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RAN as a predictor of reading skills, and vice versa: results from a randomised reading intervention

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Abstract Although phonemic awareness is a well-known factor predicting early reading development, there is also evidence that Rapid Automatized Naming (RAN) is an independent factor that contributes to early reading. The aim of this study is to examine phonemic awareness and RAN as predictors of reading speed, reading comprehension and spelling for children with reading difficulties. It also investigates a possible reciprocal relationship between RAN and reading skills, and the possibility of enhancing RAN by intervention. These issues are addressed by examining longitudinal data from a randomised reading intervention study carried out in Sweden for 9-year-old children with reading difficulties (N=112). The intervention comprised three main elements: training of phonics, reading comprehension strategies and reading speed. The analysis of the data was carried out using structural equation modelling. The results demonstrated that after controlling for autoregressive effects and non-verbal IQ, RAN predicts reading speed whereas phonemic awareness predicts reading comprehension and spelling. RAN was significantly enhanced by training and a reciprocal relationship between reading speed and RAN was found. These findings contribute to support the view that both phonemic awareness and RAN independently influence early phases of reading, and that both are possible to enhance by training.

Keywords Dyslexia · Intervention · Phoneme awareness · RAN · Reading speed

While phonemic awareness has for several decades been regarded as the main factor predicting early reading (for a review see Mellby-Lervåg, Lyster, & Hulme, 2012), there is also evidence that Rapid Automatized Naming (RAN) is an independent factor that contributes to early reading. Although originally used as a measure of recovery from brain injury (Denckla & Cutting, 1999), Denckla and Rudel (1972, 1974) later used RAN as a measure for predicting reading development. Since then, RAN has gained increasing attention, and many aspects of RAN have been studied, such as articulation and speed of processing. However, in terms of the nature of RAN and its role in relation to reading, much is still unknown.

By letting an individual name aloud a list of familiar digits, letters, objects and/or colours as quickly as possible, RAN can easily be assessed. The use of the different RAN tasks varies over studies. For example, at the preschool level, it is probably only possible to use object

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naming, or perhaps object and colour naming. However, Lervåg and Hulme (2009) have demonstrated that early non-alphanumeric RAN skills predict later alphanumeric RAN, suggesting that they tap the same neural mechanisms. On the other hand, alphanumeric RAN tasks have been found to be the most predictive of early reading skills, which may imply that alphanumeric RAN tasks mirror knowledge of digits and letter names (Bowey, 2005).

According to the double-deficit hypothesis proposed by Bowers and Wolf (1993; Wolf and Bowers, 1999), phonological processing deficits and naming speed problems may appear either independently or together. Thus, individuals with dyslexia may have phonological deficits only, naming deficits only, or both types of deficit. Individuals with both deficits, i.e. the double-deficit subgroup, are the most impaired readers. Wolf and Bowers (2000) point out that there is a risk that children with naming speed deficits do not receive adequate treatment. The reason is that the children with only naming speed deficits run the risk of not being detected at all because their phonological decoding skills are intact, and that children with a double-deficit receive treatment only related to the phonological deficit. Wolf and Bowers hypothesize that this may be one explanation for the treatment resistors described for example by Torgesen, Wagner, and Rashotte (1994). The double-deficit hypothesis is in line with Cronin's findings (2011), which also showed that RAN can vary independently of phonology, and that both RAN and phonological awareness are necessary in phoneme/grapheme mapping. In contrast, Vaessen, Gerretsen, and Blomert (2009) in a sample of 162 primary school children, demonstrated that RAN does not represent an independent core deficit in dyslexia, but rather seems to reflect a speed component of phonological processing.

Some researchers argue that phonemic awareness is related to dyslexia in deep (inconsistent) orthographies and to reading speed in more transparent (consistent) orthographies. However, in transparent orthographies, word reading can reach a high level of accuracy at an early stage. Therefore, it is often measured by speed, while in deeper orthographies it is measured by accuracy (Seymour, Aro, & Erskine, 2003; Wolff, 2009). Looking at predictors of reading in the transparent German orthography, Landerl and Wimmer (2008) found RAN to be the best predictor of growth of reading fluency while phonological awareness was found to be the best predictor for spelling. However, Vaessen et al. (2010) investigated the influence of phonological awareness and RAN on reading fluency in Grades 1–4 in three different orthographies, Hungarian, Dutch and Portuguese. They found a strong influence of phonological awareness on reading in early grades. This influence decreased in significance with more reading experience, whereas the influence from RAN increased. This pattern of development was the same in all three orthographies, even though modulated by the depth of the orthography. Parrila, Kirby and McQuarrie (2004) investigated the importance of phonological awareness and RAN in a Canadian sample of 161 children. The children were tested annually from kindergarten to Grade 3. Parrila et al. (2004) found that kindergarten phonological awareness and naming speed were significantly related to word identification and passage comprehension in Grade 1 through Grade 3. When RAN and phonological awareness were measured in Grade 1, phonological awareness became an even stronger predictor of word identification and passage comprehension, whereas the opposite was true for RAN. A somewhat different pattern was identified by Allor (2002) in a review of more than 20 studies of phonemic awareness and RAN with English-speaking children. There was converging evidence of a stronger contribution of phonemic awareness than RAN to word reading from kindergarten through the fifth grade. However, there was also a unique contribution to word reading from RAN up to about the second grade. The results also indicated that RAN uniquely could predict reading difficulties in older students. This is in line with Kirby, Parrila, and Pfeiffer (2003), who also found evidence for kindergarten RAN as a predictor of reading difficulties, especially in combination with poor phonological awareness. Puolakanaho et al.

