

## SHORT REPORT

### Recognition of oral spelling is diagnostic of the central reading processes

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The task of recognition of oral spelling (stimulus: “C-A-T”, response: “cat”) is often administered to individuals with acquired written language disorders, yet there is no consensus about the underlying cognitive processes. We adjudicate between two existing hypotheses: Recognition of oral spelling uses central reading processes, or recognition of oral spelling uses central spelling processes in reverse. We tested the recognition of oral spelling and spelling to dictation abilities of a single individual with acquired dyslexia and dysgraphia. She was impaired relative to matched controls in spelling to dictation but unimpaired in recognition of oral spelling. Recognition of oral spelling for exception words (e.g., colonel) and pronounceable nonwords (e.g., larth) was intact. Our results were predicted by the hypothesis that recognition of oral spelling involves the central reading processes. We conclude that recognition of oral spelling is a useful tool for probing the integrity of the central reading processes.

**Keywords:** acquired dyslexia; recognition of oral spelling; reverse spelling; reading; spelling

Recognition of oral spelling (e.g., stimulus “C-A-T”, response “cat”), also called naming from oral spelling and reverse spelling, has been used for decades in studies of acquired dyslexia and dysgraphia. However, the importance of impaired or spared performance is not entirely clear due to a lack of consensus about the cognitive underpinnings of the task. Two hypotheses have been proposed. The first, which we refer to as ROS-read, states that recognition of oral spelling proceeds via, and provides information about, the central *reading* mechanisms. The second hypothesis, ROS-spell, posits that recognition of oral spelling requires and probes the central *spelling* mechanisms. In this short report we delineate the two alternative hypotheses and

present evidence in favour of the ROS-read position.

Consider first the ROS-read hypothesis: Recognition of oral spelling probes central reading mechanisms (Coltheart, Masterson, Byng, Prior, & Riddoch, 1983; Forde & Humphreys, 2005; Greenwald & Gonzalez Rothi, 1998; Hanley & Kay, 1992; Katz, 1989; Patterson & Kay, 1982; Tainturier & Rapp, 2003). According to this hypothesis, impaired recognition of oral spelling will co-occur with central reading deficits because both require the central lexical and sublexical reading processes (see Figure 1). Central reading mechanisms take as input a string of abstract letter identities; in reading these are generated through visual letter

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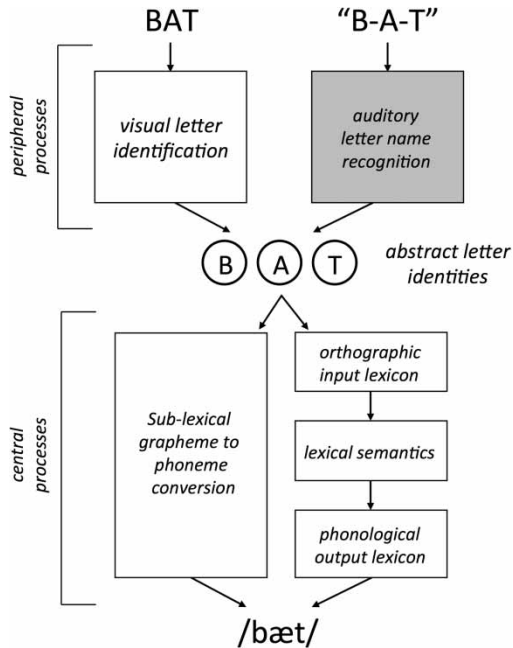


Figure 1. Schematic of cognitive reading mechanisms. Sublexical processes indicated on left, lexical processes on right. Auditory letter name recognition, a component of recognition of oral spelling according to ROS-read (where ROS denotes recognition of oral spelling), is also depicted (grey shading).

identification. For recognition of oral spelling rather than reading, an auditory letter name recognition process computes the abstract letter identities. The letter identities generated by either peripheral process serve as input to central lexical and sublexical reading processes, which compute a phonological output. The only reading process not shared by recognition of oral spelling is visual letter identification; auditory letter name recognition is employed instead. According to this view, the cognitive processes involved in recognition of oral spelling are the central reading processes, along with distinct peripheral input processes. The bulk of previous evidence for ROS-read has been from individuals with impairments to both spelling and central reading processes, with impairment of recognition of oral spelling paralleling the reading deficit (Forde & Humphreys, 2005; Hanley & Kay, 1992; Katz, 1989).

