Scandinavian Journal of Educational Research

Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/csje20

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Published online: 16 Nov 2011.

To cite this article: Monica Melby-Lervåg (2012) The Relative Predictive Contribution and Causal Role of Phoneme Awareness, Rhyme Awareness, and Verbal Short-Term Memory in Reading Skills: A Review, Scandinavian Journal of Educational Research, 56:1, 101-118, DOI: 10.1080/00313831.2011.621215

To link to this article: http://dx.doi.org/10.1080/00313831.2011.621215

Scandinavian Journal of Educational Research
Vol. 56, No. 1, February 2012, 101–118

The Relative Predictive Contribution and Causal Role of Phoneme Awareness, Rhyme Awareness, and Verbal Short-Term Memory in Reading Skills: A Review

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The acknowledgement that educational achievement is highly dependent on successful reading development has led to extensive research on its underlying factors. A strong argument has been made for a causal relationship between reading and phoneme awareness; similarly, causal relations have been suggested for reading with short-term memory and rhyme awareness alike. Here a meta-analysis is presented that seeks to determine spuriousness in these factors' relationships with reading by examining each factor's unique predictive value. The results show that phoneme awareness is the strongest unique predictor. Since the meta-analysis is based on concurrent data, it is unsuited to enlighten time-order relationships, but longitudinal and experimental studies both support the notion of a causal relationship between phoneme awareness and reading, in contrast to rhyme awareness and verbal short-term memory.

Keywords: reading, rhyme awareness, phoneme awareness, verbal short-term memory

More than two decades have passed since Wagner and Torgesen (1987) published their widely cited paper concerning the nature of phonological processing and its causal role in the acquisition of reading skills. The authors' concluded that the existence of a causal relationship between phonological skills and the development of reading skills is beyond doubt. On the basis of this, they argue that critical questions for future studies should be more complex and concern those aspects of phonological processing that are casually related to reading and the directions of these relationships. The foci here are two aspects of phonological processing: phonological awareness and verbal short-term memory and their relation to the development of reading skills. Phonological awareness refers to one's ability to make judgments of and perform conscious manipulations on the sound structure (i.e. syllables, rhymes, phonemes) of spoken words (Hulme, Snowling, Caravolas, & Carroll, 2005), while verbal short-term memory typically refers to the ability to retain items of verbal information passively and then reproduce them in their original form (Swanson & Ashbaker, 2000). The term reading skills is here used to describe sight-word decoding skills.

Great advancements have been made in understanding how phonological awareness and verbal short-term memory relate to early reading skills since Wagner and Torgesen (1987) published their article. In the wake of their article, three main causal hypotheses have been

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ISSN 0031-3831 print/ISSN 1470-1170 online

http://dx.doi.org/10.1080/00313831.2011.621215
http://www.tandfonline.com

suggested: First, most researchers in the field of reading seem to agree that phoneme awareness is causally related to early reading attainment and that the ability to manipulate phonemes in words is probably a precondition for later reading success (Brady, 1997; Elbro, 1996; Hulme & Roodenrys, 1995; Hulme, Snowling et al., 2005; Snowling, 2000; Snowling & Hulme, 1994; Wagner, Torgesen, Laughon, Simmons, & Rashotte, 1993). Secondly, strong arguments have been presented for the case that rhyme awareness is causally related to later reading abilities in inconsistent orthographies, such as English, because rhymes are the most transparent component and, therefore, used as support in early reading acquisition (Bryant, 1998; Goswami, 1993, 1999, 2002; Goswami & Bryant, 1990). Finally, it has been suggested that verbal short-term memory can influence the development of a phonological decoding strategy and thereby affect the early attainment of reading skills (Gathercole & Baddeley, 1993). The purpose of this paper is to evaluate these causal claims by means of narrative review and a meta-analysis.

In evaluating each of the above assertions, four important criteria for establishing the existence of a causal relationship will be discussed (e.g. MacMillan, 2002; Schult, 1999; Singleton & Straits, 2005): First, since phoneme awareness, rhyme awareness, and verbal short-term memory are all aspects of phonological processing, a prerequisite for each of them to be causally related to reading is that it is meaningful to treat them as separate constructs. Studies that have examined the dimensionality of phonological processing will, therefore, be examined first of all. Secondly, a precondition for a causal relationship is that an association exists between two variables; this is non-spurious, cannot be explained by a third variable, and will be considered by the means of a meta-analysis. Finally, a critical issue in determining causality is that the time-order of the relationship between the variables supports that the hypothesized cause precedes effect. A review of studies with designs suitable for examining the time-order of the variables (i.e. longitudinal studies and experimental studies) will, therefore, be conducted.