(2007) found phonological awareness, letter naming and RAN to be the best predictor for reading difficulties from the age of 3.5 years old.

The findings diverge concerning whether RAN is a more important predictor for reading at younger or at older ages. One explanation may be that the reading measures in the Vaessen et al. (2010) study were speeded, and therefore RAN increased in significance. However, converging evidence in many studies (e.g. Allor, 2002; Lervåg, Bråten, & Hulme, 2009; Parrila et al., 2003; Puolakanaho et al., 2007) demonstrates that RAN is a significant contributor to word reading in early grades. These studies also show that RAN contributes to reading in older ages for children with word reading deficits. Thus, it may be the case that RAN is most important when reading is not successfully mastered or fluent, either because it is in an early stage of reading instruction, or because of obstacles in the typical development.

In a 3-year longitudinal study, Lervåg and Hulme (2009) monitored 233 Norwegian children. The study began 1 year before formal reading instruction started. The authors suggest that RAN reflects "stable and durable aspects of brain functioning" (p. 1047), implying that it may serve as a good tool for predicting reading difficulties, although it would be hard to modify by training. They hypothesize that RAN and reading both tap the same temporal phonological activation. Yet, attempts have been made to improve RAN by training, although without much success. de Jong & Vrielink (2004) trained first-grade children with a mean age of 6 years 11 months. The children were assigned to one of three groups: rapid letter-sound naming training, addition training or no training control group. After the training, the intervention group did not perform better on RAN as compared to the control groups. This is also in accordance with an overview of naming speed and reading (Kirby, Georgiou, Martinussen, & Parrila, 2010), in which some evidence was found that RAN can be enhanced by training, but substantially more evidence was found for the opposite view that it cannot be enhanced by training.

There is also conflicting evidence concerning the effect of RAN training in a study by Conrad and Levy (2011). Children at the ages between 6 years, 9 months and 8 years, 4 months who were poor performers on word reading and naming speed participated in the study. The children received training in orthographic pattern recognition and speeded letter recognition. Some children received the speeded letter training first and then the orthographic training, whereas some children received the training the other way round. The results showed that the RAN letter training alone had no effect, and that RAN letter training led to improvement only if it was done after orthographic recognition training. The authors suggest that enhanced awareness of orthographic consistencies may benefit the efficiency of processing of letters within a string.

A possible reciprocal relationship between RAN and reading speed is another area of research which has not shown consistent results. Lervåg and Hulme (2009) found no evidence of a reciprocal relationship between RAN and reading fluency in their longitudinal study of a sample of children without reading difficulties. In order to investigate if RAN influences word decoding, or if word decoding influences RAN, or if there might be a bidirectional relationship, Compton (2003) followed first-grade children once a month for 7 months with a test battery consisting of measures of RAN numbers, RAN colours, and word and non-word reading. The results suggest a bidirectional relationship between RAN numbers and word reading, whereas RAN numbers was not related to non-word reading, and RAN colours was related to neither word nor non-word reading. The strongest correlation between RAN numbers and word reading was found among the weakest decoders.

While phonemic awareness and RAN have been established as predictors of reading, there is still uncertainty which aspects of reading they predict and whether phonemic awareness and RAN are two distinct skills. This will be examined in the Swedish orthography, which is transparent as compared to the English orthography. Swedish is a morpho-phonological language, more opaque than German but more transparent than French (see Wolff, 2009). The aims of the current paper are (1) to study RAN and phonemic awareness as predictors of reading, measured as reading comprehension, reading speed and spelling for children with reading difficulties, (2) to study a possible reciprocal relationship between RAN and reading skills, (3) to study the possibility to enhance RAN by intervention. These issues are addressed by examining longitudinal data from a reading intervention study carried out in Sweden with 9-year-old children with reading difficulties. The intervention study will be described further in the "Method" section. In an earlier report of this study, the results presented showed that, compared to the control group, there were significant gains in reading comprehension, reading speed, phonemic awareness and spelling for the intervention group and, further, that these gains were sustained one year later (Wolff, 2011). In the present study, these aspects of reading are included in the context of the possible predictive power of RAN and phonemic awareness on reading skills. The effect of phonemic awareness on reading skills in this study has already been reported. Although the focus is on RAN, phonemic awareness is included to make it possible to investigate if RAN and phonemic awareness uniquely and independently contribute to reading speed, reading comprehension and spelling.