Consider next the ROS-spell hypothesis: Recognition of oral spelling taps central (lexical and sublexical) spelling mechanisms. This position has often been adopted implicitly, as in the following description of results: “He could spell common words without difficulty and understood words spelled to him” (Benson, Brown, & Tomlinson, 1971, p. 951). Here the authors report performance in recognition of oral spelling and spelling to dictation tasks in the same sentence, tacitly assuming that they probe the integrity of the same cognitive system. Other researchers have explicitly claimed that recognition of oral spelling and spelling to dictation share mechanisms (e.g., Cipolotti & Warrington, 1996; Shallice & McCarthy, 1985; Warrington & Langdon, 2002). Specifically, proponents of ROS-spell claim that central spelling processes are involved in recognition of oral spelling, through use of a “reverse spelling procedure” (e.g., Shallice & McCarthy, 1985, p. 366). On this basis, ROS-spell posits that damage to central spelling mechanisms will impair both recognition of oral spelling and spelling to dictation.

To explore the claims of ROS-spell, we consider a standard dual-route spelling theory, as depicted in Figure 2 (e.g., Miceli & Capasso, 2006; Tainturier & Rapp, 2001). Central lexical and sublexical spelling processes take as input a sequence of phonemes. If the phoneme sequence is that of a familiar word, the lexical route retrieves the spelling from long-term memory. The sublexical route generates a plausible spelling (for words or nonwords) through phoneme–grapheme correspondences. The output of both routes is a string of abstract letter identities that are held in the graphemic buffer for production as written letter forms or spoken letter names, following peripheral output processing.

Considering ROS-spell in light of the spelling theory raises the question of how the spelling processes—which normally take as input a sequence of phonemes and produce as output a sequence of abstract letter identities—could accomplish recognition of oral spelling. Descriptions of ROS-spell do not answer this question; proponents of the hypothesis even note that “it is unclear how such a [reverse-spelling] process operates” (Shallice & McCarthy, 1985, p. 366). A solution to

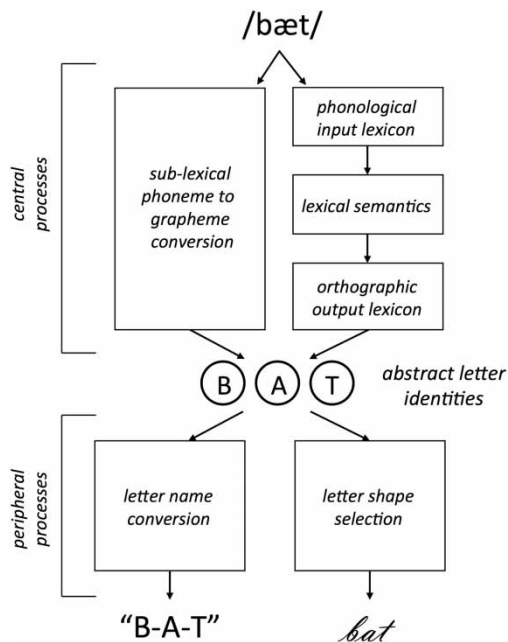


Figure 2. Schematic of cognitive spelling mechanisms. Sublexical processes indicated on left, lexical processes on right.

this theoretical issue must be provided for ROS-spell to have any explanatory power. With this caveat, we proceed with an exploration of the ROS-spell hypothesis, asking how such a system could in principle result in recognition of oral spelling performance as diagnostic of the central spelling system.

Reverse-spelling mechanisms would take letter identities as input and produce a sequence of phonemes as output. Based on these inputs and outputs, reverse spelling could accomplish recognition of oral spelling. Likewise, the reverse-spelling mechanisms could also accomplish reading. Therefore the reverse-spelling mechanisms could either be the normal reading mechanisms or duplicate reading computations. If the former, this hypothesis reduces to the ROS-read hypothesis: Recognition of oral spelling uses reading mechanisms. However, the crux of ROS-spell is that recognition of oral spelling recruits spelling mechanisms rather than reading mechanisms. Presumably, then, proponents of ROS-spell do not intend for the

reverse-spelling mechanisms to perform reading. Hence, we assume that the reverse-spelling process is used *only* for recognition of oral spelling. ROS-spell therefore assumes that the reverse-spelling procedure performs the same computations as the central reading system, yet is not used for reading; and similarly that the central reading mechanisms perform the computations required for recognition of oral spelling yet a special-purpose reverse-spelling procedure is used instead. These assumptions appear to be without independent motivation.