Dimensionality

Several studies have used Confirmatory Factor Analysis (CFA) to test hypotheses about how different measures make up underlying constructs (latent variables) and examine the common variability that can be accounted for by the different measures. Regarding the relationship between verbal short-term memory and phonological awareness, the results from the CFA studies show that the best fitting measurement models seem to be where verbal short-term memory and phonological awareness are separated in two different constructs (de Jong & van der Leij, 1999; Lervåg, Bråten, & Hulme, 2009; Näslund & Schneider, 1991; Wagner, Torgesen, & Rashotte, 1994; Wagner et al., 1993).

On the matter of the nature of phonological awareness tasks, the results are less clear. It has been argued that phonological awareness can be separated in different constructs based on the size of the unit that is being manipulated, since manipulating large units, such as rhymes, presumably entails different skills than manipulating small units, such as phonemes (Hulme, 2002; Muter, Hulme, Snowling, & Taylor, 1998). In a CFA study by Muter, Hulme, Snowling, and Stevenson (2004), the model that best conceptualized phonological awareness was one in which rhyme and phoneme awareness are two distinct but correlated constructs ($r = .42$). In contrast, several authors have also used CFAs to argue that phonological awareness is a unitary construct but that children learn to manipulate various unit sizes in different

stages of language and reading development (Anthony & Lonigan, 2004; Anthony et al., 2002; Papadopoulos, Spanoudis, & Kendeou, 2009).

A closer examination of the studies that allegedly support the notion of a unitary phonological awareness construct, however, reveals a more debatable conclusion. In the study by Papadopoulos et al. (2009), awareness of syllables, onset/rhyme, and phonemes were measured; results suggest that a two-factor solution best conceptualizes the kindergarten data. In the study by Anthony et al. (2002), a four-factor solution (words, syllables, rhymes, and phonemes) generated a significantly better fit to the data from 4–5 year-olds than the one-factor solution. Also in the study by Anthony and Lonigan (2004), the main findings suggest that rhyme and phoneme awareness cannot be separated in younger children but that, in older children (second grade), the two skills can be conceptualized in two different, but highly correlated constructs. A common factor for these studies is that they justify the choice of a single-factor solution for reasons of parsimony, despite a multidimensional model providing the best fit for some age-groups. However, this "law of parsimony" has been questioned and extensively debated in methodology literature, and using this as justification can be questioned, especially when a multifactor model shows a better fit (Marsh & Hau, 1996, 1998; Mulaik, 1998; Sivo & Willson, 1998).

Regardless of whether a unitary model or a model where rhyme and phoneme awareness are conceptualized as two different constructs is chosen, all of the studies clearly show that phoneme and rhyme awareness are related abilities with a high degree of common variance. Furthermore, Muter et al. (1998) emphasize that both a unitary construct and a multidimensional model are compatible with a developmental view in which awareness of units in different sizes develops at different times and have different causal relationships with reading abilities. If one's goal is to compare the predictive power based on a hypothesis that phoneme and rhyme awareness have different causal relations with reading abilities, as is the case here, it will be necessary to treat them as separate constructs.

Association and Non-spuriousness

A substantial body of concurrent correlational studies demonstrate an association between phoneme awareness, rhyme awareness, verbal short-term memory, and reading skills (for reviews see Castles & Coltheart, 2004; MacMillan, 2002; National Institute for Literacy, 2008; Swanson, Trainin, Necoechea, & Hammill, 2003). With respect to phoneme awareness, the overall correlation with reading tends to be moderate to large, but there is large variability between studies. Some studies of phoneme awareness report moderate correlations with reading (e.g. Oney & Durgunoglu, 1997; Rispens, McBride-Chang, & Reitsma, 2008) while others report very large correlations (Holopainen, Ahonen, Tolvanen, & Lyytinen, 2000; Huang & Hanley, 1997; Plaza & Cohen, 2003).

Overall, the association between rhyme awareness and reading seems to be smaller in size than for phoneme awareness (for review see MacMillan, 2002), but also for rhyme awareness there is a large variation between studies: Some studies of the relationship between rhyme awareness and reading demonstrate moderate correlations, (e.g. Ho, 1997) while others demonstrate a very small association (e.g. Duncan & Johnston, 1999; Wood & Terrell, 1998). The large variation between studies of rhyme awareness has often been explained in terms of how rhyme awareness is measured (MacMillan, 2002). Several studies have shown that tasks used to measure rhyme awareness in general tend to have lower alpha reliability than tasks measuring phoneme awareness (e.g. Anthony et al., 2002; Muter

et al., 2004; Papadopoulos et al., 2009). Also, for the oddity task, which is a common measure of rhyme awareness, MacMillan (2002) argues that in both versions of the tests (the sound-categorization oddity test and the rhyme-only oddity test), the correct answer can also be obtained by using phoneme awareness. Hence, both the reliability of rhyme awareness measures and what skills these measures entail have been put into question.

