Abstract

A study of the concurrent relationships between naming speed, phonological awareness and spelling ability in 146 children in Year 3 and 4 of state funded school in SE England (equivalent to US Grades 2 and 3) is reported. Seventy-two children identified as having normal phonological awareness but reduced rapid automatized naming (RAN) performance (1 standard deviation below the mean) participated in the study. A group of 74 children were further identified. These children were matched on phonological awareness, verbal and non verbal IQ, and visual acuity but all members of this group showed normal rapid automatized naming performance. Rapid automatized naming made a significant unique contribution to spelling performance. Further analyses showed that the participants with low naming performance were significantly poorer spellers overall and had a specific difficulty in spelling irregular words. The findings support the view that rapid automatized naming may be indexing processes that are implicated in the establishment of fully specified orthographic representations.

Introduction

In this paper we address issues concerning the relationship between performance on rapid automatized naming (RAN) tasks and spelling ability when spelling words to dictation. This relationship has attracted far less attention from researchers than the parallel relationship between RAN performance and reading and yet it is reasonable to argue that the underlying cognitive processes that RAN may be indexing are equally as likely to influence ability to spell words accurately as they are to influence ability to read words accurately.

All current of models of skilled word spelling (Brown & Loosemore, 1994; Campbell, 1987; Caramazza, 1988; Ellis, 1989; Tainturier & Rapp, 2000) postulate the existence of two routes by which accurate spellings are produced.

In this paper, we investigate the potential influence of the underlying cognitive processes assessed in the RAN task on both these routes. One route, often referred to as an "assembled" route, operates by converting the sequence of phonemes in a word to a corresponding sequence of graphemes, which are then written down. The other route, often referred to as an "addressed" route, operates by holistic access to a stored orthographic representation of the word, which is then written down.

Research into spelling development has shown that ability to segment the word into its phonemic structure is crucial to the generation of a plausible spelling by the assembled route. For regular words, namely those which conform to the sound-spelling correspondences (i.e. feedback consistency) in English such as HEN, DOG, FREED, successful conversion from phonemes to graphemes will lead to accurate spelling. However, for irregular words, those which violate the sound-spelling correspondences (i.e. feedback inconsistency) in English like SAID, BREAD, WOMEN, spelling via the assembled route is likely to generate phonologically plausible errors such as SED, BRED and WIMMIN. Many such errors are produced in the early stages of learning to spell (Read, 1986), but even skilled adult spellers may continue to produce phonologically plausible errors when writing under stress (Wing & Baddeley, 1980). Poor phonemic awareness is likely to compromise the spelling of words via the assembled route (Stage & Wagner, 1992; Bruck & Treiman, 1990) because of a difficulty in identifying the component phonemes on which to map potential graphemes. Languages where the orthographies are more regular and more transparent than English, might be considered not to pose such great demands when children are learning to spell. However, in Turkish, an orthographic system which is highly transparent and consistent both from letter to sound and sound to letter, Grade 2 children, who reach ceiling on word reading accuracy, do not do so when spelling (Babayigit & Stainthorp, 2007). Thus even highly consistent transparent orthographies pose challenges for developing spellers.

Treiman's work on very early spelling development shows that phonological awareness is one of the two foundations on which spelling rests, the other being letter knowledge (e.g., Treiman, 1993). Young children's attempts to transcribe language into visual representations show that they do not behave randomly when writing in the early stages of literacy development (Read, 1986). Their insights into the phonological structure of words and how these phonological segments can be mapped onto letters play an important role. Thus, knowledge of the letters themselves is also essential. A recent study by Lervåg and Hulme (2010) of the development of spelling skills in children becoming literate in Norwegian, which has a consistent orthography, accords with Treiman's findings about the importance of both phonemic awareness and letter knowledge to later spelling performance. Treiman's work on children's over use of the letters (particularly initials) that occur in their own name when writing in the early stages illustrates this importance of letter awareness (e.g., Treiman & Broderick, 1998). However, Puranik, Lonigan and Kim (2011) in a study of preschool children found that letter-writing abilities made a significant unique contribution to the prediction of spelling when both letter-writing and name-writing skills were considered together. They argued that name-writing reflects limited knowledge of the letters in a child's name rather than the broader knowledge of letters found in letter-writing skills that may be needed to support early spelling development. In other words, the more letters children could write, the better were their spelling skills.

Development of an addressed route to spelling is particularly important in a language such as English with a deep opaque orthography, which is characterized as being morphophonemic, but which also has a high degree of irregularity and inconsistency. Here, ability to establish fully specified orthographic representations of words, given knowledge of letters of the alphabet, is likely to facilitate word spelling and support the growth and extension of a comprehensive orthographic lexicon. Conversely, where the ability to establish orthographic representations is compromised, accurate spelling may be deficient. This is likely to be the case particularly for irregular words, which by definition, cannot be accurately spelled by an assembled route using sound-letter correspondences.

