee of the University of Jyväskylä in accordance with the Declaration of Helsinki. Before each measurement (pre-school and first-grade ages), we fully informed the children and their parents about the aims and methods of the study. All the participants and their parents were asked to give their written consent before

TABLE 1 | Demographic information of the pre-school and first-grade children included in the data analyses.

Morphological task	**Real words**		**Pseudowords**	
Age of the measurement and groups	**Pre-school children: typically developing**	**Pre-school children: at risk for dyslexia**	**Pre-school children: typically developing**	**Pre-school children: at risk for dyslexia**
Number of participants	16	11	14	9
Age (average)	6 years and 7 months (*SD* = 0.36)	6 years and 8 months (*SD* = 0.44)	6 years and 8 months (*SD* = 0.37)	6 years and 8 months (*SD* = 0.49)
Gender	9 girls and 7 boys	4 girls and 7 boys	8 girls and 6 boys	3 girls and 6 boys
Handedness	15 right-handed	11 right-handed	13 right-handed	9 right-handed
Age of the measurement and groups	**First-grade children: typically developing**	**First-grade children: at risk for dyslexia**	**First-grade children: typically developing**	**First-grade children: at risk for dyslexia**
Number of participants	16	11	14	9
Age (average)	7 years and 7 months (*SD* = 0.36)	7 years and 8 months (*SD* = 0.44)	7 years and 8 months (*SD* = 0.37)	7 years and 8 months (*SD* = 0.49)
Gender	9 girls and 7 boys	4 girls and 7 boys	8 girls and 6 boys	3 girls and 6 boys
Handedness	15 right-handed	11 right-handed	13 right-handed	9 right-handed

participating in the study. For the MEG measurements, a movie ticket was given to each child as a compensation token for the time spent participating in the study. Both the pre-school and first-grade children undertook all the aforementioned behavioral assessments—except RAN (letters), dictation, and non-word text reading, which were carried out by only the first-grade children.

Behavioral Assessments

A number of behavioral tests were administered to the participants (pre-school and first grade) in each measurement session on a separate visit to the Department of Psychology at the University of Jyväskylä (**Table 2**). These behavioral tests were conducted to run correlation analyses between the children's performance in the MEG morphological task and cognitive skill levels.

From the Wechsler Intelligence Scale for Children—Fourth Edition (Wechsler, 2003), the following tests were administered: to assess visuospatial reasoning, a *block design* was used. In this test, the children were shown how to make a specific design of arranged blocks, and then they had to build the same design. In the test of expressive *vocabulary*, the children heard a specific word (e.g., "car," "legend," "posture," "rarely") and had to describe the meaning of that word. To assess working memory, the *digit span* test was used, where a series of numbers was said to a child. The series of numbers had increasing difficulty: starting with two digits (e.g., 2, 9) and they were ending with a series of eight digits (e.g., 4, 2, 6, 9, 1, 7, 8, 3). Each child had to repeat all the series of numbers first in forward order and then the series of numbers in backward order.

Phonological decoding and memory were assessed with the *Repetition of Nonsense Words* subtest from NEPSY I (Korkman et al., 2007). During the test, each participant was asked to repeat non-sense words (e.g., esse) out loud. Phonological awareness was tested using the *Phonological Processing Task* from NEPSY II (Korkman et al., 2007). In this task, the participant had to perform word segment recognition, where he/she had to identify words from segments and make phonological elision. He/she had to repeat a word and then repeat another word by omitting a phoneme or a syllable (e.g., say the word "pusero" ("blouse") without the syllable'se', for which the correct response would be "puro"). Memory for linguistic material was assessed by the *Sentence Repetition Test*, where the child had to repeat sentences of increasing length and complexity [e.g., "Koira juoksi kotiin" (The dog ran home)].

RAN (Denckla and Rudel, 1976) was used to test the ability to quickly name familiar objects. In this task, the participants had to name five objects as quickly and accurately as possible. The objects were frequent, everyday life objects arranged in 5 rows, with 10 objects per row. The task was recorded, and the performance of the participants was calculated in seconds based on the recordings. For the first-grade children, *RAN letters* was also measured: the participants had to name five letters as quickly and accurately as possible in a similar task.

The participants' reading skills at pre-school age were assessed with two reading tests (*word list reading* and *non-word list reading*) and at first-grade age with three reading tests (*word list reading, non-word list reading*, and *non-word text reading*). For *word list reading*, we used a standardized test (Lukilasse: Häyrinen et al., 1999) in which the participants had to read a list of 105 words in 45 s. These words were of increasing difficulty starting with 3 letters (e.g., "eli" = or) and ending with 17 letters (e.g., ratsastussaappaat = riding boot). The total number of correctly read words during this time was used as the score. *Non-word list reading* modified from the Tests of Word Reading Efficiency (Torgesen et al., 1999) was used to assess decoding skills independent of familiar representations for real words; the participants had to read as many non-words as possible in 45 s from a 4list of 90 pseudowords (e.g., *nalosta, *okan, *nalhajat). The number of correctly read non-words during this time was used as the score. *Pseudoword text reading* measured the participants' fluency in decoding skills (Eklund et al., 2015). During the task, the participant had to read a text consisting

TABLE 2 | Descriptive statistics of the participants' cognitive skill measures (*N* = 16 pre-school and first grade typically developing children, *N* = 11 pre-school and first grade at-risk for dyslexia children, separated by "/").