For verbal short-term memory, a similar picture appears; the correlations with reading seem to be smaller in size than for phoneme awareness, but there is large variation between studies. Some studies examining the relationship between verbal short-term memory and reading demonstrate an association that is moderate to large (e.g. de Jong & van der Leij, 1999; Plaza & Cohen, 2003), while others show a small association (e.g. Leather & Henry, 1994). Thus, it is clear that there is a large variation between studies in correlation magnitude for reading with phoneme awareness, rhyme awareness, and verbal short-term memory.

In order to pursue the issue of a causal relationship, establishing an association between variables is evidently insufficient; it is also necessary to demonstrate non-spuriousness by taking into account whether the observed relationship can be explained by a third variable. Although the size of the correlation varies across studies, most studies tend to find reliable correlations between phoneme awareness, rhyme awareness, and verbal short-term memory. A relationship that is moderate in size is demonstrated between phoneme awareness and verbal short-term memory (e.g. Oakhill & Kyle, 2000; Plaza & Cohen, 2003; Rohl & Pratt, 1995), between phoneme awareness and rhyme awareness (e.g. Carrillo, 1994; de Jong & van der Leij, 1999;) and between rhyme awareness and verbal short-term memory (e.g. de Jong & van der Leij, 1999; McDougall, Hulme, Ellis, & Monk, 1994; Wagner et al., 1993). On this basis, the various strands of research have argued extensively about the independent predictive role of rhyme awareness (Bradley & Bryant, 1983; Goswami & Bryant, 1990), phoneme awareness (Hulme, 2002; Hulme et al., 2002; Muter et al., 1998) and verbal short-term memory (Gathercole & Baddeley, 1993; Mann, 1984; Mann & Lieberman, 1984), respectively, in relation to reading. In order to demonstrate non-spuriousness in their relationship with reading, one must combine relative contribution for phoneme awareness, rhyme awareness, and verbal short-term memory in predicting reading skills. In light of this, studies that have included measures of phoneme awareness, rhyme awareness, verbal short-term memory, and reading in combination are particularly interesting. A meta-analysis will be used as a tool to examine spuriousness by presenting a summary of the relative strength of phoneme awareness, rhyme awareness, and verbal short-term memory as predictors of reading skills. The meta-analysis will further examine variables that can potentially explain variation in the correlational outcomes between the studies.

Method

Data Collection

PsycINFO, PsycAPA, Medline, and ERIC were systematically scanned for studies reported from 1959 to March 2007. In the literature search, combinations of keywords related to reading (reading, word recognition, decoding) were crossed with terms related to memory (short-term memory, memory span, working memory) and phonological awareness (phon* awareness, phon* sensitivity, metalinguistic awareness). The reference lists from studies already included in the meta-analysis were scanned to expand the sample of

studies. Finally, well-known published authors within the field were used as keywords in separate electronic searches.

Each abstract gained from the search was thoroughly reviewed according to criteria established for inclusion in order to make a decision about whether a study could be included. The criteria were that all studies included should: (1) Use a decoding measure, (2) use a digit span or word span measure in which items were to be repeated verbally to the tester immediately after presentation, (3) use a phoneme awareness measure (i.e. in which sound structures in words are manipulated), (4) use a rhyme awareness measure (i.e. in which rhymes are manipulated, detected, or generated), and (5) report simple bivariate concurrent correlations between all these measures in unselected children that have started formal reading instruction. Studies concerning adults, children with additional handicaps, and children with learning difficulties were excluded. The review yielded a total of seven studies that met the criteria for inclusion.

Statistical Analysis

All combinations of pair-wise correlations between phoneme awareness, rhyme awareness, verbal short-term memory, and reading were entered into the program "Comprehensive Meta-analysis" (Borenstein, Hedges, Higgins, & Rothstein, 2005). For all combinations of variables, an overall average correlation was calculated. This was based on a random effects model which is built on the assumption that heterogeneity between studies is not only due to random errors but also to systematic differences between the studies. Heterogeneity between the correlations across studies was examined by the means of a Q-test; if significant, it can be assumed that there is true variance across the studies that differs significantly from zero (Hedges & Olkin, 1985). Also, I -squared (I^2) was used in order to determine the degree of heterogeneity. I^2 describes the between-study variance percentage that is caused by true heterogeneity.

For continuous moderator variables, regression analyses for random effects models (method of moments) were used to estimate the impact from moderators on correlation magnitude. Also, percentage proportion of between-study variance explained (R^2) was used as an effect size in order to determine the strength of the predictors on study outcome. For the categorical moderator variables, a Q-test was used to examine whether there was a significant impact from different levels in a categorical variable on the effect size.