This complex orthography makes English a particularly challenging language in which to develop accurate spelling skills (see Nunes & Bryant, 2009). Potentially, regular words could be spelled either by an assembled route, or, once an orthographic representation had been established in the lexicon, by an addressed route. In this sense, for regular words, the establishment of the orthographic representation is optional. However, this is not the case for irregular words. These require the establishment of accurate orthographic representations which need to be accessed if they are to be spelled correctly.

Using the models of word spelling as a framework, it is possible to argue that the development of accurate spelling ability is dependent to some extent on the aspect of phonological awareness that enables children to segment words into their component phonemes and to map these onto graphemes as quickly and accurately as possible. This means they need to be phonemically aware and to have accurate knowledge of the individual letters. Thus, any deficit in accuracy or speed in processing either phonemes or letters has the potential to compromise accurate word spelling. However, certainly in English, children need to be able to build up accurate orthographic representations of words. This is likely to be particularly true of those words that do not conform to regular phoneme-grapheme correspondences. Any deficits in the processes that underlie this ability are therefore also likely to compromise accurate word spelling.

Why might performance on RAN tasks impact on spelling? In order to begin to answer this question we first need to rehearse what is known about the relationship between RAN and reading.

RAN tasks require individuals to name as quickly as possible a small set of familiar items, for example 6 items repeated 6 times in random order in a linear matrix. There is now strong evidence that a significant relationship exists between performance on rapid automatized naming (RAN) tasks and word reading (Blachman, 1984; Bowers, 1995; Bowers & Swanson, 1991; Cutting & Denckla, 1999; de Jong & van der Leij, 1999; Denckla & Rudel, 1974, 1976; Georgiou, Parrila, & Kirby, 2006; Kirby, Parrila, & Pfeiffer, 2003; Scarborough, 1998; Schatschneider, Fletcher, Francis, Carlson, & Foorman, 2004; Spring & Capps, 1974; Van den Bos, Zijlstra, & Spelberg, 2002).

This relationship is observed to hold across a range of alphabetic orthographies: for example Dutch (de Jong & ven der Leij, 2003; Vaessen, Bertrand, Tóth, Csépe, Faísca, et al., 2010; Verhagen, Aarnoustse, & van Leeuwe, 2010), German (Wimmer, 1993; Wimmer, Mayringer, & Landerl, 2000), Greek (Nikolopoulos, Goulandris, Hulme, & Snowling, 2006; Georgiou, Parrila & Papadopoulos, 2008), Hungarian and Portuguese (Vaessen et al., 2010) and Italian (Di Filippo et al., 2005), and non-alphabetic orthographies such as Chinese (Pan, McBride-Chang, Shu, Liu, Zhang, & Li, 2011; Tan, Spinks, Eden, Perfetti & Siok, 2005). Typically the items are letters, digits, colours or pictures of nameable objects. Performance on alphanumeric RAN tasks is generally found to correlate more highly with reading than performance on colour or object naming (Bowey, McGuigan, & Ruschena, 2005; Wolf, Bally, & Morris, 1986). Letters and digits each form a small discrete set of unambiguously nameable stimuli, whereas colours and particularly objects are drawn from a large open set with items that potentially have different labels. Thus, alphanumeric RAN tasks are different in kind from those for colours and objects. However, when investigating the performance of preliterate children, colour and object naming tasks have to be used because they are unlikely to reliably know the names of letters and numbers consistently (e.g., Lervåg & Hulme, 2010).

Since there is evidence that phonological awareness correlates highly with word reading across a wide range of ability from disabled through to exceptionally able early readers (e.g., Jorm & Share, 1983; Share, 1995; Snowling, 1991; Stainthorp & Hughes, 2004;

Wagner & Torgesen, 1987), for some researchers, the relationship between RAN and reading arises because RAN performance is deemed to be an index of phonological processing (Torgesen, Wagner, Rashotte, Burgess, & Hecht,1997). Torgesen and colleagues argue that this relationship arises because RAN tasks measure the rate that individuals can access the phonological information stored in long term memory.

However, for others, the relationship between RAN and reading arises in part from factors independent of the phonological component of RAN performance (Conrad & Levy, 2007; Georgiou, Parrila, Kirby, & Stephenson, 2008; Kirby, Parrila, & Pfeiffer, 2003; Powell, Stainthorp, Stuart, Garwood, & Quinlan, 2007; Wolf, 1991; Wolf & Bowers, 1999). Swanson, Trainin, Necoechea, and Hammill (2003) found that phonological awareness correlated only modestly with performance on RAN tasks at .30. Powell et al. (2007) reported similar findings with RAN correlating .30 with phoneme elision and .19 with phoneme blending. This suggests that, though there is undoubtedly a phonological component to RAN performance, it also recruits other processes which are distinct. Manis, Seidenberg, and Doi (1999) and Wolf and Bowers (1999) propose that RAN performance may be tapping ability to form orthographic representations of words. If this is the case then, beyond the impact of RAN performance on word reading, it may impact on spelling ability, since spelling by the addressed route is dependent on accessing orthographic representations.