Behavioral assessments	Pre-school children (27)				First grade children (27)			
Groups	Typically developing children /At-risk for dyslexia children				Typically developing children /At-risk for dyslexia children			
Values	Mean	SD	Range	N	Mean	SD	Range	N
Block design (max. 68)	24.12/23.27	9.82/9.97	10–44/10–42	16/11	32.43/28.00	12.85/12.19	10–52/14–53	16/11
Vocabulary (max. 66)	16.87/16.72	7.28/9.00	4–34/5–40	16/11	16.28/22.90	9.04/7.02	14–46/13–37	16/11
Digit span (max. 32)	9.93/9.72	3.10/2.72	0–14/4–14	16/11	12.00/11.54	1.82/2.54	9–16/8–15	16/11
Repetition of nonsense words (max. 16)	9.00/8.27	2.36/2.45	5–13/4–12	16/11	10.87/10.90	1.66/2.16	7–13/8–14	16/11
Phonological processing (max. 53)	32.68/31.00	7.06/8.02	23–45/23–50	16/11	41.50/38.45	6.77/6.77	24–53/29–50	16/11
Sentence repetition (max. 34)	22.50/21.36	6.86/2.83	0–29/17–26	16/11	25.75/25.00	2.26/1.84	21–29/23–27	16/11
RAN objects	70.30/78.25	17.33/19.94	48.63–103.75/49.20–121	16/11	66.63/62.10	19.31/8.96	39.71–119.39/46.49–74.66	16/11
RAN letters	–/–	–/–	–/–	–/–	42.68/42.54	12.83/9.65	28.39–78.08/30.11–56.98	16/11
Dictation	–/–	–/–	–/–	–/–	30.87/28.81	8.07/7.82	15–40/16–40	16/11
Word list reading	31.40/44.66	35.79/38.88	0–100/0–71	3/10	59.37/45.45	21.27/20.25	32–102/18–83	16/11
Non-word list reading (max. 90)	10.06/6.90	16.36/15.47	0–46/0–42	16/11	32.18/25.63	10.74/10.95	15–52/10–45	16/11
Non-word text reading (max. 38)	–/–	–/–	–/–	–/–	106.88/146.68	54.71/74.44	13–38/18–36	16/11

The cognitive performance for RAN letters, Dictation and Non-word text reading were measured only in children at first grade. Max. means the maximum value of the cognitive measure.

of pseudowords; the number of correctly read words and total reading time were used as the scores from a maximum of 38 pseudowords.

Also, *dictation* was assessed; the participants heard 20 words and had to write them down on a sheet of paper (e.g., "suu" (mouth), "kani" (rabbit), "juusto" (cheese). The number of correctly written words was used as the score.

MEG Morphological Task

Stimuli

In this study, we used the MEG data acquired previously from our morphological task (Louleli et al., 2020; Louleli et al., under review). The task included 216 pairs of sentences (see **Table S1**).

For *real words*, the first pair of sentences consisted of a third-person pronoun (*Hän*) and a verb—for example, *johtaa* ("to lead" [verb])—while the second pair of sentences consisted of the same third-person pronoun (*Hän*), a verb (*on*) and a noun derived from the verb with the derivational suffix *–jA* (/-ja/ - /-jä/) *johta**ja*** ("lead**er**" [noun with the agentive marker]). The suffix *–jA* (/-ja/ - /-jä/) is frequently used in the Finnish language in derivational operations, in which a verb produces a noun (*johtaa—johtaja*). The word pairs (verb–noun) were selected based on their frequency and length from a Finnish corpus of words (2010; https://github.com/GrammaticalFramework/GF/blob/master/lib/src/finnish/frequency/src/suomen-sanomalehtikielen-taajuussanasto-utf8.txt).

Pseudoword pairs were created to test the ability to apply the derivational rules for new non-existing words. These were created based on the real words. The pseudowords were pairs of words (verb–noun) with no semantic meaning and were created according to Finnish morphophonological, grammatical, and syntactic rules (Louleli et al., 2020; Louleli et al., under review). The pseudowords were matched with the real words in the number of syllables and letters and derivational ending. Further, the correctly derived nouns were matched similarly with the incorrectly derived nouns in the word and pseudoword conditions. All the real words and pseudowords were trisyllabic, including 11 words with 6 letters, 24 words with 7 letters, and 19 words with 8 letters.

All the derivational nouns were subdivided into correctly and incorrectly derived nouns, with 54 stimuli in each subdivision. The correctly derived nouns were typical Finnish word forms, whereas the incorrectly derived nouns contained an incorrect morphophonological change in the last vowel before the derivational suffix /-jA/ (e.g., *joht**i**ja* instead of *johtaja*; for more details, see Louleli et al., 2020). All the incorrectly derived forms, including the pseudowords, were created based on Finnish vowel harmony rules (for more details, see Louleli et al., 2020).

All the items of the morphological task were recorded in stereo channels by a female native Finnish speaker in a recording studio at the University of Jyväskylä using a 44 kHz sampling frequency and 32-bit quantization. The recorded sound files were edited with Sound Forge Pro 11.0 (5 ms of silence was added to each sound file at the beginning and end of each sentence).