In order to compare the relative contribution from each of the variables in their relationship with reading, the correlation matrices from each study were analyzed by the multiple group component in the Mplus software (Muthén & Muthén, 2006). Cholesky factoring was used in the analysis (de Jong, 1999). This is analogous to hierarchical regression and implies that one can determine which of the factors that can predict variance after the shared variance with other constructs are partitioned out. The various studies made use of tests based on different scales. Since the covariance matrix is not standardized, and thereby dependent on the scales for the raw data scores, this implies that a covariance matrix generated from the various studies could not be merged into one analysis. This analysis is, therefore, conducted directly on the Pearson's r correlational matrix for each study. As shown by Cudeck (1989), however, applying covariance models to sample correlation matrices can lead to incorrect values for the omnibus fit test and produce erroneous standard errors. Therefore, in this case, when drawing conclusions from the analysis, the effect sizes are emphasized rather than the z-values.

Results

Study Characteristics

The total sample size for the seven studies included in the meta-analysis was 589 children ($M = 84$, range 34 – 244), with a mean age of 7.83 years (range 5.16 – 10.58 years). The sample of included studies, with their respective sample size, age of children studied, and measures used are displayed in Table 1.

Table 1
Summary of Sample Size and Mean Age for Correlational Studies of the Relationship between Reading, Verbal Short-term Memory, and Phonological Awareness

Study	Sample size	Age (*months*)	Measures
Duncan & Johnston, 1999	41	127	RA: Rhyme judgment PA: Phoneme deletion STM: Digit span RDN: BAS reading
Farrington-Flint, Wood, Canobi, & Faulkner, 2004	51	66	RA: Rhyme judgment PA: Phoneme deletion STM: Backward Digit span RDN: BAS reading
McDougall, Hulme, Ellis, & Monk, 1994	69	100	RA: Blending onset rhyme PA: Phoneme deletion STM: Digit span RDN: BAS reading
Metsala, 1999	61	61.39	RA: Rhyme discrimination PA: Phoneme deletion STM: word span RDN: WRAT- r
Muter & Snowling, 1998	34	117	RA: Rhyme discrimination PA: Phoneme deletion STM: Word span RDN: NARA reading accuracy
Wagner, Torgesen, & Rashotte, 1994	244	68	RA: Blending onset rhyme PA: Phoneme deletion STM: Digit span RDN: WRMT- word Id
Wagner, Torgesen, Laughon, Simmons, & Rashotte, 1993	89	97	RA: Blending onset rhyme PA: Phoneme deletion STM: Digit span RDN: WRMT- word Id

Note. RA = Rhyme Awareness; PA = Phoneme Awareness; STM = Verbal Short-term Memory; RDN = Reading.

Correlations and Moderator Variables

Table 2 shows overall average for all combinations of correlations between phoneme awareness, rhyme awareness, verbal short-term memory, and reading. As shown in Table 2, the correlation with reading is significant for all measures, but the mean correlation with reading is higher for phoneme awareness than for rhyme awareness and verbal short-term memory. Table 2 also shows that the correlation between phoneme awareness and rhyme awareness is higher than the corresponding correlation for each of these constructs with verbal short-term memory. It is also apparent that there is a large variation in correlations magnitude between studies for the pair-wise correlations between phoneme awareness with reading, rhyme awareness with reading, and phoneme awareness with rhyme awareness but non-significant variation in correlation magnitude between studies for all pair-wise correlations involving verbal short-term memory.

For the correlations between phoneme awareness with reading, rhyme awareness with phoneme awareness, and rhyme awareness with reading, the variation in correlations between studies was significant. It was, therefore, meaningful to conduct an analysis of moderator variables for these correlations. First, the relationship between correlation size and age were examined. For the correlation between phoneme awareness and reading skills, the regression analysis showed that age was not a significant predictor of differences in correlations between studies, $z(7) = 0.84$, $p = .40$ (i.e. the size of the correlation is stable across the different age levels in the samples). For the correlation size between phoneme awareness with rhyme awareness, age was a significant predictor, $z(7) = -2.06$, $p < .05$ (i.e. the correlation between phoneme awareness and rhyme awareness tend to decrease as children get older, and age as a covariate was able to explain 67% of the variation in correlations between studies). For the correlation between rhyme awareness and reading, age as a predictor was not significant, $z(7) = -1.45$, $p = .14$. Yet, age was able to explain 25% of the variation in correlation magnitude for rhyme awareness and reading between studies (i.e. children tend to demonstrate lower correlations between rhyme awareness and reading as they get older).