Method

Participants

Pupils in Grade 3 with reading difficulties participated (N=112) in the study. They were selected by screening from a larger sample of 2,212 students from 11 municipalities. A broad range of schools (N=59) were represented, situated in rural as well as urban regions with various levels of socioeconomic status reflecting the Swedish society. The screening comprised of a word decoding test (Jacobson, 2001), an orthographic choice task and a phonological choice task (Wolff, 2010). Participants were selected if they performed at least one standard deviation below the mean on two of the tasks, of which one should be the phonological choice task. The intention was to include students with word reading difficulties caused by a phonological deficit. Students with a known diagnosis of ADHD or autism were excluded, as were pupils who did not speak Swedish at the age of three. The selected pupils were randomly assigned to an intervention group (n=57; 32 boys and 25 girls) and a control group (n=55; 41 boys and 14 girls). The mean age of the children was 9.25 years (SD=0.3).

Intervention

The intervention group received one-to-one instruction in school every day for 40 min a day over a 12-week period, i.e. 40 h. The training sessions were conducted during the school day by teachers working in the municipality with a graduate diploma in special education. The teachers were also trained within the research project to deliver the reading programme. Programme fidelity was checked in two ways: (1) the project leader visited each teacher during an intervention session, and (2) the teachers reported in writing how the implementation of the programme progressed each day and if there were any deviations from the programme. If a pupil was absent, efforts were made to compensate for this at another time. The control group participated in the ordinary class room activities offered by the school. For around 75 % of the pupils in the control group, this also involved special education in groups or individually.

The intervention was based on three main components (for a more detailed description, see Wolff, 2011): (1) *Phonemic decoding and phonemic awareness training*. There is a consensus that training of phonemic awareness and phonemic decoding are important components of reading intervention programmes (e.g. Rack, 2004; Torgesen, 2005). The intervention was very structured, first introducing simple phoneme/grapheme mappings, and the first 5 weeks were spent on phonetic reading and spelling. During the following 7 weeks, more complex orthographic patterns were systematically introduced. Around 60 % of the time was spent on this part of the programme. The training was tailored to the Swedish orthography. (2) *Reading fluency training*. Reading fluency is of critical importance for reading comprehension (National Reading Panel, 2000) and has been shown to be difficult to enhance, both in interventions when reading speed is explicitly addressed (Thaler, Ebner, Wimmer, & Landerl, 2004), and when it is not (Torgesen et al., 2001). In the present study, fluency is addressed by repeated oral text reading as there is some support for its positive impact on improving reading speed (National Reading Panel, 2000; Vadasy & Sanders, 2009). Around 20 % of the time was spent on fluency training. (3) *Reading comprehension strategies*. According to the National Reading Panel (2000) explicit instruction of comprehension strategies has proven to be very effective in enhancing reading comprehension. In the current study, it was applied with the intention of encouraging pupils to actively relate to the texts they read. Some of the pupils were not able to read a text long enough to be used in exercises in reading comprehension strategies, and consequently their teachers read aloud to them. Around 20 % of the time was spent on reading comprehension strategies.

The main results from the previously reported study (Wolff, 2011) showed that it is possible to enhance reading comprehension skills, spelling, phonemic awareness and reading speed by structured phonics-linked instruction with remaining effects 1 year later.

Instruments

The tests used in this study are hypothesized to reflect five aspects related to reading: phonemic awareness, reading comprehension, spelling, reading speed and rapid automatized naming. Non-verbal IQ was also included in the test battery used on the pre-test, and was then used as a covariate with the other tests, with the purpose of controlling for possible differences between the intervention and control groups. In a first step, composites were formed for the five groups of tests, and means and reliability measures for the composites are reported in Table 1. In a second step, latent variables of these concepts were formed to be used in the analyses, i.e. using structural equation modeling (SEM). Three separate SEM models were created to test the relations between RAN and phonemic awareness, and each of the tasks. These were, respectively, reading comprehension, reading speed and spelling. The tests included in the study are described below. Note that the reading comprehension tests at the follow-up were not the same as at the pre- and post-testing.

Phonemic awareness

Spoonerism This task was modelled after Perin (1983). It is a word game where the participant is asked to make the initial sounds of two words swap places, i.e. *nice garden* becomes *gice narden*. In this version of the task, six word pairs were presented orally. The words of each pair had a natural association, i.e. they occur together with high frequency in natural language. Accuracy and reaction times were recorded. The test used was specially developed for this study.