Procedure

The participants sat comfortably in a magnetically shielded soundproof room and at a one-meter distance from the projection screen. The projector's screen refresh rate was 60 Hz. Before each morphological task, instructions were presented via headphones at 60 dB (SPL). The instructions were small stories, which fit into the children's school life to make the task more interesting and child-friendly. For the real words, a small girl had to practice for a language school exam, and the participant was asked to give her an input about which word pairs she had learned correctly and which she had not. For the pseudowords, a girl in the story was trying to form a secret language to be able to talk secretly with her friends, and the participant was asked to consult her about which word pairs could be thought of as correct Finnish words and which ones could not. In both cases, the participant had to use the response buttons: a right-button press for the correct pairs for real words or pairs that could be thought of as Finnish for pseudowords and a left-button press for the incorrect pairs for real words or pairs that could not be considered Finnish for pseudowords. The morphological task was presented with Presentation software (Neurobehavioral Systems, Inc., Albany, CA, United States) running on a Microsoft Windows computer. After the instructional stories, there was a practice task with six trials to help the participants avoid possible misunderstandings. Each child had to respond correctly in at least four or more trials in order to start running the morphological task. Otherwise, the task was explained again to the participant and the practice trials rerun.

After hearing the instructions, the main task started immediately. For each trial of the morphological task, a black fixation cross was presented on the screen for 500 ms, followed by word pairs of sentences (e.g., *Hän johtaa. Hän on johtaja* = He leads. He is a leader), followed by a blank screen for 500 ms, and then the participants were asked to give their responses through the response buttons.

Four blocks of 54 word pairs (216 word pairs in total) were presented in each measurement session. The first two blocks always included real words (real words with a correct or incorrect morphophonological change), and the next two blocks included pseudowords (pseudowords with a correct or incorrect morphophonological change). The word pairs within a condition were always presented together (yoked/joined stimuli); however, all the pairs were randomly intermixed. After each block of trials, short (1-min) animated videos were presented to help the participants concentrate on the task. All the items were presented only once. In total, the morphological task lasted ∼40 min. *Accuracy and reaction times* during the MEG recordings were also recorded for each stimulus type.

MEG Data Acquisition

MEG data were collected at the Center for Interdisciplinary Brain Research at the University of Jyväskylä using a 306-channel whole-head device Elekta Neuromag TRIUX system (Elekta AB, Stockholm, Sweden) with 204 gradiometers and 102 magnetometers in a magnetically shielded room. The MEG system was in a 68° upright gantry position in all the measurements. The data were collected with a sampling rate of 1,000 Hz and an online band-pass filter of 0.1–330 Hz. Continuous head position monitoring was used based on five head-position indicator coils, with three placed at the forehead and two placed behind the ears. The locations of the head-position indicator coils were determined with the Polhemus Isotrak digitizer (Polhemus, Colchester, VT, United States) based on three anatomical landmarks (nasion, right and left pre-auricular points). Additional digitized points (∼120) were also taken on the scalp for each subject for head movement compensation after the recording session. Electro-oculography was recorded using two pairs of electro-oculograms; one pair was placed horizontally and the other vertically to the participants' eyes. They were used to capture eye blinks and eye movements produced by the participant during each measurement session. An additional electrode was placed on the participant's right collarbone as a ground reference.

Head movements were corrected offline, and external noise sources were attenuated using the temporal extension of the source subspace separation algorithm (Taulu and Kajola, 2005; Taulu and Simola, 2006) in the MaxFilter program (Elekta Neuromag, Finland).

MEG Data Analysis

First, all MEG data were preprocessed with the temporal extension of the signal-space separation method (tSSS; Taulu and Kajola, 2005; Taulu and Simola, 2006) of the MaxFilter 2.2 program (Elekta AB, Stockholm, Sweden) with 30s buffers to remove external noise sources and correct for possible head movements. Bad channels were identified by visual inspection during and after each measurement. They were manually marked and then reconstructed in the MaxFilter 2.2 program.

MEG data were analyzed with BESA Research 6.1 (BESA GmbH, Munich, Germany). Independent component analysis (infomax algorithm) was applied separately for the magnetometers and gradiometers in a representative 60 s time window to remove cardiac artifacts, eye blinks and eye movements. Data were low-pass filtered at 30 Hz (zero phase, 24dB/oct) and high-pass filtered at 0.5 Hz (zero phase, 12dB/oct). Then the continuous MEG recording was epoched into trial-based windows from−200 to 1,100 ms with respect to the onset of the derivational suffix /-jA/, with a pre-stimulus baseline of 100 ms. Actually, the correctness of the morphological ending /-jA/ takes place starting from the preceding vowel, but the beginning of the suffix /-jA/ was used as the trigger point because it is a clear identifier acoustically, whereas the preceding vowel might be slightly varied in length (∼100 ms). MEG epochs exceeding over 1200 fT/cm for gradiometers and 4000 fT for magnetometers peak-to-peak amplitudes were excluded from further analysis. Each participant from both groups (typically developing and at-risk for dyslexia children) had more than 70% accepted trials (38 trials out of 54 trials accepted for the further analyses) except for three participants (1 control and 2 at risk), who had 50% accepted trials. The groups of children (typically developing and at-risk for dyslexia) did not differ in terms of removed trials. Event-related fields were obtained by averaging trials for different conditions, separately for the correctly and incorrectly derived real words and pseudowords. The two orthogonal gradiometer channel pairs were combined in Matlab R2015b using the vector sum. Based on our previous studies (Louleli et al., 2020), three time windows were investigated: 0–300, 300–700, and 700–1,100 ms.