Appertaining to test type, the correlation between phoneme awareness with reading and type of reading, tests were separated into three categories: Studies using BAS ($k = 3$), studies

Table 2

Number of Effect sizes, Effect size, 95% Confidence Interval, and Heterogeneity Statistics for Combinations of Correlations between Decoding, Phoneme Awareness, Rhyme Awareness, and Verbal Short-term Memory

Pair-wise Correlations	*r*	*95% CI*	*Range of variation*	I^2
Phoneme awareness—Reading	.56**	.45 – .66**	.37– .84	67.64**
Rhyme awareness—Reading	.41**	.28 – .54**	.05 – .58	67.01**
Verbal short-term memory—Reading	.28**	.20 – .35**	.14 – .46	ns
Phoneme awareness—Rhyme awareness	.54**	.45 – .63**	.27 – .67	51.21*
Phoneme awareness—Verbal short term memory	.27**	.18 –.34**	.03 – .34	ns
Rhyme awareness—Verbal short-term memory	.29**	.21– .35**	.12 – .49	ns

Note. r = mean weighted correlation; I^2 = the proportion of total variation between the effect sizes that are caused by real heterogeneity rather than chance; ns = non-significant; * = $p < .05$, ** = $p < .01$.

using WRAT-r ($k = 2$), and studies using other tests ($k = 2$). For the correlation between phoneme awareness and reading, there was no significant difference in effect sizes between studies using different reading tests, $Q(2) = 0.78$, $p = .68$. Secondly, the impact from the type of reading test was also examined for the correlations between rhyme awareness and reading. Similarly, reading test was not a significant moderator variable, $Q(2) = .21$, $p = .90$. The impact of rhyme test type on correlation size was also examined by separating rhyme tests into three categories: Studies using rhyme judgment tasks ($k = 2$), studies using rhyme discrimination tasks ($k = 2$), and studies using blending onset and rhyme task ($k = 3$). Rhyme test type was not a significant moderator for the correlation between rhyme awareness and reading, $Q(2) = 0.24$, $p = .89$ or for the correlation between rhyme awareness and phoneme awareness, $Q(2) = 1.56$, $p = .46$. Since all studies use phoneme deletion tests, it was not meaningful to use phoneme awareness test type as a moderator variable.

Cholesky Factoring

Table A1 (appendix) shows the observed correlations between all variables for each of the seven studies in the sample separately as they were entered into Mplus. Overall, the correlations were restricted to be equal across studies. In spite of significant heterogeneity between some of the correlations, overall this model fitted the data well, $\chi^2(60) = 72.13$, $p < .001$, $CFI = 0.98$, $RMSEA = 0.049$, (90 percent C.I. $= 0.00 - 0.08$), $SRMR = 0.08$, $AIC = 6154.62$, $BIC = 6198.40$. The results from the analysis with the Cholesky factoring showed that the three variables together explained 34.5% of the variance in reading skills. When rhyme awareness was entered first in the equation, the results showed that rhyme awareness explained 17.6 % of the variance in reading skills across the seven studies. This was a significant contribution, ($z = 12.64$, $p < .01$). Further, when verbal short-term memory was entered first, this could explain 7.7% of the variance. This contribution was also significant ($z = 7.32$, $p < .01$). In contrast, when phoneme awareness was entered first, the results showed that phoneme awareness alone could account for 31.1% of the variance in reading skills across the studies. This was highly significant ($z = 19.68$, $p < .01$). When both phoneme awareness and verbal short-term memory were partitioned out, rhyme awareness could explain only 1.4% of the variance in reading skills. This contribution was significant ($z = 3.59$, $p < .01$). When rhyme awareness and phoneme awareness were partitioned out, verbal short-term memory could only explain 1.3% of the variance. This contribution was also significant ($z = 3.43$, $p < .01$). In contrast, when both verbal short-term memory and rhyme awareness were partitioned out, phoneme awareness could still explain 13.6% of the variance. This was a highly significant contribution ($z = 11.60$, $p < .01$).

Discussion

Results From the Meta-analysis

This meta-analysis clearly shows that phoneme awareness is a stronger predictor of reading skills than rhyme awareness and verbal short-term memory. It is, however, worth noting that measures of rhyme awareness have often been criticized for low reliability (e.g. Muter et al., 2004; Papadopoulos et al., 2009). If measures of rhyme awareness generally have lower alpha reliability than measures of the other variables, this may offer an

alternative explanation for dominance of phoneme over rhyme when it comes to unique prediction value. Three studies in the meta-analysis reported alpha reliability, and these studies show an average alpha of .83 for rhyme awareness and .89 for phoneme awareness. At least for the studies in the meta-analysis that have reported reliability, it seems unlikely that this can explain the large differences between the variables in the hierarchical regression. This provides further support for the dominance of phoneme awareness compared to rhyme awareness in predicting reading skills.