Stainthorp, Powell, Stuart, Quinlan, and Garwood (2010) found that children who had unimpaired phonological awareness, but whose alphanumeric RAN performance was more than one standard deviation below the mean, were significantly slower to discriminate between very simple visual stimuli such as lines of different orientations and open or closed curves relative to children with whom they were matched on phonological awareness but who were unimpaired on the RAN tasks. These stimuli are the fundamental stroke elements that make up letters (Boles & Clifford, 1989; Geyer, 1977; Geyer & DeWald, 1973; Gibson, 1969, Gibson, Osser, Schiff, & Smith, 1963; Mueller & Weidemann, 2012). The children with slower RAN performance did not differ in terms of accuracy, only speed. Kail, Hall, and Caskey (1999) have argued that individual differences in naming speed are related to a general speed of processing deficit. However, Stainthorp et al. (2010) showed that the children with slower RAN performance were not slower when performing an auditory discrimination task analogous to the visual discrimination task, which would suggest that RAN tasks are not simply indexing general speed of processing.

Investigation of the relations between phonemic awareness and development of word reading skills has also been extended to spelling development (Bruck & Treiman, 1990; Frith, 1985; Stage & Wagner, 1992; Treiman, 1993). However, given the wealth of research on RAN in the domain of reading, there has until very recently been surprisingly little published literature about the potential relationship between individual differences in RAN and word spelling.

This has been investigated in English by a number of researchers (e.g. Georgiou, Torppa, Monolitsis, Lyytinen, & Parrila, 2012; Savage & Fredrickson, 2006; Savage, Pillay, & Melidona, 2008; Smythe et al., 2008; Sunseth & Bowers, 2002), who have reported that RAN is an independent predictor of word spelling. Furthermore, Amtmann, Abbott and Berninger (2008) suggested that poor RAN performance may well be a marker of children who responded more slowly to instruction in spelling in English.

The relationship has also been investigated in the more transparent languages of Dutch (e.g., Verhagen, Aarnoutse, & Leeuwe, 2010), Finnish (e.g., Torppa, Georgiou, Salmi, Eklund, & Lyytinen, 2012), German (e.g., Moll, Fussenegger, Willburger, & Landerl, 2009; Landerl & Wimmer, 2008), Greek (e.g., Nikolopoulos et al., 2006), Norwegian (e.g., Lervåg & Hulme, 2010), and Turkish (e.g., Babayigit & Stainthorp, 2010); and cross-linguistically by Furnes & Samuelsson (2010, 2011), Georgiou et al. (2012), and Smythe et al. (2008). The picture that emerges, however, is far from clear.

Lervåg and Hulme (2010) found that non alphabetic RAN measured before the start of literacy instruction in Norwegian children made a unique contribution to spelling fourteen months later when the children had begun to receive literacy instruction. Verhagen et al. (2010) showed that initially, for children learning to read and spell in Dutch, phonemic awareness was a stronger predictor than naming or vocabulary. However, by Grade 2 phonemic awareness and rapid naming made equally strong and unique contributions to word spelling. This finding could be accounted for by RAN indexing processes which support the establishment of orthographic representations of words. With similar age children, Furnes and Samuelsson (2010) found that phonological awareness and RAN were independent significant predictors of spelling difficulties in both an English language sample and children in Sweden and Norway becoming literate in more transparent orthographies. Subsequently they reported from the same study (Furnes & Samuelsson, 2011) that RAN was more related to reading than spelling across the orthographies.

Babayigit and Stainthorp (2010) found that RAN performance failed to predict any reliable variance in spelling skills in Grades 1 and 2 (aged between 6 and 7 years) in a group of children becoming literate in Turkish, which has one of the most transparent, consistent and symmetrical[i] alphabetic orthographies. A similar result was reported by Nikolopoulos et al. (2006) for Greek, and by Landerl and Wimmer (2008) for German. Moll, Fussenegger, Wilburger, and Landerl (2009) conducted a study investigating, among other things, the contribution of RAN to spelling in German in three samples of older children aged 10 and 11 years. They found that in this asymmetric orthography, phonological awareness explained more variance in spelling than RAN. Torppa et al. (2012) found that a RAN deficit predicted spelling difficulties in Finnish children after Grade 1. However, a further cross-linguistic study by the same group (Georgiou et al., 2012) found that RAN only predicted spelling in Greek and English and not in Finnish in typically developing children. The cross linguistic study by Smythe et al. (2008) involved five different language groups, namely: Arabic, Chinese, English, Hungarian and Portuguese. They found a complex pattern of predictors of both reading and spelling with RAN only predicting unique variance in spelling for English and Hungarian. Their findings did not follow the prediction that the influence of RAN on spelling would be observed more in inconsistent orthographies since Hungarian was the most consistent alphabetic orthography they studied and English was the least consistent.