Statistical Analysis

First, for the longitudinal sample, descriptive statistics were calculated in SPSS for the children's cognitive measures during pre-school and the first grade (**Table 2**), as well as for the accuracy and reaction times of the participants during the MEG morphological task (**Table 3**). Second, correlation analyses (Spearman's correlation coefficients) were carried out to explore (a) whether pre-school cognitive skills were correlated with first-grade cognitive skills (**Table 4**), (b) whether there was a continuation in morphological skills (accuracy and reaction times during MEG) from pre-school to the first grade (**Table 5**) and (c) whether the pre-school morphological measures during MEG were associated with the first-grade cognitive skills (**Table S2**). Third, we correlated, in BESA Statistics 2.0 (BESA GmbH, Munich, Germany), the pre-school children's brain responses to the correctly derived words vs. the incorrectly derived words and pseudowords with the first-grade children's cognitive skills (**Table S3**). All the comparisons and correlations were corrected by applying a false discovery rate (FDR) correction value of 0.05 (Benjamini and Hochberg, 1995) into the p-values. The FDR correction was applied separately for the comparisons for real words and pseudowords.

RESULTS

Behavioral Assessments of Cognitive and Morphological Skills

The behavioral measures of cognitive skills in pre-school and first grade children are presented in **Table 2** for the control and at-risk groups.

Behavioral morphological processing measures during the MEG, accuracy and reaction times for real words and pseudowords, in pre-school and first grade children are presented in **Table 3**. The results are presented separately for the control and at-risk groups.

Longitudinal Results From the Analysis of Pre-school to First-Grade Children: Cognitive and Reading Skills

Pre-school children's cognitive skills were correlated with first-grade children's cognitive skills (**Table 4**). Consistent correlations were found between the ages (pre-school age and first-grade age) in the block design, vocabulary, digit span, phonological processing, RAN objects, word list reading and non-word list reading tasks after the FDR correction. No consistent correlations were observed between non-word text reading and any other cognitive skill measures. In addition, pre-school children's phonological processing showed systematic associations with first-grade children's repetition of non-sense words, sentence repetition, RAN objects, RAN letters, word list reading and non-word list reading. Consistent correlations were found between pre-school children's word list reading and first-grade children's sentence repetition, RAN letters, dictation and non-word list reading. A correlation pattern was also observed between pre-school children's non-word list reading and first grade children's repetition of non-sense words, sentence repetition, RAN letters, dictation and word list reading (**Table 4**). In general, we found that most of the cognitive skills measured at the pre-school age were associated with the majority of the cognitive skills measured at the first-grade age.

Longitudinal Results Between Pre-school and First Grade Children: Behavioral Performance During the MEG Morphological Task

Pre-school children's behavioral performance during the MEG morphological task was correlated with first grade children's behavioral performance during the MEG morphological task for real words and pseudowords (**Table 5**). No significant correlations were found for accuracy or reaction times between age groups after FDR correction.

Longitudinal Results From the Pre-school to First Grade Children: Correlations Between Pre-school Behavioral Morphological Measures and First Grade Cognitive Skills

We studied next, how morphological information processing during the MEG morphological task at pre-school is associated with reading at the first grade (see **Table S2**). A significant correlation was observed between the pre-school children's reaction time for correctly derived real words and the first grade children's performance in the RAN letters task ($r = 0.730$, $p < 0.001$) after FDR correction. No other significant correlations were found between the pre-school's accuracy or reaction time of the MEG morphological task with the first grade's cognitive skill measures.

Longitudinal Results Between Pre-school and First Grade Children: Correlations Between Pre-school Brain Responses and First Grade Cognitive and Reading Skills

We examined next, how brain responses during the MEG morphological task at pre-school are associated with cognitive skills and reading at the first grade. Specifically, the correlations between the event-related field responses (ERF responses) of pre-school children for the correct vs. incorrect morphological contrast for real words and pseudowords and the cognitive measures of first grade children were not significant after FDR correction (see **Table S3**).

TABLE 3 | Accuracy and reaction times for real words and pseudowords (% for correct responses) for the participants' behavioral performance during the MEG morphological task (*N* = 27 pre-school children with and without risk, *N* = 27 first grade children with and without risk), separated by "/").

Morphological task	**Real words**							
Age groups	**Pre-school children (27)**				**First grade children (27)**			
Groups	**Typically developing children/At-risk for dyslexia children**				**Typically developing children /*At-risk for dyslexia children***			
Values	**Mean**	**SD**	**Range**	**N**	**Mean**	**SD**	**Range**	**N**
Accuracy, correctly derived	89.22/84.17	7.59/13.05	77.77–98.14/53.70–100	16/11	93.85/90.39	5.35/9.43	79.62–100/66.66	16/11
Accuracy, incorrectly derived	88.07/71.88	15.92/32.95	31.48–98.14/0–96.29	16/11	95.24/94.10	4.53/6.61	85.18–100/81.48–100	16/11
RT, correctly derived	1735.12/1238.03	1945.31/385.03	821.90-8847.85/557.55-1702.77	16/11	1324.68/1015.95	868.80/422.64	548.33–4049.53/552.79–1903.75	16/11
RT, incorrectly derived	1172.56/1114.55	575.75/376.51	705.88–3038.25/456.66–1639.29	16/11	1055.03/891.39	485.79/174.01	472.33–2374.07/556.37–1138	16/11
Morphological task	**Pseudowords**							
Age groups	**Pre-school children (27)**				**First grade children (27)**			
Groups	**Typically developing children /At-risk for dyslexia children**				**Typically developing children /At-risk for dyslexia children**			
Values	**Mean**	**SD**	**Range**	**N**	**Mean**	**SD**	**Range**	**N**
Accuracy, correctly derived	41.44/48.98	29.41/24.33	1.85–85.18/0–87.03	13/11	73.78/67.50	17.70/19.88	50–98.14/38.88–96.29	16/11
Accuracy, incorrectly derived	68.79/74.23	25.50/18.49	20.37–98.14/46.29–100	13/11	68.16/56.05	15.77/24.18	46.29–92.59/25.92–94.44	16/11
RT, correctly derived	1351.32/1424.69	662.14/682.42	505.12–2371.98/643.77–2895.85	13/11	2029.94/1672.01	1442.11/870.22	61.11–5660.44/579.44–3604.94	14/11
RT, incorrectly derived	1323.22/1355.38	746.20/651.37	411.96–2663.40/479.09–2414.98	13/11	1955.46/1580.55	1164.70/630.56	614.68–5163.75/482.79–2597.79	16/11

Fifty-four (54) responses was the maximum number of responses per category.