Table 1 Means (sd in brackets) of the composite scores for the control group (n=55) and the intervention group (n=57) at pre- post- and follow-up testing

	Pre-test		Post-test		Follow-up test	
	Control	Intervention	Control	Intervention	Control	Intervention
Spelling (alpha=.87)	16.9 (4.72)	16.7 (4.82)	18.6 (5.04)	19.9 (3.39)	21.9 (3.31)	22.6 (4.13)
Phonemic awareness (alpha=.70)	8.53 (4.34)	6.68 (3.98)	10.2 (4.04)	10.2 (4.66)	12.53 (3.85)	11.2 (4.76)
Reading comprehension (pre- post-; alpha=.65) (follow-up; alpha=.85)	16.8 (7.22)	16.0 (6.26)	22.7 (8.91)	24.4 (8.90)	20.5 (8.40)	22.4 (5.82)
Reading speed, words/min[a]	37 (19.8)	35 (20.8)	54 (24.4)	56 (24.1)	87 (4.02)	86 (3.44)
Rapid naming, rate[a]	76.3 (14.4)	81.2 (17.9)	–	–	64.2 (20.4)	59.4 (9.30)
Non-verbal IQ (alpha=.77)	24.2 (7.08)	24.0 (6.64)	–	–	–	–

[a] Alpha was not possible to calculate as the tests were speeded

Reversed spoonerism This task captures phonological skills with a more limited memory load. Two associated words were presented. However, already at the presentation the initial sounds are swapped (an equivalent in English would have been the word pair *red book* changed to *bed rook*). The task facing the child is to reconstruct the spoonerized word pair back into the original words. A total of six pairs were presented. Accuracy and reaction times were recorded. The test used was specially developed for this study.

Phonemic deletion The pupil was presented with a word orally by the test leader, and was then required to say the word with a designated phoneme omitted. The target word was a real word, e.g. *stay* without /t/ becomes *say*. The test used was specially developed for this study.

Reading comprehension

Pre- and post-tests: DLS, Diagnostiskt material för analys av läs- och skrivförmåga. Reading comprehension, grade 2 (Järpsten, 1999) This task captured the ability to read and understand connected text. Multiple-choice questions were interposed within the text. No time limit was imposed.

Reading comprehension (Lundberg, 2001) Short statements were presented, each with four alternative pictures. The task was to choose among the pictures and indicate which one corresponded to the statement. The distractor alternatives could, for example, illustrate a boy skating where the statement reads "The boy goes skiing." Working time was 10 min and the total score was the number of correct answers in the given time.

Follow-up tests: Seven passages from the IEA Reading Literacy Studies, carried out by The International Association for the Evaluation of Educational Achievement (IEA) in 1991 (Elley, 1992) The texts here were two narratives, four expository and two document texts (i.e. information in the form of maps, tables, graphs etc.), and ranged in length from 43 to 517 words. Each passage was followed by three to five multiple-choice questions.

Reading speed

Pupils read aloud two different texts. They were narrative passages used in the IEA Reading Literacy Studies carried out in Grade 3 (Elley, 1992). Rate was measured for each text, and was recorded as words per minute.

Word reading list The task was to read as many printed real words as possible within 60 s. Words were presented in vertical lists, and were not graded by difficulty. The test used was specially developed for this study.

Spelling

DLS, spelling test, grade 2 (Järpsten, 1999) The test administrator read aloud a short story with 20 embedded target words. After each target word, there was a pause, and the pupil was asked to spell the word. No time restriction was imposed, and accuracy was recorded.

Spelling, eight words The test leader dictated eight single words with varying complexity concerning for example clusters and phoneme/grapheme correspondence, which the pupils were required to spell. Accuracy was recorded. The test used was specially developed for this study.

DLS, spelling test, grade 3 (Järpsten, 1999) The test administrator read aloud a short story with 20 embedded target words. After each target word there was a pause, and the pupil was required to spell this word. No time restriction was imposed. Accuracy was recorded. This test was only used in the follow-up testing.

Rapid automatized naming, RAN

Object naming This task involved naming nine objects as quickly as possible. The objects were all very familiar, one-syllable words, presented in 9×5 randomly ordered arrays on a single page.

Letter naming This task involved naming nine consonant letters as quickly as possible. They were presented in 9×5 randomly ordered arrays on a single page.

Digit naming The task involved naming nine digits as quickly as possible. They were presented in 9×5 randomly ordered arrays on a single page.

The RAN tests were only administrated at the pre-test and the follow-up.

Non-verbal IQ

Standard progressive matrices A, B, C and D were performed (Raven, Raven, & Court, 2000). The non-verbal IQ test was administrated only at the pre-test.

Analytic procedure

Analysis of the data was carried out using SEM with the Mplus 6 program, used under the STREAMS modelling environment (Gustafsson & Stahl, 2005). As the sample size did not allow for multiple-group analysis, a one-group model was applied.