This meta-analysis also showed that there were large variations in the strength of correlations between studies. When examining variables that could potentially explain variation between studies, age was a significant predictor for the correlation between rhyme awareness and phoneme awareness and explained as much as 67% of the variation between studies. This relationship was negative, which implies that the strength of the correlation between rhyme awareness and phoneme awareness decreases as children get older (i.e. rhyme awareness is more related to phoneme awareness in younger than in older children). Moreover, age was also approaching significance as a predictor for the correlation between rhyme awareness and reading. This relationship was also negative, and this implies that the correlation between rhyme awareness and reading is stronger in younger children than in older children. Overall, the findings involving age as a moderator variable is in accordance with studies which show that the development of phonological skills progress from awareness of large to small units as a function of age (Anthony & Lonigan, 2004; Carroll, Snowling, Hulme, & Stevenson, 2003; Goswami & Bryant, 1990; Treiman, 1985). Theoretically, this is often explained by the lexical restructuring hypothesis suggested by Metsala and Walley (1998) who claim that phoneme awareness develops from larger grained representations on a word level to fine-grained phoneme-based representations during childhood as a result of vocabulary growth. If the relationship is developmental, then the findings in the present meta-analysis of higher correlations that rhyme awareness is a stronger correlate of both reading and phoneme awareness in younger children than in older children seems reasonable.

As for test type, all studies used phoneme deletion tasks as measures of phoneme awareness, and this was, therefore, not meaningful as a moderator variable. It is, however, worth noting that no moderator variables could reliably explain variation in correlation between phoneme awareness and reading, and this means that much of the variation between studies for this relationship remains unexplained. When grouping the studies on the basis of type of reading test, this did not yield significant differences in correlation magnitude. This finding is perhaps not surprising given that most decoding tests tend to be very highly correlated. With regards to rhyme awareness tests, grouping the studies on the basis of test type did not demonstrate significant differences between the subsets of studies using different tests. This is a somewhat unexpected finding given the discussions in the literature of different measures of rhyme awareness (e.g. MacMillian, 2002). However, it is important to notice that separating seven studies in subsets will yield very low power to detect differences between the subsets, and in a larger sample of studies, it is possible that a different pattern could be present.

An important limitation of this meta-analysis when it comes to causation is that it is based on concurrent correlations that are not suited to enlighten the time-order relationship between the variables. Since all the studies in the meta-analysis examined children that had started formal reading instruction, it is possible that the dominance of phoneme awareness in predicting reading skills can reflect that learning to read has an impact on phoneme awareness. Also, from this meta-analysis, one cannot rule out the possibility that rhyme awareness and/or

verbal short-term memory can affect reading at an earlier point in the developmental course, either indirectly, directly, or both. Finally, the meta-analysis examines variables related to phonological processing, and no other possible third variables are included. Therefore, in order to further pursue the issue of causality, studies using designs that are suited to establish the time direction of a relationship after controlling for relevant third variables must be explored.

Time-order Relationships

Concerning time-order, the strongest case for a probable causation with reading for any aspect of phonological processing has been made for the causal hypothesis that phoneme awareness yields influence on early reading development. This hypothesis has been supported by longitudinal studies which show that neither awareness of larger units (such as rhymes), verbal short-term memory, nor other relevant third variables (such as IQ and rapid naming) are able to predict reading longitudinally beyond phoneme awareness (de Jong & van der Leij, 1999; Lervåg, Bråten & Hulme, 2009; Näslund & Schneider, 1991; Wagner et al., 1994), and from experimental training studies that show that training phoneme awareness has an impact on reading skills (Bus & van Ijzendoorn, 1999). This is also in line with the findings from the present meta-analysis, which shows that phoneme awareness is the strongest predictor of reading skills when compared with other aspects of phonological processing.

Caveats towards the alleged causal relationship between phoneme awareness and reading have been argued by Castle and Coltheart (2002). In their view, the causal relationship between phoneme awareness and reading is not unequivocally proven because it is possible that the process of gaining letter knowledge can affect the strength of the relationship between phoneme awareness and decoding (moderate), that phoneme awareness leads to letter knowledge which in turn affects reading skills (mediate), and/or that letter knowledge and reading skills in turn affect phoneme awareness (reciprocal). In response to this, Hulme, Snowling et al. (2005) referred to studies that have shown that children can have phoneme awareness without knowing the corresponding letter (Caravolas, Hulme, & Snowling, 2001; Hulme, Caravolas, Malkova, & Brigstocke, 2005; Lundberg, 1994), and this supports that letter knowledge and phoneme awareness can operate as independent processes. They also note that even if the relationship between phoneme awareness and reading are mediated by letter knowledge and/or if letter knowledge and learning to read also affects phoneme awareness, this does not make phoneme awareness a less genuine cause but gives us a better understanding of the mechanisms that operate in this relationship. On this basis, they proposed an alternative model to the unidirectional causal arrow model from phoneme awareness to reading. The alternative causal model denotes a close and reciprocal relationship between phoneme awareness and letter knowledge, but each of them affects reading independently. This model gains support from a recent longitudinal study (Lervåg et al., 2009), which showed that phoneme awareness and letter knowledge were two independent but highly correlated latent constructs (estimated correlation .85) that both had unique prediction value on reading skills. The study also supported a reciprocal relationship between reading and phoneme awareness, since reading skills measured at time 2 predicted phoneme awareness at time 3, beyond the effects from phoneme awareness at time 2 (Lervåg, 2005).