In addition to assuming that recognition of oral spelling is accomplished by the reverse-spelling mechanisms, ROS-spell also assumes that spelling and reverse-spelling mechanisms are functionally a unitary system: When the spelling system is damaged, both forward and reverse spelling processes are disrupted. Only with this additional assumption can recognition of oral spelling performance be taken as evidence concerning the integrity of central spelling mechanisms. If damage could disrupt one direction of processing while leaving the other intact, recognition of oral spelling performance would not elucidate the integrity of the forward spelling processes.

In summary, we have articulated a version of ROS-spell that is faithful to the intentions of the hypothesis: Recognition of oral spelling uses reverse-spelling mechanisms (but not reading mechanisms), and recognition of oral spelling and spelling to dictation will be impaired in concert. Articulating the assumptions of the ROS-spell hypothesis allows us to test its predictions empirically alongside the ROS-read hypothesis.

Warrington and Langdon (2002) argued for ROS-spell based on one individual with impaired reading but spared recognition of oral spelling and spelling to dictation, and a second with impaired recognition of oral spelling and spelling to dictation but intact reading. However, these patterns are not inconsistent with the ROS-read hypothesis: A peripheral deficit in reading should not impair recognition of oral spelling (e.g., Greenwald & Gonzalez Rothi, 1998), and impaired recognition of oral spelling with intact reading is expected in the presence of a verbal working memory impairment (as documented for M.R.F. in Warrington &

Langdon, 2002). Conclusions have also been drawn on the basis of individuals with central deficits in both reading and spelling (Cipolotti & Warrington, 1996), but these results are also subject to multiple interpretations. Well-articulated cognitive theories of reading, spelling, and recognition of oral spelling are vital to interpreting patterns of spared and impaired performance across all three tasks.

The present study considers an individual (L.H.D.) with peripheral dyslexia and central dysgraphia, allowing a clear test of the ROS-spell and ROS-read hypotheses. ROS-spell predicts that an impairment of recognition of oral spelling will co-occur with a central spelling impairment and therefore that L.H.D. will show impaired recognition of oral spelling. Conversely, ROS-read predicts that a central reading deficit will affect recognition of oral spelling. According to this hypothesis, neither L.H.D.'s peripheral dyslexia nor her central dysgraphia will affect recognition of oral spelling so her performance should be intact.

### Case history

L.H.D. is a right-handed woman with a master's degree; she was 72 years old at the time of testing (2013). In 2007, L.H.D. suffered a ruptured posterior cerebral artery aneurysm; haemorrhage and subsequent surgery resulted in a large left-hemisphere ventromedial lesion. Ophthalmological testing revealed a right homonymous hemianopia. Images of L.H.D.'s lesion and additional case history information can be found in Schubert and McCloskey (2013; also McCloskey, Fischer-Baum, & Schubert, 2013; McCloskey & Schubert, 2014).

### Reading

L.H.D. is severely impaired in single-word reading. On a corpus of 5915 words and 629 nonwords, with unlimited exposure duration, her accuracy was 62% (3658/5915) for words and 44% (277/629) for nonwords. Letter substitutions accounted for 94% of her errors (e.g., front → frowt, bishop → diskop). Extensive testing revealed a deficit in visual letter identification (Schubert & McCloskey, 2013).

Specifically, L.H.D. is impaired in activating abstract letter identities from visual letter stimuli. This deficit results in letter substitution errors in reading, cross-case transcoding, and naming of letters in words and nonwords, as well as impairment in other tasks requiring visual letter identification (e.g., cross-case same/different judgements). L.H.D.'s letter identification deficit does not imply any deficit affecting abstract letter identity representations or subsequent central reading processes.