There are four main reasons for using this method of analysis in the present study, as compared to the more standard multiple regression analyses: (1) It allows for using measures on different scales at different time points, (2) as the manifest variables are not perfectly reliable, it is more appropriate using latent variables that only takes the common variance into account, (3) it allows for estimation of relations between multiple dependent variables, and (4) it allows for reciprocal effects. As noted earlier, RAN has appeared to be a stable skill, not possible to modify by training, and seems to predict different skills in different orthographies. In the current study, one aim was to analyze the predictive power of RAN and phonemic awareness on reading speed, spelling and reading comprehension in the transparent Swedish orthography. Another aim was to examine a possible reciprocal relationship between RAN and the three reading skills. A third aim was to examine the effects of the intervention. In order to systematically address these research questions, three different models were created. Each model comprised the three latent variables, phonemic awareness, RAN and non-verbal IQ, and, additionally, one of the other latent variables, reading comprehension, reading speed or spelling. RAN was measured at two points in time, at the pre-test and at the follow- up testing 1 year later. Non-verbal IQ was measured at the pre-test only. The remaining four latent variables were measured at all three time points; pre-, post- and follow-up testing. The latent reading variables at the pre-test and non-verbal IQ served as control variables.

The models will be reported with corresponding chi-square and degrees of freedom measures. Root Mean Square of Approximation (RMSEA) and confidence intervals will also be reported. To indicate good fit, the RMSEA estimate, and the upper range of its 90 % confidence interval, should be lower than .06 (Hu & Bentler, 1999) or .07 (Steiger, 2007). CFI should be close to .95 in combination with a SRMR value close to, or less than, .09 (Hu and Bentler, 1999).

Results

In this section, means and standard deviations for the control and intervention groups are presented (Table 1). The latent variables in the analyses are measured by sets of manifest variables. These sets are, in Table 1, collapsed into composite scores equivalent to the latent variables representing spelling, phonemic awareness, reading comprehension, reading speed, RAN and non-verbal IQ. Three measurement models with loadings of the manifest variables on the latent variables (Table 2) are reported. The three SEM models are depicted in Figs.1, 2, 3.

Table 2 Factor loadings of the manifest variables at pre- post- and follow-up tests

	Pre-test	Post-test	Follow-up test
Spelling	.772–.902	.634–.941	.647–.816
Phonemic awareness	.570–.750	.568–.870	.576–.960
Reading comprehension	.625– .691	.654–.746	.529–.713
Reading speed	.368–.947	.641–.984	.885–.823
Rapid naming	.444–.850	–	.242–.849
Non-verbal IQ	.566–.804	–	–

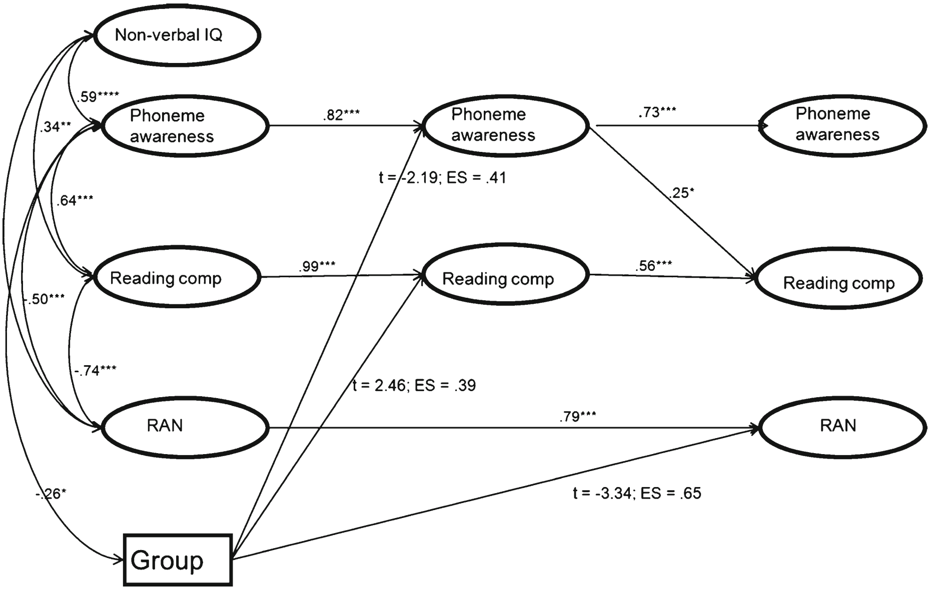

Fig. 1 Structural equation model with non-verbal IQ at the pre-test, RAN at the pre-test and the follow-up test one year later, phonemic awareness and reading comprehension at the pre-, the post-, and the follow-up test. Group condition, intervention or control, is included in the model. The significant correlations between the variables are shown in the figure. Note: *p<.05; **p<.01; ***p<.001

Confirmatory factor analyses

Three oblique, simple-structure, confirmatory factor analysis models were fitted to the data. The four latent variables in each model were related to their three to seven indicators (Table 2). The measurement models fitted the data well: Model 1 included non-verbal IQ, RAN, phonemic awareness and reading comprehension: (χ^2=66.615; *df*=60; RMSEA=.03; CI=.000–.068; SRMR=.057), Model 2 included non-verbal IQ, RAN, phonemic awareness and reading speed (χ^2=67.151; *df*=59; RMSEA=.04; CI=.000–.070; SRMR=.062), and Model 3 included non-verbal IQ, RAN, phonemic awareness and spelling (χ^2=65.223; *df*= 59; RMSEA=.03; CI=.000–.068; SRMR=.055).