We therefore now turn directly to the question we posed earlier: Why might performance on RAN tasks impact on spelling?

If, as Stainthorp et al. (2010) propose, weak RAN performance is an index of compromised ability to identify letters as visual entities at speed, the processing involved in letter identification could well be a barrier to establishing efficient word spelling skills. This could be because poor ability to identify individual letters as visual entities would have the effect of compromising capacity to establish accurate orthographic representations of words. This accords with the proposal by Manis et al. (1999) and Wolf and Bowers (1999) that the non phonological processes indexed by RAN influence the ability to form orthographic representations of words.

As we have argued above, English is a particularly challenging orthography for developing accurate spelling skills. Regular words could be spelled by an assembled route, but irregular words require the establishment of accurate orthographic representations to be accessed if they are to be spelled correctly. This requires accurate letter knowledge. However, even for regular words, poor speeded letter knowledge potentially poses problems for spelling since the slowness increases the demands on working memory.

If RAN is an index of processing in the central nervous system, which is at least partially independent of phonology (e.g., Powell et al., 2007; Wolf, Bowers, & Biddle, 2000), and which is specifically involved in the accurate and efficient establishment of the orthographic information of words (e.g., Manis, Doi, & Bhadha, 2000; Wolf & Bowers, 1999), a consequence would be that individual differences in the non phonological processes underlying RAN performance would be specifically reflected in ability to spell irregular words. Spelling can be considered to be a more sensitive measure of the quality of orthographic representations because there is no room for approximation.

This study was therefore designed to investigate the following hypotheses:

1) that RAN performance makes a specific contribution to spelling ability over and above the contribution of phonological awareness and phonological memory.

2) that weakness in RAN performance will impact on ability to spell irregular words in English.

The method chosen to investigate these hypotheses was to select a criterion group of children who were identified as having a weakness in RAN performance but no weakness in phonological awareness, and to match these children pair-wise with a group who showed no weakness in RAN performance but who were carefully matched on cognitive abilities, age, and importantly on phonological awareness and phonological memory.

Method

Participants

To select criterion groups for a study of the impact of low RAN performance in the absence of a phonological deficit on aspects of literacy, the Comprehensive Test of Phonological Processing (CTOPP; Wagner, Torgesen, & Rashotte, 1999) and the British Ability Scales Word Reading Test (Elliot, Murray, & Pearson, 1983) were administered to a total of 1,010 children in Years 3 and 4 in nine state-funded primary schools in an urban area to the west of London, UK (Powell et al., 2007). On the basis of performance on the CTOPP, 154 pupils were chosen to form two criterion groups: a Low RAN group and a matched Control group. Of these, 146 (72 Low RAN and 74 Controls) were available to take the spelling test which forms the basis of this paper. All the pupils were receiving their education in mainstream classrooms.

The RAN letters and RAN digits subtests from the CTOPP were administered to assess naming speed. Both of these subtests require participants to name as quickly as possible two 4 x 9 arrays containing repetitions of either six letters or six digits. Phonological awareness (PA) was assessed using the elision and blending subtests of the CTOPP. Elision requires the participant to say out loud the word that results from the deletion of a designated sound (e.g., “Say *cup* without saying /k/”). Blending requires the participant to combine a sequence of discrete phonemes to form a word (e.g., “What word do these sounds make? / m/- /ă/ -/d/”). Phonological memory (PM) was assessed using the memory for digits subtest and the nonword repetition subtest. The CTOPP manual gives procedures for calculating composite scores for each of RAN, phonological memory and phonological awareness by summing the standard scores for the two measures of each construct. However, because the instrument was not standardized on a UK population composite scores for RAN, PM and PA were calculated by summing the raw scores rather than the standard scores.

The participants in the Low RAN group were identified as having a RAN deficit (defined as RAN performance of at least 1 standard deviation below the mean of the original population of 1,010 pupils) and normal phonological awareness (defined as performance not less than 1 standard deviation below the mean of the original population of 1,010 pupils). The Control group was selected to show normal phonological awareness as defined above and normal RAN performance (defined as scores not less than 1 standard deviation below the mean of the original population of 1,010 pupils). In addition, each child in the Control group was selected as a match for a Low RAN child on the basis of age, verbal, and nonverbal ability as measured respectively by the Vocabulary and the Block Design subtests of the Wechsler Intelligence Scale for Children and for visual acuity as measured by the Freiburg Visual Acuity Test (Bach, 1996).