### Spelling

L.H.D. is impaired in written and oral spelling of words to dictation, with average accuracy in both modalities of 88% (288 words correct out of 326). Her accuracy is below the range of control participants on the same items (93–100% correct; Goodman, 1986). L.H.D.'s errors in both written and oral spelling were phonologically plausible misspellings (e.g., “nuisance” spelled as NEWS-ANCE). L.H.D. spelled high-frequency words more accurately than low-frequency words (92% vs. 83% correct),  $\chi^2(1, N=584)=13.2, p<.001$ , and regular words more accurately than irregular words (93% vs. 81% correct),  $\chi^2(1, N=220)=4.87, p<.05$ . No significant effects of grammatical word class, concreteness, or length were observed. She was unimpaired at spelling nonwords, scoring 97% (66/68) correct (controls = 91–100% correct; Goodman, 1986).

Four aspects of L.H.D.'s spelling performance combine to indicate a central lexical spelling impairment: impairment on words and not nonwords; phonologically plausible errors; frequency and regularity effects; and parity of performance across oral and written spelling tasks. Specifically, L.H.D.'s spelling deficit appears to be in retrieving word spellings from the orthographic lexicon (Goodman & Caramazza, 1986).

Both L.H.D. and her husband reported that she was an excellent speller prior to her stroke. They provided a brief premorbid writing sample, containing 86 words, including long and low-frequency words (e.g., residue, horizontal, flammable). For one of the words we were unable to interpret L.H.D.'s handwriting, but the remaining 85 were

spelled correctly. The correctly spelled words included one that L.H.D. misspelled in the testing reported in this section (“knife”, misspelled as NIFE). Therefore, we are confident that L.H.D.’s spelling performance reflects an acquired impairment.

### Experiment 1

The combination of L.H.D.’s peripheral dyslexia and central dysgraphia allowed us to test the ROS-spell and ROS-read hypotheses. According to ROS-spell, L.H.D.’s central spelling deficit should produce impaired performance on recognition of oral spelling. According to ROS-read, L.H.D. should show intact performance on recognition of oral spelling (as long as her visual letter identification deficit is her only reading impairment). We compared L.H.D.’s recognition of oral spelling and written spelling to dictation, of the same items, to that of control participants.

### Method

L.H.D. and eight control participants took part in the experiment. Control participants were female, right-handed, native speakers of English and did not differ from L.H.D. in age or education (mean 69.4 years old, mean 17.6 years of education;  $ps > .25$ ).

Eighty-eight words, 3–7 letters in length, were selected from the target words of the Peabody Picture Vocabulary Test (PPVT–R, Dunn & Dunn, 1981). All stimuli were items to which L.H.D. had responded correctly during administration of the vocabulary test (e.g., *jaw*, *full*, *wrath*, *solemn*, *penguin*). Regular words were excluded, as determined by the N-Watch program (Davis, 2005), to provide a more stringent test of lexical processing. The list was divided into two halves.

In a single session, all participants performed recognition of oral spelling and written spelling to dictation for all items in an ABBA design; order of tasks and list halves were counterbalanced. On spelling to dictation trials, participants repeated the dictated stimulus prior to writing their response. In both tasks, the first complete response was scored. Results were analysed according to the methods developed by Crawford and Howell

(1998) and Crawford and Garthwaite (2005) for comparison of a single case to a group of control participants, using the program DISSOCS.EXE made available by those authors.

### Results

The results are presented in Figure 3. Control participants performed near ceiling on both tasks. Accuracy for recognition of oral spelling ranged from 93% to 100% with a mean of 97.6%. Accuracy for spelling ranged from 91% to 100% with a mean of 96.8%. Control performance did not differ across the two tasks ( $\chi^2 < 1$ ); accuracy differences ranged from 0 to 2.3% (indicating higher accuracy on recognition of oral spelling).

L.H.D. was 97.8% correct at recognition of oral spelling, corresponding to intact performance [Crawford’s *t*-test compared to controls  $t(7) = 0.06$ , *ns*]. She made 2 errors; control participants made 0–6 (mean = 2.5). L.H.D.’s performance falls well within the control participants’ range; an estimated 52% (95% confidence interval, CI [26, 78]) of the control population would be expected to obtain a lower score. Though speed of responding was not emphasized, the experimenters noted that L.H.D.’s responses were prompt and confident. Scoring of her response times from video recordings yielded an average response time of under 4 s per item; 30% of her responses were given within approximately one second.