Structural equation modelling

In order to investigate the effect of the reading intervention on reading comprehension and RAN, and the impact of phonemic awareness and RAN on reading comprehension and vice versa, the first of the SEM models was constructed. It included the latent variables non-verbal IQ, phonemic awareness, RAN and reading comprehension (Fig. 1). The model fitted the data well (χ^2=606.173; *df*=507; RMSEA=.04; CI=.027–.054; CFI=.93; SRMR=.068). The model was autoregressive, and latent variables at the pre-test were allowed to covary. The model included a dummy for group condition (intervention or control). Phonemic awareness and pre-test reading comprehension predicted phonemic awareness and reading comprehension, respectively, at the post-test, and they in turn predicted phonemic awareness and reading comprehension at the follow-up testing 1 year later. RAN at the pre-test predicted RAN at the follow-up test. The results also show that there was a significant effect of the intervention on

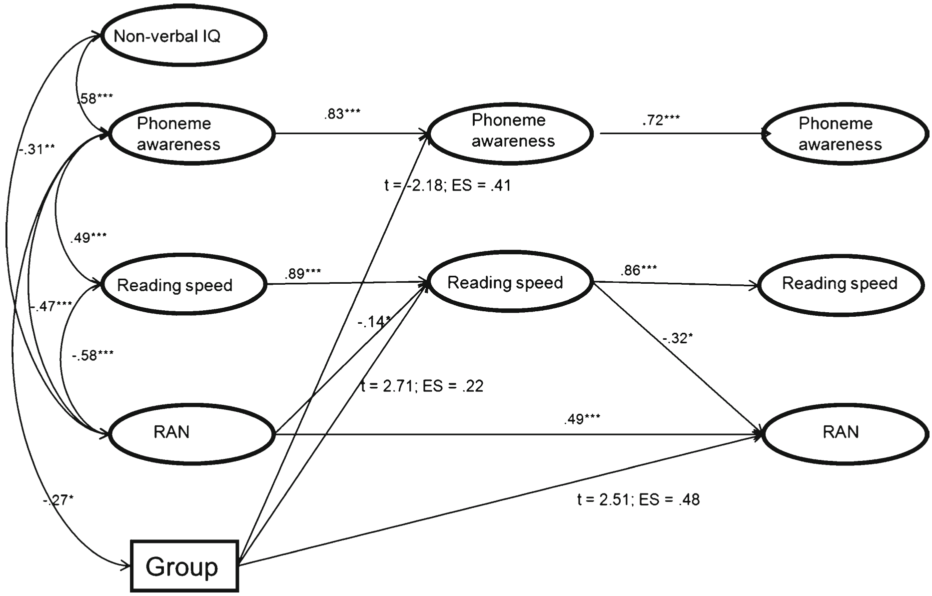

Fig. 2 Structural equation model with non-verbal IQ at the pre-test, RAN at the pre-test and the follow-up test one year later, phonemic awareness and reading speed at the pre-, the post-, and the follow-up test. Group condition, intervention or control, is included in the model. The significant correlations between the variables are shown in the figure. Note: *$p<.05$; **$p<.01$; ***$p<.001$