There were 146 participants available to take part in this current study which was conducted when they were in school years 4 and 5 (pupils reach their ninth birthday in Year 4 and their tenth birthday in Year 5). There were 72 participants from the original Low RAN group and 74 from the Control group available to take the spelling test. There were five children unavailable from the original Low RAN group and three unavailable from the original Control group. The lack of their data did not affect the overall matching of the groups on the baseline data. The mean age of the participants was 8 years 5 months (range

8 years 2 months to 10 years 5 months) with the mean age of the Low RAN group being 110.8 months and the mean age of the Control group being 111.2 months.

Full ethical procedures to gain informed consent and to safeguard anonymity were followed.

Table 1 shows the mean performance of the two groups on the initial assessments. These data were analysed using independent *t* tests to verify the accuracy of the matching procedure. No significant differences were found between groups on any of these control measures. As expected, there were differences on British Ability Scales word reading test ($t(144) = 3.28$, $p < .001$) with control children scoring significantly higher than the Low RAN children. This test assesses single word reading accuracy without any time constraints.

Insert Table 1 about here

Materials and Measures

For this study, in order to assess spelling performance, the Young Parallel Spelling Test (Young, 1998) was administered in addition to the assessments that had been used to select the criterion groups. The Young test is a closed test so it is inappropriate to publish the items. However, words such as DRINK would be categorized as regular for spelling, and MONTH would be categorized as irregular for spelling (spelling via the assembled route could result in MONTH being spelled as MUNTH). Of the 46 items in the test, 32 are regular and 14 are irregular. The psycholinguistic characteristics of word length, word frequency, bigram and trigram frequencies and age of acquisition were calculated for each word using the NWatch software (Davis, 2005). Mann-Whitney *U* tests were conducted on the data for each of these characteristics. There were no significant differences between the two types of words on any of the characteristics. These data are presented in Table 2.

Insert Table 2 about here

Procedure

The spelling test was administered as prescribed in the manual on a group basis. All children were given the opportunity to attempt every test item. Accuracy scores were recorded. Additionally, since we had hypothesized that the Low RAN group would have a specific difficulty in spelling irregular words relative to spelling regular words we calculated the number of regular and irregular words correctly spelled separately. The percentages of correctly spelled regular words and irregular words were then computed.

Results

Performance data for spelling accuracy (percentage correct) and the percentage of regular words correct and irregular words correct are presented in Table 3.

Insert Table 3 about here

In order to investigate the first hypothesis, we first investigated the correlations between spelling, phonological awareness, phonological memory, RAN and age. Table 4 shows the correlation coefficients between the variables.

Insert Table 4 about here

Phonological awareness and RAN correlated highly with spelling, but there was a more modest correlation between phonological memory and spelling. The three scales of the CTOPP were not significantly correlated with each other. Partial correlation was used to explore the relationship between RAN and spelling, while controlling for phonological awareness. There was a strong correlation, $r = -.50$, $df = 143$, $p < .001$ with more accurate spelling being associated with faster naming speed. Inspection of the zero order correlation between RAN and spelling ($r = -.46$) suggested that controlling for phonological awareness had very little effect on the strength of the relationship between RAN performance and spelling.

Hierarchical multiple regression analysis was then used to assess the ability of RAN to predict spelling after controlling for the influence of phonological awareness (see Table 5). As inspection of the correlation matrix revealed that the two independent variables of age and phonological memory had correlations below .3 with spelling, these were not entered into the regression analysis.

Insert Table 5 about here

The composite scores for phonological awareness were entered at Step 1. This accounted for 21% of the variance. After entry of the composite scores for RAN at Step 2 the model as a whole accounted for 41% of the variance. In the final model both phonological awareness ($\beta = .46$, $p < .001$) and RAN ($\beta = -.44$, $p < .001$) were statistically significant.

In order to investigate the second hypothesis an independent *t* test was conducted to investigate whether the children in the Low RAN group were significantly worse spellers on the full spelling test than the control children (see Table 3). There was a significant difference between the two groups, $t(144) = 4.01$, $p < .001$, $\eta^2 = .10$. Because of the known relationship between word reading and spelling, additionally an ANCOVA was conducted on the data with BAS word reading scores entered as the control variable. After further controlling for word reading there was a reduced but still significant difference between the two groups $F(1,143) = 3.86$, $p = .05$, $\eta_P^2 = .03$.

In order to investigate the hypothesis that RAN performance is related to the development of the orthographic lexicon we conducted a more detailed analysis of the spelling performance by comparing the percentage of correct spellings of regular and irregular words for each group. These percentage correct scores were subjected to a two factor ANOVA with word type (regular and irregular) as the within group variable, and group as the between group variable. This showed that there was a significant main effect of group, $F\ (1,144) = 16.31$, $p < .001$, $\eta_P^2 = .10$; a significant main effect of word type, $F\ (1,144) = 584.96$, $p < .001$, $\eta_P^2 = .80$; and a significant interaction between word type and group, $F\ (1,144) = 7.28$, $p < .01$, $\eta_P^2 = .05$. Both groups were less accurate when spelling irregular words, but the interaction can be explained by the difference between regular and irregular words being greater for the Low RAN group than for the Control group.