As for the interpretation of the underlying mechanisms in the relationship between phoneme awareness and reading, it has been suggested that phoneme awareness tasks

reflect the quality of phonemic representations in long-term memory and that the quality of these representations is causally related to reading (Elbro, 1996; Hulme & Roodenrys, 1995; Hulme, Snowling et al., 2005; Snowling, 2000; Snowling & Hulme, 1994; Wagner et al., 1993). In line with this view, performance on not only phoneme awareness tasks, but also on other types of phonological processing measures, are proxies for the quality of phonemic representations (Hulme et al., 2005; Wagner et al., 1993). However, this hypothesis that the quality of phonemic representations is a distal cause in the relationship between phoneme awareness and reading has proven to be difficult to test directly. Wessling and Reitsma (2001) argue that measuring the quality of phonemic representations is complex because it is difficult to construct indicators of the quality of phonemic representations that clearly capture this underlying process but yet differ from other phoneme awareness tasks. They further claim that knowledge about the nature of phonemic representations and how these representations are related to lexical items is unclear. Therefore, due to the methodological problems involved in measuring the quality of phonemic representations, much of the existing theory on this construct has been deduced on the basis of studies using common phonological awareness measures.

As for the second causal hypothesis, that preschool rhyme abilities are directly casually related to later reading abilities (Bryant, 1998; Goswami, 1993, 1999, 2002; Goswami & Bryant, 1990), an underlying mechanism has been explained in terms of reading by analogy and the grain size theory. Reading by analogy is based on studies showing that children can use rhymes as a means of support in early reading acquisition when reading unknown words (e.g. use cake as support when reading lake) (Goswami, 1990, 1993). More recently, the notion of reading by analogy has been refined by the grain size theory which relates reading by analogy to differences in orthographies (Ziegler & Goswami, 2005). According to this theory in English, in contrast to other shallower orthographies, rhymes are the most transparent components and phonemes are not as easily accessible. Rhymes are, therefore, seen as a prerequisite of learning to read in English because the awareness of onset and rhyme gives children a strategy for connecting spoken with written units.

However, the empirical evidence from longitudinal and experimental studies seems rather scarce for the hypothesis that rhyme awareness yields direct causal influence on reading (for reviews see Castles & Coltheart, 2004; MacMillan, 2002). This also corresponds with the findings from the present meta-analysis which shows that rhyme awareness only could explain 1.4% of reading skills beyond phoneme awareness and verbal short-term memory. MacMillan (2002) argues that many of the longitudinal studies that show a direct link between rhyme awareness and reading contain general methodological problems, such as skewed scores, small sample size in relation to number of variables, and failure to control for important third variables that might influence reading skills. Also, when reviewing studies that have attempted to train rhyme awareness and examine effects on reading, only one study using pure rhyme training has been identified (Duncan & Seymour, 2000), and in this study, rhyme training had an impact on rhyming skills but no transfer effects to reading. In a randomized trials study, Hatcher, Hulme, and Snowling (2004) compared reading instruction and rhyme training with reading instruction and phoneme training, and in children at risk of reading failure the reading + phoneme condition had significantly better reading skills after training than the reading + rhyme condition. Further, more conclusive evidence was obtained in a short-term longitudinal study by Hulme et al. (2002), where the task characteristics were constant (detection, oddity, and deletion) and unit size varied (onset, rhyme, first, and last phoneme). The results showed that phoneme manipulation

had predictive value beyond the other unit sizes both concurrently and at later time points. Yet, even though the empirical evidence speaks against a direct causal link between rhyme awareness and reading, it is still possible that rhyme awareness can affect reading via phoneme awareness, as demonstrated in a longitudinal study by Carroll et al. (2003).