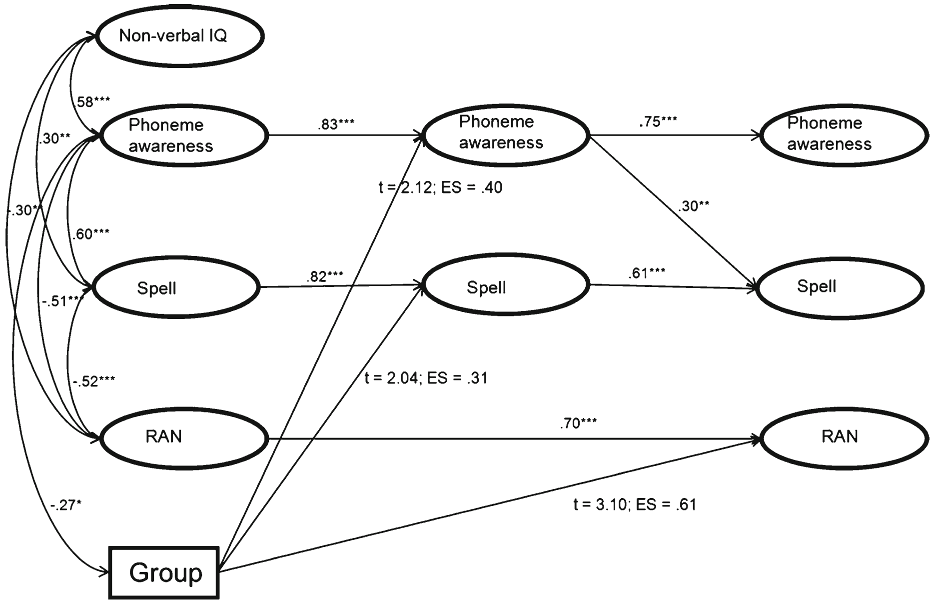

Fig. 3 Structural equation model with non-verbal IQ at the pre-test, RAN at the pre-test and the follow-up test one year later, phonemic awareness and spelling at the pre-, the post-, and the follow-up test. Group condition, intervention or control, is included in the model. The significant correlations between the variables are shown in the figure. Note: *$p<.05$; **$p<.01$; ***$p<.001$

both phonemic awareness (t=2.19; ES=0.41) and reading comprehension (t=2.46; ES=0.39) at the post-test in favour of the intervention group. There was also a significant effect of the intervention on RAN at the follow-up 1 year later (t=−3.34; ES=0.65), thus indicating that it is possible to enhance RAN by means of the intervention. Phonemic awareness at post-test predicted reading comprehension one year later. Non-significant relations are not included in Fig. 1. The results from this model could partly answer the first research question: reading comprehension can be predicted by phonemic awareness but not by RAN. The third research question could also be answered: it is possible to enhance RAN by intervention.

In Fig. 2, the second model is depicted. The effect of reading intervention on reading speed and RAN, and the impact of phonemic awareness and RAN on reading speed and vice versa, were investigated. The model fit was good (χ^2=463.963; df=354; RMSEA=.05; CI=.038–.065; CFI=.94; SRMR=.074). The autoregressive relations in the model were all significant, and there were significant effects of the intervention on phonemic awareness (t=2.18; ES=0.41) and reading speed (t=2.71; ES=0.22) at the post-test and on RAN (t=−2.51; ES=0.48) at the follow-up test. RAN at the pre-test predicted the post-test reading speed. The results also indicated a reciprocal relationship between reading speed and RAN, in that reading speed at the post-test predicted RAN at the follow-up. Non-significant relations are not included in Fig. 2. The results from this model could partly answer the first research question: reading speed can not be predicted by phonemic awareness but it can be predicted by RAN. The second research question could also be answered: the relationship between reading speed and RAN is reciprocal.

The third model (Fig. 3) included the variables non-verbal IQ, phonemic awareness, RAN and spelling. It fitted the data well (χ^2=478.439; df=383; RMSEA=.05; CI=.032–.060; CFI=.93; SRMR=.067). The autoregressive relations were significant and there were significant effects of the intervention on spelling (t=2.04; ES=0.31) and phonemic awareness (t=2.12; ES=0.40) at the post-test and on RAN (t=−3.10; ES=0.61) at the follow-up. Phonemic awareness at the post-test predicted spelling at the follow-up. Non-significant relations are not included in Fig. 3. By adding the results from the third model the research question 1 is answered: phonemic awareness, but not RAN, can predict spelling.

Discussion

The first aim of the current study was to examine the predictive power of RAN and phonemic awareness on reading, measured as reading comprehension, reading speed and spelling for children with reading difficulties. The second aim was to study a possible reciprocal relationship between RAN and reading skills, and the third aim was to study the possibility to enhance RAN by intervention. The results showed that it is possible to enhance RAN by training and that whereas RAN predicts reading speed, phonemic awareness predicts reading comprehension and spelling. The results also indicate a reciprocal relationship between reading speed and RAN.

As previously reported, the intervention comprised three main elements; the training of phonics, reading comprehension strategies and reading speed. Compared to the control group, these skills were significantly enhanced in the intervention group (Wolff, 2011). In an intervention study where RAN was explicitly trained, de Jong and Vrielink (2004) reported that they failed to enhance RAN. In the present study, RAN was not explicitly trained. Nevertheless, beyond the autoregressive effect, there was a medium strong effect (according to Cohen's convention, 1992) of the intervention on RAN at the follow-up. Thus, the question arises as to what RAN really represents. Why was it possible to improve RAN? Lundberg and Sterner (2006) have demonstrated that task orientation is a determinant of successful learning. It may also be a consequence of learning, which could be the case here. Thus, one possibility is that the improvement simply reflects the power of the training to mobilize cognitive courage or task orientation. On the other hand, the answer may be more specific than this, in that pre-test RAN predicted reading speed, but not reading comprehension or spelling at the post-test. Another possibility is the fact that the multicomponent feature of the intervention makes it possible to support the enhancement of various reading skills, including the speed factor. This would be in line with Wolf and Bowers' (2000) suggestion that students with a double deficit may be "treatment resistors", because they do not receive training directly aimed at both of their deficits.