Finally we investigated correlations between spelling regular and irregular words, phonological awareness and RAN for each group separately (see Table 6) prior to conducting a series of four hierarchical regression analyses to examine the extent to which phonological awareness and RAN explained individual differences in Low RAN and Control participants' spelling of regular and irregular words. For the Low RAN group there was a modest significant correlation between RAN and regular word spelling ($r = -.25$) but the correlation between RAN and irregular words ($r = -.21$) just missed significance. For the Control group, RAN correlated significantly with both regular words ($r = -.42$) and irregular words ($r = -.50$).

Insert Table 6 about here

Table 7 shows the summary of the results of the regression analyses for each group. In each case the composite score for phonological awareness was entered at Step 1 and RAN was entered at Step 2.

Insert Table 7 about here

For the Low RAN group, RAN did not contribute to spelling either regular or irregular words. In each case it was only phonological awareness that contributed significantly to spelling both regular and irregular words. The model explained 27% of the variance for regular words with phonological awareness recording a beta value of .48, $p < .001$. The model explained 24% of the variance for irregular words with phonological awareness recording a beta value of .47, $p < .001$.

However, for the Control group both RAN and phonological awareness made significant unique contributions to regular and irregular word spelling. The model explained 29% of the variance for regular words with phonological awareness recording a beta value of .38, $p < .01$, and RAN recording a beta value of -.38, $p < .001$. The model explained 33% of the variance for irregular words with phonological awareness recording a beta value of .35, $p < .01$, and RAN recording a higher beta value of -.47, $p < .001$.

Discussion

This study was designed to shed further light on questions about the contribution that RAN performance makes to word spelling and whether individual differences in RAN impact differentially on the spelling of regular and irregular words in English.

The first set of analyses investigated the patterns of performance of the whole group of children. The pattern of correlations and the first regression analysis suggest that RAN performance predicts unique variance in word spelling. This accords with the findings of Furnes and Samuelsson (2010), Savage et al. (2008) and Verhagen et al. (2010). Together with the findings that RAN and phonological awareness scores did not correlate significantly, we would argue that there are processes driving RAN performance which are important for accurate word spelling and which are separate from phonological processes.

The comparison of the performance of the two groups showed that the Low RAN group were significantly worse spellers overall than the Control group. Given that the Low RAN children had been carefully matched with the Control group on phonological awareness, cognitive measures and age, we can begin to suggest that the cognitive processes underlying RAN might be compromising the establishment of efficient spelling skills. Sunseth and Bowers (2002) and Wolf et al. (2000) argue that it is these processes indexed by RAN, which support the establishment of the orthographic representations of words; and it is these representations to which spellers need fast access in order to spell accurately. This difference between the two groups was still evident after controlling for the differences in word reading. This suggests that there is something beyond word reading that is compromising spelling performance. Nevertheless, we cannot totally discount the possibility that the Low RAN group's poorer spelling skills could arise from the fact that they would be likely to have had less exposure to print and therefore less opportunity to develop orthographic representations (Cunningham & Stanovich, 1998). Under these circumstances, the poorer spelling of the Low RAN group could be an indicator of the poor quality of the orthographic representations (c.f. Perfetti, 2011) with a cause other than the processes underlying RAN.

To consider this further we now turn to the analyses examining the patterns of performance of the two groups when spelling regular and irregular words. The proposal that RAN performance may be an index of processes that support the establishment of accurate orthographic representations of words is supported by the interaction observed between the groups and word type. Both groups were significantly less accurate when spelling irregular words. This suggests that these words were in some way harder to spell even though they were not different in terms of the psycholinguistic variables of length, word frequency (both spoken and written) and bigram and trigram frequency. The models of spelling discussed above suggest that regular words could be spelled either by the assembled route or by the addressed route, if orthographic representations had been established, whereas irregular words require orthographic representations because they can only be accurately spelled via the addressed route. Under these circumstances, given that the two types of words did not different in the psycholinguistic characteristics measured, the difficulty the irregular words posed for the children might be because generating an accurate spelling was dependent entirely on the establishment of the orthographic representation with no potential augmentation from the assembled route, whereas accurate spelling of a regular word could recruit information about phoneme-grapheme correspondences from this route.

The interaction between group and word type in the ANOVA showed that the children with weak RAN performance were even less accurate when spelling irregular words. This would suggest that, if as Wolf et al. (2000) argue that the non phonological processes indexed by RAN support the establishment of orthographic representations, where RAN performance is weak, establishing these representations becomes compromised and therefore spelling via the addressed route, a requirement for irregular words, will be less accurate.