The third causal hypothesis that verbal short-term memory can affect the attainment of reading skills, possibly by influencing the development of a phonological decoding strategy (Gathercole & Baddeley, 1993; Wagner & Torgesen, 1987), also lacks support from longitudinal and experimental studies. In longitudinal studies that measure verbal short-term memory before the onset of formal reading instruction, taking into account relevant third variables and skills on prior time points, results show that verbal short-term memory does not predict reading skills longitudinally, nor that learning to read cannot predict variation in verbal short-term memory at later time points (de Jong & van der Leij, 1999; Lervåg et al., 2010; Näslund & Schneider, 1991; Wagner et al., 1994). This is also in accordance with the findings from the present meta-analysis which shows that verbal short-term memory was only able to explain 1.3% of the variance after phoneme and rhyme awareness were taken into account. This notion of a causal relationship between verbal short-term memory and reading also lacks support from experimental training studies; no studies have managed to reliably demonstrate that one can affect reading through verbal short-term memory training (Wagner & Torgesen, 1987). However, the results from an experimental training study by Melby-Lervåg and Hulme (in press) showed that when training phoneme awareness, reliable increase was observed in verbal short-term memory performance (as measured by word span). This provides convincing evidence that the quality of phonemic representations can be an underpinning factor influencing not only performance on phoneme awareness tasks, but also on verbal short-term memory tasks; and that verbal short-term memory is related to reading because tasks that presumably measure this also, at least partly, depends on the quality of phonemic representations.

Final remarks

The foci here have been two aspects of phonological processing, phonological awareness and verbal short-term memory, and their relation to the development of reading skills. As for the question raised by Wagner and Torgesen (1987) concerning which aspects of phonological processing that are casually related to reading, and the directions of these relationships, a large number of studies have demonstrated a close association between phoneme awareness, rhyme awareness, and verbal short-term memory with reading, and also with each other. However, in the meta-analysis presented here, phoneme awareness represented the largest independent predictive value of reading skills by far. For phoneme awareness, in contrast to rhyme awareness and verbal short-term memory, longitudinal and experimental studies also speak in favor of a causal link with reading. Yet, even if prior studies support the idea that phoneme awareness, or more precisely, the quality of phonemic representations, causally affects reading, the relationship is most likely reciprocal because the development of reading skills also affects the development of phoneme awareness. The development of phoneme awareness is also closely, and probably reciprocally, related to the development of letter knowledge. In relation to Wagner and Torgesen's question, it is important to note that recent studies have found supporting evidence for the case that naming speed, an aspect of phonological awareness beyond the scope here, is also causally related to

reading skills independent of phoneme awareness (Lervåg et al., 2009; Lervåg & Hulme, 2010).

Finally, an important matter is how the advancements in reading research can help guide educational practice. One important practical consequence is related to the detection of children at risk of developing reading problems. Since phoneme awareness was found to be the best predictor for early reading skills, when screening beginning readers for potential decoding problems, tasks focusing on phoneme awareness will be an important assessment tool. On the topic of implications for intervention, it might be tempting on the basis of these results to conclude that remediation for children with reading problems should focus on phoneme level training. However, studies have shown that awareness for larger units, such as rhymes, can be an important precursor for later development of phoneme awareness (Carroll et al., 2003). Therefore, in remediation for children with reading difficulties, it will be useful to focus on both larger and smaller units.

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Appendix

Table A1
Observed Correlations between Verbal Short-term Memory, Phoneme Awareness, Rhyme Awareness, and Reading for Each Study in the Sample

1) Duncan & Johnston, 1999 ($N = 41$)

	RA	PA	STM	RDN
1 RA	1			
2 PA	.27	1		
3 STM	.34	.19	1	
4 RDN	.05	.37	.24	1

2) Farrington-Flint, Wood, Canobi, & Faulkner, 2004 ($N = 51$)

	RA	PA	STM	RDN
1 RA	1			
2 PA	.53	1		
3 STM	.12	.03	1	
4 RDN	.54	.50	.23	1

3) McDougall, Hulme, Ellis, & Monk, 1994 ($N = 69$)

	RA	PA	STM	RDN
1 RA	1			
2 PA	.67	1		
3 STM	.39	.29	1	
4 RDN	.58	.61	.35	1

4) Metsala, 1999 ($N = 61$)

	RA	PA	STM	RDN
1 RA	1			
2 PA	.66	1		
3 STM	.39	.31	1	
4 RDN	.43	.38	.40	1

5) Muter & Snowling, 1998($N = 34$)

	RA	PA	STM	RDN
1 RA	1			
2 PA	.42	1		
3 STM	.24	.27	1	
4 RDN	.47	.84	.46	1

6) Wagner, Torgesen, & Rashotte, 1994 (*First grade sample* $N = 244$)

	RA	PA	STM	RDN
1 RA	1			
2 PA	.60	1		

(*Continued*.)

Table A1. (*Continued*.)

1) Duncan & Johnston, 1999 ($N = 41$)

	RA	PA	STM	RDN
3 STM	.29	.34	1	
4 RDN	.50	.61	.27	1

7) Wagner, Torgesen, Laughon, Simmons, & Rashotte, 1993 (*Second grade sample*, $N = 89$)

	RA	PA	STM	RDN
1 RA	1			
2 PA	.45	1		
3 STM	.19	.16	1	
4 RDN	.19	.51	.14	1

Note. RA = Rhyme Awareness; PA = Phoneme Awareness; STM = Verbal Short-term Memory; RDN = Reading