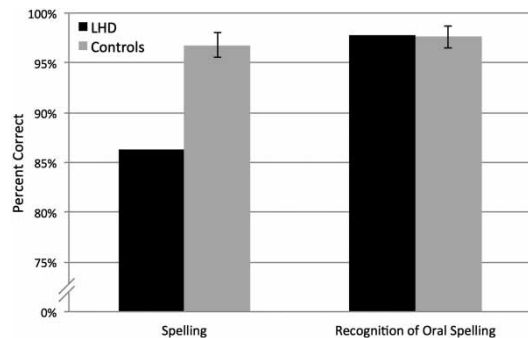


Figure 3. Results of Experiment 1: Performance by L.H.D. and control participants on spelling to dictation and recognition of oral spelling. Error bars reflect  $\pm$ SEM.



L.H.D.'s spelling accuracy on the same items was 86%, significantly worse than her recognition of oral spelling performance,  $\chi^2(1, N=176)=7.76, p<.01$ . Compared to controls, she was significantly impaired on spelling [Crawford's  $t(7)=-2.61, p<.05$ ]. L.H.D. made 12 spelling errors while controls made 0–8 (mean = 2.5). The estimate of control population scores falling below L.H.D.'s is 2% (95% CI [0, 12]), indicating that the vast majority of controls would be expected to outperform her on this task.

Using criteria developed by Crawford and Garthwaite (2005), L.H.D.'s pattern qualifies as a classical dissociation: She displays no deficit relative to control participants in recognition of oral spelling and a significant deficit in spelling to dictation. L.H.D. demonstrated an 11.5% difference in accuracy between the tasks, and it was estimated that only 0.01% of the control population would exhibit a larger discrepancy.

These data argue against the ROS-spell hypothesis, according to which L.H.D.'s central spelling deficit should have led to impaired performance on recognition of oral spelling. Instead, she showed normal recognition of oral spelling for the same items on which her spelling to dictation was impaired, suggesting that recognition of oral spelling does not require the central spelling system. Our results are also inconsistent with an alternative version of ROS-spell positing that recognition of oral spelling is a central spelling task yet easier than spelling to dictation: Controls demonstrated no difference between performance on the tasks while L.H.D. demonstrated a clear dissociation. Rather, the data support the ROS-read hypothesis: Recognition of oral spelling is accomplished via central reading processes, which are intact in L.H.D. Recognition of oral spelling begins with recognition of auditory letter names, activating abstract letter identities. The abstract letter identities are then processed by the central reading mechanisms, just as in the reading of a visually presented word (see Figure 1).

## Experiment 2

In Experiment 2 we sought further evidence bearing on the ROS-read hypothesis by administering lists

of items designed to specifically test the sublexical reading route (pronounceable nonwords) and the lexical reading route (exception words). Based on the outcome of Experiment 1, we expect that L.H.D. will perform normally on recognition of oral spelling of the exception items, and together the two lists provide stringent tests of the two central reading routes.

## Method

A 20-item list of 4- to 5-letter nonwords (e.g., *larth*, *worg*) was created to test the sublexical route. The lexical reading route cannot process nonwords; instead the output of grapheme-to-phoneme conversion will be observed. A second list of 28 highly exceptional words (e.g., *colonel*, *yacht*), 3 to 7 letters in length, was created to investigate the lexical route. The sublexical route in isolation cannot produce a correct pronunciation for these stimuli because they do not conform to regular grapheme–phoneme correspondences; the lexical route is required. L.H.D. completed recognition of oral spelling of the lists in separate sessions.

## Results

L.H.D.'s performance on both lists was excellent. On the nonword list her performance was perfect (20/20). On the exception word list she responded correctly to 27 of the 28 items (96%); her sole error was the naming of “H-E-I-R” as “hair”.

L.H.D.'s excellent performance on these lists further suggests that recognition of oral spelling involves reading rather than spelling processes. Additionally, her performance implies that both of her reading routes are functioning normally and that her only reading deficit is the peripheral deficit in visual letter identification that we previously identified. This is also consistent with previous findings of a lack of regularity effect in L.H.D.'s reading (Schubert & McCloskey, 2013).