TABLE 4 | Correlations (Spearman's) between cognitive skills of pre-school and first grade children (*N* = 27, 16 Controls & 11 At-risk).

	Correlations between pre-school and first grade behavioral cognitive measures											
Behavioral assessments	**Block design_1gr**	**Vocabulary_1gr**	**Digit span_1gr**	**Repetition of non-sense words_1gr**	**Phonological processing_1gr**	**Sentence repetition_1gr**	**RAN objects_1gr**	**RAN letters_1gr**	**Dictation_1gr**	**Word list reading_1gr**	**Non-word list reading_1gr**	**Non-word text reading_1gr**
Block design_pre	**0.789***	0.300	0.227	0.076	0.391*	0.163	−0.175	0.008	0.222	0.115	0.225	0.063
	***p* < 0.001**	*p* = 0.128	*p* = 0.255	*p* = 0.708	*p* = 0.043	*p* = 0.417	*p* = 0.382	*p* = 0.970	*p* = 0.266	*p* = 0.566	*p* = 0.260	*p* = 0.754
Vocabulary_pre	0.305	**0.596***	0.147	0.354	**0.549***	**0.523***	−0.301	−0.221	0.114	0.205	0.212	−0.043
	p = 0.122	***p* = 0.001**	*p* = 0.465	*p* = 0.70	***p* = 0.003**	***p* = 0.005**	*p* = 0.128	*p* = 0.267	*p* = 0.570	*p* = 0.305	*p* = 0.289	*p* = 0.830
Digit span_pre	0.425*	**0.623***	**0.563***	0.349	**0.551***	**0.772***	−0.347	**−0.474***	**0.560***	**0.518***	**0.596***	0.272
	p = 0.27	***p* = 0.001**	***p* = 0.002**	*p* = 0.075	***p* = 0.003**	***p* < 0.001**	*p* = 0.076	***p* = 0.013**	***p* = 0.002**	***p* = 0.006**	***p* = 0.001**	*p* = 0.170
Repetition of non-sense words_pre	−0.058	0.323	**0.465***	0.356	0.270	0.425*	−0.291	−0.348	0.093	0.361	0.344	−0.065
	p = 0.774	*p* = 0.100	***p* = 0.015**	*p* = 0.68	*p* = 0.174	*p* = 0.027	*p* = 0.141	*p* = 0.075	*p* = 0.645	*p* = 0.064	*p* = 0.079	*p* = 0.749
Phonological processing_pre	0.135	0.206	0.322	**0.471***	**0.474***	**0.741***	**−0.506***	**−0.472***	0.437*	**0.569***	**0.560***	0.309
	p = 0.502	*p* = 0.302	*p* = 0.101	***p* = 0.013**	***p* = 0.012**	***p* < 0.001**	***p* = 0.007**	***p* = 0.013**	*p* = 0.023	***p* = 0.002**	***p* = 0.002**	*p* = 0.116
Sentence repetition_pre	0.090	**0.456***	0.174	0.256	0.400*	**0.687***	−0.369	−0.325	0.022	0.147	0.185	−0.036
	p = 0.656	***p* = 0.017**	*p* = 0.384	*p* = 0.197	*p* = 0.038	***p* < 0.001**	*p* = 0.058	*p* = 0.098	*p* = 0.915	*p* = 0.466	*p* = 0.355	*p* = 0.859
RAN objects_pre	−0.156	−0.236	−0.354	**−0.578***	−0.013	−0.418*	**−0.532***	**0.618***	−0.297	**−0.490***	**−0.476***	−0.037
	p = 0.437	*p* = 0.236	*p* = 0.070	***p* = 0.002**	*p* = 0.948	*p* = 0.030	***p* = 0.004**	***p* = 0.001**	*p* = 0.133	***p* = 0.009**	***p* = 0.012**	*p* = 0.856
Word list reading_pre	**0.576***	0.526	0.169	0.341	0.593*	**0.655***	−0.077	**−0.646***	**0.686***	**0.895***	**0.863***	0.416
	***p* = 0.039**	*p* = 0.065	*p* = 0.580	*p* = 0.254	*p* = 0.033	***p* = 0.015**	*p* = 0.802	***p* = 0.017**	***p* = 0.010**	***p* < 0.001**	***p* < 0.001**	*p* = 0.157
Non-word list reading_pre	0.313	0.357	0.279	**0.492***	**0.554***	**0.667***	−0.434*	**−0.546***	**0.519***	**0.952***	**0.733***	0.288
	p = 0.111	*p* = 0.068	*p* = 0.158	***p* = 0.009**	***p* = 0.003**	***p* < 0.001**	*p* = 0.024	***p* = 0.003**	***p* = 0.006**	***p* < 0.001**	***p* < 0.001**	*p* = 0.145

Bold are the significant correlations, which remain significant after FDR corrections.