The series of hierarchical multiple regression analyses carried out separately on the data from each group lends support to this interpretation. Taking the Control group first, both phonological awareness and RAN contributed to regular word spelling. Phonological awareness and RAN also contributed significantly to irregular word spelling, but the beta value for RAN was greater than for phonological awareness. This group of children had no deficits in either phonological awareness or RAN. We argue that they were had been able, and would continue to be able to recruit the non phonological processes underlying RAN to support the establishment of orthographic representations which enabled them to spell via the addressed route as well as using their phonological awareness to spell via the assembled route.

The regression analyses on the data from the Low RAN group revealed that RAN did not contribute to individual differences in spelling either the regular or the irregular words by these children. They all had weak RAN performance but no deficits in phonological awareness. The data suggest that they were more reliant on the assembled route to spelling. The deficit in the processes indexed by RAN which support the establishment of orthographic representations would compromise spelling in general, but differentially affect irregular words.

Stainthorp et al. (2010) found that the children with a RAN performance deficit were significantly slower to process the basic stimuli that make up letters. They argued that this is likely to have a negative effect on decoding of words for reading because it would make it slower and more effortful. However, when spelling words, a consequence of this deficit leading to slower and more effortful processing of letters as indexed by RAN could explain the difficulty in establishing orthographic representations thereby compromising the development of appropriately accurate word spelling skills relative to children with the same level of phonological awareness but no RAN deficit.

This interpretation is consistent with research that reports different relationships between RAN and spelling depending on the level of consistency of the alphabetic orthography. With consistent orthographies such as Finnish (Georgiou et al., 2012), German (Landerl & Wimmer, 2006) and Turkish (Babayigit & Stainthorp, 2010) RAN was found not to predict unique variance in spelling. However, in the present study and in that reported by Savage, Pillay and Melidona (2008), all the children were spelling words in a very inconsistent orthography and RAN predicated significant unique variance in spelling over all. This relationship was also reported for Dutch (Verhagen et al., 2010) and Greek (Georgiou et al., 2012). In these orthographies accurate spelling may be more reliant on well specified orthographic lexical representations, the development of which may be compromised when the cognitive processes underlying RAN performance are weak. However, this account should be treated with caution at this stage because the cross linguistic study reported by Smythe et al. (2008) presents a more confusing picture with RAN accounting for unique variance in spelling in English and Hungarian but not in Portuguese, Arabic or Chinese.

The participants who took part in this study were all in mainstream classrooms and the study was not designed to answer questions about the nature of dyslexia directly. However, the double deficit theory of dyslexia proposes that RAN indexes processes that are independent of phonology and these data lend further weight to this view.

A limitation of this study is that the spelling data relate only to performance on words from a standardized spelling test. Having identified, as hypothesized, that the Low RAN group had specific difficulty spelling irregular words, further research is indicated to investigate performance when spelling not just the different types of English words including regular and irregular words such as included in this study, but also polymorphemic words with different types of affixes (Nunes, Bryant, & Bindman, 1997). Additionally, a stronger test of the degree to which RAN impacts lexical processes specifically would be to include pseudoword spelling (see Savage et al., 2008).

As is typical with standardized spelling tests, the participants wrote down the words to dictation. Further studies are needed where spelling data is generated from other tasks such as error detection and correction, and supplying words to definitions. Such tasks would lead to data generated without any phonological input to elicit the word. The recruitment of software to analyse speed of generation of letters and letter clusters could also help to advance understanding of how the representations are specified in the lexicon.

Conclusion

This study has provided support for the view that performance on rapid automatized naming tasks indexes processes which are in part independent of phonology. It was hypothesized that these processes are recruited to establish fully specified orthographic representations of words in an orthographic lexicon. As such, individual differences in the processes underlying RAN are likely to manifest themselves in individual differences in spelling words. The finding that children with weak RAN performance were significantly poorer on a standardized spelling test confirmed this hypothesis. The additional, detailed analysis comparing accuracy levels when spelling regular versus irregular words lends further support to the view that the processes that are recruited to perform RAN alphanumeric tasks may be implicated in the establishment of fully specified orthographic word representations.

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Table 1

Mean (and Standard Deviation) Composite Raw Scores on Phonological Awareness (PA), Phonological Memory (PM) and RAN Core Subtests of the CTOPP, Chronological Age, Scaled Scores on the Block Design and Vocabulary Subtests of the WISC IIIR, and BAS Word Reading Standard Scores for Low RAN and Control Groups with *t* Values from Independent *t* Tests (2-tailed) Comparing the Group Performances.

	Low RAN (*n* = 72)	Controls (*n* = 74)	t value
PA (composite raw score)	20.42	20.14	.35 NS
	(4.83)	(4.79)	
PM (composite raw score)	19.83	19.47	.63 NS
	(3.73)	(2.85)	
RAN (composite raw score in secs.)	110.60	74.59	14.73**
	(17.07)	(12.13)	
WISC-IIIR			
Block Design (s.s.)	9.14	8.41	1.05 NS

	(4.01)	(3.71)	
Vocabulary (s.s.)	11.04	10.46	1.06 NS
	(3.45)	(3.21)	
BAS Word Reading (s.s.)	126.86	142.68	3.28*
	(31.95)	(26.13)	
Visual acuity	17.82	17.52	.04 NS
	(5.89)	(4.67)	

Table 2

Median Characteristics of the Regular and Irregular Words from the Young Parallel Spelling Test with the *U, z* and Probability Values from Mann-Whitney U Tests Comparing the Characteristics of each Word Type.