The implications of this experiment are somewhat limited due to the small number of items tested. However, we feel confident that these results provide a representative snapshot of L.H.D.'s capabilities, and her excellent performance is consistent with that in Experiment 1. As

this experiment was intended mainly to verify the functioning of L.H.D.'s central reading system, control participants were not tested. One might expect high accuracy by control participants on these items, consistent with their ceiling performance in Experiment 1.

### General discussion

We examined competing hypotheses about the cognitive processes underlying recognition of oral spelling, reporting evidence from an individual with a peripheral reading deficit and a central spelling deficit. Despite her central spelling deficit, L.H.D. was unimpaired in recognition of oral spelling. Therefore, we concluded in favour of ROS-read, which states that recognition of oral spelling engages central reading rather than central spelling processes.

Recognition of oral spelling involves processes that convert auditory letter name information into abstract letter identities, which enter the central reading system. Our results therefore favour reading theories that posit abstract letter identities as the entry point to central reading processes, both for reading and for recognition of oral spelling. This conclusion contrasts with theories of reading positing orthographic representations that can only be accessed from visual input (e.g., Dehaene, Cohen, Sigman, & Vinckier, 2005; Grainger & Ziegler, 2011; Whitney & Marton, 2013). Our position is consistent with accounts of a graphemic buffer in which abstract letter identities are held during access to the central processes used for reading and recognition of oral spelling, as well as peripheral spelling processes (Forde & Humphreys, 2005; Tainturier & Rapp, 2003).

Another interpretation of our data could be that recognition of oral spelling uses reverse-spelling processes in such a way that central spelling can be impaired while recognition of oral spelling is unaffected. However, this interpretation would require assuming a reverse spelling process that is used only for recognition of oral spelling and is susceptible to selective damage. This theoretical position seems implausible and unparsimonious, as also noted by previous authors (Cipolotti & Warrington, 1996; Katz, 1989). By contrast, the ROS-

read hypothesis accounts for our empirical data without the need for additional theoretical assumptions.

### *Diagnostic use of recognition of oral spelling*

Recognition of oral spelling is a valuable tool for probing central reading processing because it does not require visual letter identification. The task does require auditory letter name recognition and the ability to maintain letter names in working memory. When these abilities are intact—verified by independent testing as needed—recognition of oral spelling speaks to the integrity of abstract letter identity representations and the central reading processes. Because recognition of oral spelling bypasses the peripheral reading processes, an isolated peripheral reading deficit will not affect performance. Therefore, impaired performance on recognition of oral spelling indicates a deficit in central reading processes, while intact performance demonstrates intact central reading processes. Diagnostic use of the task was advocated by Greenwald and Gonzalez Rothi (1998), and a number of authors have done so (e.g., Chialant & Caramazza, 1998; Forde & Humphreys, 2005; Miozzo & Caramazza, 1998; Patterson & Hodges, 1992; Perri, Bartolomeo, & Silveri, 1996; Tainturier & Rapp, 2003).

Testing can be tailored specifically to assess the integrity of sublexical and lexical reading routes, as in our Experiment 2. Pronounceable nonwords and exception words require an intact sublexical route and lexical route, respectively, to achieve accurate performance. An impairment in recognition of oral spelling with pronounceable nonwords implies a sublexical deficit, while an impairment with exception words implies a lexical deficit.

The rationale for use of recognition from oral spelling can also be extended to lexical decision from oral spelling (e.g., Greenwald & Gonzalez Rothi, 1998). Whereas visual lexical decision requires visual letter identification and the orthographic lexicon, lexical decision from oral spelling requires auditory letter name recognition and the orthographic lexicon. Lexical decision from oral spelling not only delineates function of the orthographic lexicon from the remainder of central

reading processes, it also bypasses visual letter identification, effectively isolating the orthographic lexicon from all other components of the reading system.

Our explicit description of the cognitive processes involved in recognition of oral spelling provides a theoretical framework for interpreting performance on this task. We hope that researchers will make use of recognition of oral spelling as a diagnostic tool for investigating central reading deficits in individuals with acquired dyslexias.

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