TABLE 5 | Correlations (Spearman's) between the pre-school children's behavioral performance during the MEG morphological task and the first grade children's behavioral performance during the MEG morphological task for real words (*N* = 27 pre-school children with and without risk, *N* = 27 first grade children with and without risk) and for pseudowords (*N* = 23 pre-school children with and without risk, *N* = 23 first grade children with and without risk).

Real Words

Behavioral assessments	Accuracy for correctly derived_1gr	Accuracy for incorrectly derived_1gr	RT for correctly derived_1gr	RT for incorrectly derived_1gr
Accuracy for correctly derived_pre	0.348	0.250	0.085	−0.022
	$p = 0.076$	$p = 0.208$	$p = 0.675$	$p = 0.913$
Accuracy for incorrectly derived_pre	0.332	0.199	0.113	−0.041
	$p = 0.091$	$p = 0.320$	$p = 0.575$	$p = 0.838$
RT for correctly derived_pre	−0.095	0.134	**0.465***	**0.464***
	$p = 0.639$	$p = 0.505$	**$p = 0.014$**	**$p = 0.015$**
RT for incorrectly derived_pre	−0.240	0.077	**0.505***	**0.428***
	$p = 0.227$	$p = 0.702$	**$p = 0.007$**	**$p = 0.026$**

Pseudowords

Behavioral assessments	Accuracy for correctly derived_1gr	Accuracy for incorrectly derived_1gr	RT for correctly derived_1gr	RT for incorrectly derived_1gr
Accuracy for correctly derived_pre	0.156	0.151	−0.272	−0.263
	$p = 0.467$	$p = 0.482$	$p = 0.198$	$p = 0.214$
Accuracy for incorrectly derived_pre	−0.090	0.271	0.097	0.174
	$p = 0.675$	$p = 0.200$	$p = 0.652$	$p = 0.417$
RT for correctly derived_pre	0.295	−0.084	0.317	**0.529***
	$p = 0.162$	$p = 0.696$	$p = 0.132$	**$p = 0.008$**
RT for incorrectly derived_pre	0.304	−0.087	0.345	**0.529***
	$p = 0.149$	$p = 0.687$	$p = 0.098$	**$p = 0.008$**

Bold are the significant correlations before FDR correction. No correlations remained significant after the FDR correction.

Longitudinal Results Between Pre-school and First Grade Children: Pre-school Brain Responses and First Grade Behavioral Performance During the MEG Morphological Task

Then, we investigated the relationship between the pre-school brain responses for the correct vs. incorrect morphological contrast for real words and pseudowords with the behavioral performance of first grade children during the MEG morphological task, using correlations. No significant correlations were found between pre-school children's brain responses to the correct vs. incorrect morphological contrast and the first grade children's performance (accuracy and reaction time) after FDR correction.

Cross-Sectional Results of First Grade Children

We also conducted corresponding correlation analyses cross-sectionally at the first grade between morphological measures (both behavioral and brain measures) and reading related cognitive skills (phonological awareness, rapid automatized naming (RAN), letter knowledge, and verbal short-term memory) and reading skills. No significant correlations were observed for the aforementioned comparisons. Also, we tested between-group differences in first grade children with high and low reading performance with cluster-based permutation tests. Specifically, we compared the brain responses of 11 first grade children with high reading performance with the brain responses of 11 first grade children with low reading performance for the difference between the correctly vs. incorrectly derived real words. No significant between-group brain differences emerged for the correct vs. incorrect morphological contrast after FDR correction.

DISCUSSION

Our study longitudinally examined the developmental changes of morphological information processing in pre-school and first-grade children with and without familial risk for dyslexia. To our knowledge, this is the first study to longitudinally investigate derivational morphology in children measured at pre-school and first-grade ages. Moreover, we investigated whether morphological processing is associated with reading skills at first-grade age.

The Associations Between Reading-Related Cognitive Skills at Pre-school and First-Grade Ages Confirm Previous Literature

One of the goals was to investigate whether pre-school cognitive skills known to predict reading later on are associated with first-grade cognitive and reading skills. The correlation analyses confirmed the general findings in the literature (**Table 4**). Specifically, significant correlations were found between the same skill tested at the two ages in the block design, vocabulary, digit span, phonological processing, RAN objects, word list reading and non-word list reading. More interestingly, and mostly in line with earlier studies, pre-school children's performance in phonological processing was found to be correlated with first grade children's performance in repetition of non-sense words, sentence repetition, RAN objects, RAN letters, word list reading and non-word list reading at the first grade children. In addition, significant correlations were found between pre-school word list reading and first grade sentence repetition, RAN letters, dictation and, as expected, non-word list reading. Likewise, pre-school pseudoword reading (in a non-word list reading task) was associated with the first grade repetition of non-sense words, sentence repetition, RAN letters, dictation and word list reading. Our results are in line with previous studies, which have shown pre-school phonological processing, rapid automatized naming (RAN), letter knowledge and verbal short-term memory measured behaviorally to be good predictors of reading skills throughout school-age (Landerl and Wimmer, 2008; Puolakanaho et al., 2008; Ziegler et al., 2010; Melby-Lervåg et al., 2012; Araújo et al., 2015; Clayton et al., 2019).