	Regular Words (*n* = 32)	Irregular words (*n* = 14)	*U*	*z*	*p*
Word length	5	6	157.00	-1.62	.11
Celex word frequency (COBUILD)	61.98	55.79	207.00	-.41	.69
Celex written word frequency (COBUILD)	62.65	57.75	206.00	-.43	.67
Bigram frequency	1651.84	860.41	150.00	-1.64	.10
Trigram frequency	434.57	140.44	109.00	-1.79	.76
Age of Acquisition	309.50	272.00	56.00	-.44	.66

Table 3

Means (and Standard Deviations) of the Percentage of Words Spelled Correctly on the Full Test, the Percentage of Regular and Irregular Words Spelled Correctly by Each Group.

	Percentage of words spelled correctly (full list)	Percentage of regular words spelled correctly	Percentage of irregular words spelled correctly
Low RAN group (*n* = 72)	50.45 (17.04)	60.90 (15.29)	23.50 (23.80)
Control group (*n* = 74)	62.51 (19.23)	70.64 (16.56)	40.75 (22.89)

Table 4

Pearson Correlation and Partial Correlation Matrix Among the Comprehensive Test of Phonological Processing Measures of Phonological Awareness, Phonological Memory, RAN, Word Spelling, and Word Reading (raw scores) and Age (*N* = 146)

	1	2	3	4	5	6	7	8
1. Phonological awareness	-	.09	-.05	.46***	.40***	.37***	.43***	-.04
2. Phonological memory		-	-.11	.17*	.16*	.10	.17*	.22**
3. RAN		-.11	-	-.46***	-.42***	-.44***	-.49***	-.29**
4. Young spelling		.15	-.50***	-	-%	-%	.81***	.22**
5. Regular word spelling		.14	-.44***	-%	-	.82***	.76***	.20**
6. Irregular word spelling		.08	-.46***	-%	.79***	-	.70***	.22**
7. BAS Word Reading		.14	-.52***	.77***	.71***	.65***	-	.28**
8. Age		.23**	-.29***	.27**	.24**	.25**	.32***	-

Note. Bivariate correlations are shown above the diagonal and partial correlations controlling for phonological awareness are shown below the diagonal.

% bivariate and partial correlations between Young spelling score and both regular and irregular word spelling scores are not shown because of the statistical confound arising from the fact they are subsets of the overall score.

**p* <.05; ***p* < .01; ****p* < .001

Table 5

Hierarchical Regression Analyses Predicting Performance on the Full Spelling Test from Phonological Awareness and RAN.

	Word Spelling	
Predictor	ΔR^2	β
Step 1	.21***	
Phonological awareness		.46***
Step 2	.19***	
RAN		-.44***
Total R^2	.41***	
N = 146		

*** p < .001

Table 6

Summary of the Zero Order Pearson Correlations for the Scores on Regular and Irregular Word Spelling, Phonological Awareness and RAN. Low RAN Group (*n* = 72) and Control Group (*n* = 74) Data are Shown Above and Below the Diagonal Respectively.

Measure	*1*	*2*	*3*	*4*
1. Regular words	-	.78***	.48***	-.25*
2. Irregular words	.81***	-	.47***	-.21
3. Phonological awareness	.38**	.35**	-	-.11
4. RAN	-.42***	-.50***	-.28	-

p* < .05, ** *p* < .01, * *p* < .001.

Table 7

Hierarchical Multiple Regression Analyses Predicting Spelling of Regular and Irregular Words by the Low RAN and the Control Groups from Phonological Awareness and RAN Performance

	Spelling Accuracy							
	Low RAN group				Control group			
	Regular words		Irregular words		Regular words		Irregular words	
Predictor	ΔR^2	β	ΔR^2	β	ΔR^2	β	ΔR^2	β
Step 1	.23***		.22***		.15**		.12**	
Phonological awareness		.48***		.47***		.38***		.35**
Step 2	.04		.03		.14***		.21***	
RAN		-.19		-.16		-.38***		-.47***
Total R^2	.27***		.24***		.29***		.33***	
$n = 72$					$n = 74$			

** $p < .01$; *** $p < .001$

[ii] In a symmetrical orthography such as Turkish, the letter-sound and the sound-letter correspondences are equivalent with both high feed forward and high feedback consistency. In an orthography such as German, the letter sound correspondences for reading are regular and transparent, but for spelling this is not the case. It is asymmetrical with high feed forward but low feedback consistency.