As noted earlier in this paper, word reading is often measured by accuracy in deep orthographies. In transparent orthographies, accuracy measures easily reach ceiling because of the consistent phoneme/grapheme mapping, and reading is therefore more often measured by speed. In the present study, RAN and reading speed showed a bidirectional relationship, in that RAN predicted later improvement in reading speed, and improvement in reading speed predicted later improvement in RAN. We can thus conclude that the intervention effect found on RAN is consistent with the assumption of a bidirectional relationship between decoding skills (expressed as reading speed) and RAN (Compton, 2003). Further, the effect of RAN on reading speed, but not spelling, is consistent with the findings of Landerl and Wimmer (2008), as they in a longitudinal study from Grade 1 to Grade 8 found RAN to be the strongest predictor of reading speed. Moreover, the fact that phonemic awareness at the post-test predicted spelling at the follow-up test is similarly consistent with Landerl and Wimmer's findings that phonemic awareness, but not RAN, predicts spelling. Thus, the findings support that there is a bidirectional relationship between reading skills and RAN, and that in a transparent orthography phonemic awareness predicts spelling, in this case after improvement via the intervention. However, in contrast to most other studies, here it was shown that RAN was possible to modify by training, with a substantial effect still to be found 1 year after the intervention (Conrad & Levy, 2011; de Jong & Vrielink, 2004). This result is not simply a reflection of improved letter knowledge, because the RAN measures in the current study involved not only the naming of letters but also digits and objects.

One important finding, in accordance with that of Lervåg and Hulme (2009), was that RAN predicts reading speed. However, a number of the current findings diverge from Lervåg and Hulme's results, due perhaps to differences between the samples. In the Lervåg and Hulme study, normally developing children were followed from preschool to grade 4, whereas in the present study, children with identified reading problems were followed from grade 3 to grade 4. A reading intervention was performed in grade 3. While there was no evidence of a reciprocal relationship between RAN and reading speed among the typically developing children (Lervåg & Hulme, 2009), it was apparent among children with decoding deficiencies in the present study. After controlling for initial naming speed, reading speed, phonemic awareness and non-verbal IQ, post-test reading speed predicted RAN one year later. Based on the same sample as studied by Lervåg and Hulme (2009), Lervåg et al. (2009) found RAN to be a stronger predictor of reading among the poorer readers, which is in accordance with the review by Allor (2002) and the study by Kirby et al. (2003). This seems to be comparable to how phonemic awareness has been shown to cease as a predictor of reading in the second grade after controlling for initial skills (Lervåg et al. 2009), but seems to remain as a predictor among children and adults with reading difficulties (Wolff 2011; Wolff & Lundberg, 2003). An abundance of research has also shown that phonological awareness can be enhanced by structured training, and that reading and phonological awareness have a reciprocal relationship. These features, too, seem to be comparable to the nature of RAN according to the present study.

RAN and phonological awareness have both been investigated by brain-imaging studies. Such studies have found that object naming to some extent activates the same name retrieval and speech production area as reading aloud (Moore & Price, 1999; Price et al., 2006), and this may imply, according to Lervåg and Hulme (2009), that depending on the quality of the connections within this area (left mid-fusiform), RAN may reflect constraints on reading development. Phonological awareness and impaired reading have been subjected to research far more than RAN and reading, and several brain-imaging studies have been conducted. One example is that Pugh et al. (2000) demonstrated that another brain area active in reading, angular gyrus, is dysfunctional in dyslexic readers in tasks where substantial phonological assembly is required, i.e. when phonemic blending is involved. This is indeed a very interesting finding in that it shows that it is not an injury or global dysfunction, but a dysfunction in the context of phonology. We can conclude that there are convincing results from a broad range of research that RAN and phonological awareness are related to early reading development. They both tap some phonological processes in common with reading, and it may be reasonable to assume that RAN and phonological awareness share a number of common characteristics. The present results suggest a number of similarities and differences between RAN and phonological awareness, measured as phonemic awareness, in relation to the aims of the study. (1) These abilities predict different aspects of reading; RAN predicts reading speed, and phonemic awareness predicts spelling and reading comprehension. (2) RAN and phonemic awareness show the same pattern of a reciprocal relationship with reading. (3) RAN and phonemic awareness are both possible to enhance by training.

According to the findings in the present study, the relationship between reading speed and RAN seems to be comparable to the relationship between reading accuracy/spelling and phonemic awareness. Thus, even though phonemic awareness and RAN appear to have many features in common, they seem nevertheless to predict different aspects of reading. These findings may contribute to support the view that both phonology and RAN independently influence early phases of reading, in this case for older children with deficient word reading.

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