Preschool-Age Morphological Skills Were Only Partially Associated With the Morphological Skills at First-Grade Age

We then examined whether the morphological skills of pre-school children would be associated with the morphological skills at the first grade children, which would show how well the pre-school skills predict later skills in the domain of derivational morphology. We used a morphological task assessing Finnish derivational morphology during MEG recordings. Although none of the accuracy or reaction time measure correlations survived FDR correction (**Table 5**), reaction times showed rather consistent correlations for real words between the age groups suggesting tentatively that those who were faster at pre-school age in recognizing both the correct and incorrect derivation were also faster at the first grade. Interestingly, for pseudowords this kind of relationship was found only to the incorrectly derived word, suggesting tentatively that in case of non-existing words, only breaking the rule (incorrect derivations) was recognized faster by the same children at both ages. The failure to show correlations surviving FDR corrections could be due to a relative small sample for correlations. Alternatively, our results could suggest that behavioral differences in morphological information processing do not progress at the same pace in the majority of children at this developmental stage. Another study showed that morphological awareness is acquired at pre-school age and especially before formal reading instruction, but that it evolves continuously; children's performance in morphological tasks (tasks assessing derivational and inflectional morphology) increases from kindergarten to the first and second grades throughout adulthood (Casalis and Louis-Alexandre, 2000).

A study by Lyster et al. investigated with behavioral assessments the input of phonological, morphological and semantic awareness to reading comprehension at 1st, 2nd and 9th grade (Lyster et al., 2020). Their results showed that pre-school linguistic skills are very important for reading comprehension later on, even up to the 9th grade. However, it is noteworthy that this study itself, even though it demonstrates the importance of phonological, morphological, and semantic awareness in the acquisition of typical reading skills, it did not assess the contribution of phonological, morphological, and semantic awareness as unique variables, but rather as a sum all together (Lyster et al., 2020).

Previous studies investigated the relationship between phonological and morphological awareness (Law and Ghesquière, 2017; Law et al., 2017). Specifically, they found out that pre-school children with familial risk for dyslexia had problems in both phonological and morphological awareness skills (Wug test: 29 questions assessing inflectional and 8 questions assessing derivational morphology) (Law et al., 2017). Overall, these results indicated that phonological and morphological awareness are strongly related and that it is possible that the difficulties in morphological awareness arise from difficulties in phonological awareness (Law and Ghesquière, 2017; Law et al., 2017).

Morphological Information Processing Is Associated With Reading Development From Preschool Age to First-Grade Age in Children With and Without Risk for Dyslexia

Our main aim was to investigate the association between pre-school morphological information processing and the first grade children's reading development. For this purpose, we calculated correlations between the behavioral performance (accuracy and reaction time) of pre-school children during the MEG morphological task and the reading related cognitive skills and reading at the first grade (**Table S2**). A significant correlation was only found between the pre-school RT performance for correctly derived real words and the first grade performance in the RAN letters task ($r = 0.730$, $p < 0.001$) after FDR correction.

This correlation could indicate association between speed (or fluency) of emerging morphological information processing (Finnish derivational morphology) at pre-school and development of fluency in naming letters, an endophenotype or precursor of fluent reading. Previous studies have already shown the importance of RAN in predicting reading fluency in Finnish language (Eklund et al., 2015; Torppa et al., 2016) as well as in other orthographies (Kirby et al., 2010; Moll et al., 2014; Georgiou et al., 2016; Landerl et al., 2019). The new knowledge brought here is that morphological processing is linked to the processing or skill measured by RAN letters and RAN letters measures the fluency of lexical access to existing representations (Eklund et al., 2015; Torppa et al., 2016).

However, it should be noted that this association did not extend to actual reading skills, making strong conclusions difficult to draw. On the other hand, reading at the first grade is mainly reflecting accuracy of decoding, whereas RAN also predicts reading fluency which only starts to emerge at the first grade. It is also noteworthy that our morphological task contains a repetitive mode of morphological structure (Hän verb - Hän on verb stem + /jA/), which means that there might be automatization in the children's answers. This automatization in the response patterns is also in line with the characteristics of the rapid naming tasks, and thus that is possibly why we see a strong relationship between the pre-school children's reaction time for correctly derived real words in the morphological task and the first grade performance in RAN letters. Some forms of representations are also required for fluent morphological processing, as no correlations were found for pseudowords, which would require the ability to apply a rule to new words. Thus, it is possible that RAN letters and morphological processing might share common mechanisms related to fluency and automatization. Further studies are necessary in order to disentangle the aforementioned relationship between the tasks.

The Brain Responses of Pre-school Children With and Without Familial Risk for Dyslexia Did Not Predict Their Reading Performance 1 Year Later During First Grade

To our knowledge, this is the first study to examine the predictive value of pre-school morphological information processing at the brain level and its association with the acquisition of typical reading skills from kindergarten to first grade children. In our previous studies, we demonstrated that awareness of Finnish derivational morphology was depicted in the brain responses of both 6–7-year-old pre-school children and 7–8-year-old first grade children (with and without risk for dyslexia) (Louleli et al., 2020; Louleli et al., under review).

In the current study, we did not observe any significant correlations (after FDR correction) between pre-school children's brain responses to the correctly vs. incorrectly derived words or pseudowords and the cognitive performance or reading skills at the first grade. Even though we found the association between pre-school behavioral performance for morphological processing (reaction time for correctly derived words) and rapid naming of letters at the first grade, we did not observe the same association at the brain level. This indicates that the aggregate process reflected in reaction times seems to be a more robust measure of morphological processing compared to the ERFs which reflect specific neural processes evolving in time. Further, ERFs capture only part of the neural activity and examination of, for example, non-phase locked activity in the frequency domain could reveal further possible connection at the brain level. At any rate, our results show there is no strong link between brain activity for derivational morphological processing and emerging decoding skills.

Another reason for the lack of associations between morphological skills and reading could be due to the type of morphological skills tested, namely derivational morphology. The connection between morphological skills and reading skills has been studied before by assessing inflectional morphology (Lyytinen and Lyytinen, 2004; Torppa et al., 2010). Specifically, in the study by Lyytinen and Lyytinen (2004), Finnish inflectional morphology was investigated with behavioral tests in various pre-school ages. The results showed that children were able to manipulate units of inflectional morphology by the age of 3, which demonstrates the children's ability at pre-school age to perform basic inflectional operations of their language (Lyytinen and Lyytinen, 2004). Moreover, Torppa et al. (2010), also showed that there is an association between processing of inflectional morphology and phonological skills at the age of 3 years as well as a direct correlation between inflectional morphology and reading accuracy and fluency at 5 and 5.5 years old; these results suggest that inflectional morphology together with phonological skills could be considered as direct pre-school age pre-cursors of later reading accuracy and fluency (Torppa et al., 2010).

Leminen et al. (2013) have suggested that processing of inflectional and derivational morphology involves two different linguistic operations, which include different brain processes. In their study, they examined adults' brain responses with event-related potentials (with EEG) for both inflectional and derivational morphology (Leminen et al., 2013). They used auditory stimuli in an oddball paradigm design performed by Finnish participants. For derivational forms, they reported effects at the 130–170 ms time-window to be larger for derived words than for derived pseudowords (Leminen et al., 2013). However, for inflectional forms, they reported a different pattern; larger effects for pseudo-inflected forms than for real inflected words (Leminen et al., 2013). Their results suggest that there are distinct brain mechanisms for inflected and derived word processing based on the adults' brain activation (Leminen et al., 2013). They suggest that derivations most likely form unique brain representations, while inflections are more related with grammatical rules of morpho-syntactic processing (Leminen et al., 2013). Thus, it is possible that the acquisition of inflectional and derivational morphology enables different brain mechanisms in children as well, which still remains to be investigated, especially in native speakers of a rich morphological language like Finnish.

The morphological skills of 4–7 years old children for tasks including inflectional and derivational morphology were studied by Diamanti et al. (2018) in Greek language, which is a transparent language. In their study, they used four morphological awareness tasks to test domains of inflectional and derivational morphology (2 production tasks for inflectional morphology and 2 judgement tasks for derivational morphology). Their results showed that the production of derivational morphemes was more difficult for children than production of inflectional morphemes and judgement of derivational morphemes, which reveals that awareness of derivational morphology lacks behind that of inflectional morphology (Diamanti et al., 2018) at these early pre-reading ages.

Limitations

Our study was designed to bring new understanding about derivational morphological information processing with a longitudinal design assessing the performance of pre-school and first grade children. Our study has some limitations. For the current study, we designed our morphological task using naturally produced stimuli in order to create a more ecologically valid input for the children participating in the task. However, the naturally produced stimuli, even if they were of equal length, could be slightly different acoustically for each sentence, which might result in less robust brain responses. In addition, similar to our previous studies (Louleli et al., 2020; Louleli et al., under review), the morphological task consisted of sentences with a morphophonological change before the suffix /-jA/. However, the suffix /jA/ was rather used as the trigger point for the sensor-level analysis because it is a clear syllable acoustically, existing in all the conditions (correctly and incorrectly derived real words and pseudowords), but it was ∼100 ms after the timing of interest. Also, during the morphological awareness task, the participants had to give their responses for the correct and incorrect morphological pair of sentences through pressing right or left response buttons. The button assignment was not counterbalanced across participants, which might affect the results in terms of preparation of the motor response. However, in our study, the button press response occurred after the final syllable (500 ms waiting time and Reaction time range), which means that the button press did not likely have any effect on the responses regarding the correctly or incorrectly derived morphological endings. Moreover, the small number of participants is not ideal for correlation analyses because it could hinder to reach sensitivity to reveal significant real correlations. Also, our time did not allow us to include a comparison of inflectional vs. derivational morphology for Finnish language, which would need to be studied in the future.

CONCLUSIONS

In summary, this is the first study to examine developmentally the predictive value of processing Finnish derivational morphology from pre-school age to the first grade in children with and without risk for dyslexia both at the behavioral and neural level and their association to reading related cognitive skill and reading. First, we investigated and replicated the relationship between pre-school and first grade cognitive skills confirming the typical correlations found in the previous literature. We then examined processing of Finnish derivational morphology using both accuracy and reaction time measures in morphological tasks and the concomitantly brain responses with MEG. The significant correlation found between reaction time for correctly derived words and RAN letters could suggest an association between naming speed and fluency of morphological processing for Finnish derivational morphology at pre-school and development of fluency in naming letters. Thus, it is possible that RAN letters and morphological processing, especially derivational morphology, might contain analogous mechanisms in relation to fluency and automatization. We further compared the brain responses of pre-school children with the reading performance of first grade children. However, no significant correlations were observed for the brain responses. Finally, derivational morphology (brain responses and behavioral performance) was correlated cross-sectionally to cognitive and reading measures and no significant correlations were observed. Our current findings together with our previous neuroimaging results (Louleli et al., 2020; Louleli et al., under review), show that children possess morphological skills for derived words and pseudowords, but this skill does not seem to be related with reading acquisition.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/**Supplementary Material**, further inquiries can be directed to the corresponding authors.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the Ethical Committee of the University of Jyväskylä in accordance with the Declaration of Helsinki. Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

AUTHOR CONTRIBUTIONS

NL, JH, and PL designed the study and analyzed the data. NL performed the MEG experiments. All authors discussed the results and contributed to the final manuscript.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fcomm.2021.655402/full#supplementary-material

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Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.