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Research Report

Aphasia and spelling to dictation: Analysis of spelling errors and editing

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Abstract

Introduction: Spelling difficulty is a common symptom of aphasia and can entail editing difficulties. Previous research has shown that extensive editing is related to a lower production rate in text writing for persons with aphasia, yet editing difficulty is not commonly examined. It is not known if editing difficulty is related to reading and writing skills or to aspects of the word.
Aims: To analyse spelling and editing processes as well as errors in a dictation task performed by Swedish-speaking adults with post-stroke aphasia. Furthermore, the study aimed to identify any relationships between spelling and editing difficulties and characteristics of individual words. Finally, relationships between successful edits and reading and phonological ability were investigated and specific editing strategies or behaviours identified. Correlation analyses were performed between measures of spelling and editing and word frequency and length as well as participants' scores on tests of reading, phonological spelling and phonological decoding.
Methods & Procedures: A total of 16 Swedish speaking participants with post-stroke aphasia wrote a word-dictation task in a keystroke logging program and were tested for phonological spelling, phonological decoding and reading ability. Spelling errors were categorized and analysed.
Outcomes & Results: The most common error type was omission of letter(s) and there was evidence of aphasia-specific writing errors. Both spelling and editing difficulty were related to word frequency and word length. Successful editing was related to participants' scores on the phonological spelling task, but not to phonological decoding or reading ability. Specific editing strategies could be identified, and some strategies were individual, while others were more commonly used.
Conclusions & Implications: Word length and word frequency should be taken into consideration in spelling tests for persons with aphasia, and the presence of editing difficulty should be taken into account when assessing spelling difficulties. Treatment for writing difficulties in aphasia should include training in successful editing strategies and individual fitting of digital writing aids.

Keywords: aphasia, writing, spelling, editing.

What this paper adds

What is already known on the subject

- Post-stroke aphasia often causes writing and spelling difficulties. Spelling difficulties may entail editing difficulties, in turn causing extensive and/or unsuccessful editing. Extensive editing is known to impede productivity in text writing. Still, editing behaviour, abilities relating to editing or what features of a word that causes editing difficulty has not been investigated for persons with aphasia.

What this paper adds to existing knowledge

- This study adds an in-depth analysis of spelling ability, spelling errors and editing behaviour for persons with aphasia, using keystroke logging and a single-word dictation task. Results showed that both features

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of the target word (frequency and word length) and the individual abilities of the person with aphasia (score on a phonological spelling task) related to spelling and editing difficulty, editing behaviour and successful editing. Specific editing strategies were analysed and described.

What are the potential or actual clinical implications of this work?

- Word length and word frequency should be taken into consideration when testing single-word spelling for persons with aphasia. When assessing spelling difficulties, both correctness of spelling as well as the presence and nature of any editing difficulties should be taken into account and treatment for writing difficulties in should include training in successful editing strategies. The fitting of digital writing aids for persons with aphasia should be individual, since many of the editing strategies used were individual.

Introduction

Spelling is commonly reported as a primary area of difficulty in writing impairment caused by post-stroke aphasia (Beeson and Rapcsak 2015). Although spelling difficulty is one of the most persistent difficulties in persons with chronic aphasia, it is also a difficulty that is susceptible to treatment. The scientific investigation of spelling difficulties caused by aphasia has tended to be based mainly on single-word-dictation tasks (Beeson and Rapcsak 2015), but spelling difficulties have also been found to negatively affect aspects of text writing in persons with aphasia (PWAs). For example, studies have shown that PWAs produce more spelling errors in text than a reference group (Vandenborre *et al*. 2018) and tend to avoid words that they find difficult to spell (Johansson-Malmeling *et al*. 2020), and that this tendency affects certain lexical features (word use) of their texts (Johansson-Malmeling 2019), which may have an impact on overall text quality. To successfully treat PWAs and/or develop digital tools to facilitate their writing and spelling, it is crucial to increase knowledge about the nature of their difficulties not only with spelling but also with editing.

One theory commonly used to categorize, diagnose and explain acquired writing difficulties is the 'dual-route model' (Ellis 1982, Hatfield 1989). Originally developed to explain reading at the single-word level, it has since also been used to explain and categorize acquired writing and spelling difficulties. This model suggests there are two autonomous basic 'routes' for the processing of written words: the lexical (whole-word) route and the sub-lexical (phonological) route. In the case of writers with aphasia, one route may be selectively impaired so that the writing processes have to rely on the other, or both may be severely impaired, resulting in an inability to process written language (i.e., to read and write). A damage to the lexical route would result in errors with phonologically plausible spelling, such as *yot* instead of *yacht* and damage to the phonological route might result in an inability to write new words and errors might present as words that visually resemble the target word, such as *over* instead of *oven*. Deficits to the phonological route cause the writer to rely on the lexical route, hence frequent words have shown to be more resilient to errors. The role of the graphemic buffer was introduced by Caramazza *et al*. (1987). In a neuro-psychological model of dictation writing—it is thought that orthographical information is temporarily stored in the graphemic buffer before the stage of graphomotor execution (i.e., the physical typing). Hence, the 'graphemic buffer' is a function of verbal working memory. Deficit related to the graphemic buffer could potentially affect all aspects of writing and errors would be expected to increase in frequency with word length due to longer words putting larger demands on short-term memory storage in the graphemic buffer (Caramazza *et al*. 1987, Miceli *et al*. 1985).

The 'dual route model' was originally developed, and has primarily been used, to investigate reading and spelling in the English language. However, spelling difficulties may appear different dependent on language. Swedish is a north Germanic language with 29 letters (the same as the English alphabet, but three additional vowels; Å, Ä and Ö). Swedish has a complex syllable structure (more like English or Dutch than Spanish or Italian, for example) and semi-transparent orthography (Seymore *et al*. 2003). For a language such as Swedish, which has a fairly transparent orthography, that is, a rather good match between spelling and pronunciation, drawing a clear line between sub-lexical and lexical processes as manifested in writing and spelling tests may be more difficult than where the orthography of the language concerned is less transparent, as in the case of English, for which the dual-route model was originally developed. Swedish also has very productive compounding. For example, *buss* ('bus') and *station* ('station') are combined into *busstation* 'bus station'. Such a compound word thus consists of two or more root morphemes. Short vowels are in general, but not consistently, followed by consonant doubling. The writing of compounds and consonant doubling generally represents a challenge to writers of Swedish (Nauclér 1980).

Using the 'dual-route model' as a theoretical base, aphasia tests have been developed to assess aphasia and related reading and writing difficulties. The PALPA test (Psycholinguistic Assessment of Language Processing in Aphasia) has been suggested for research into writing impairment caused by brain lesions (Kay *et al*. 1996), but that test battery is unfortunately not yet available in Swedish. When analysing spelling errors, a categorization has been suggested for writers of English by Kay and Handley (1994) and used by Wengelin (2002) for categorizing spelling errors written by persons with developmental writing difficulties. Wengelin also added categories to better suit challenges in the Swedish language (errors in word segmentation/compounding and consonant doubling). Whitworth *et al*. (2005), who studied spelling errors made by PWAs, added a few more of specific relevance to their participants: morphological errors, semantic errors and phonological/regular spelling errors.

Spelling difficulties may also include editing difficulties. An edit is here defined as any change made to the text being produced. All writers edit their texts, and editing is a vital part of the writing process. Whether an instant edit of a typo or a comprehensive revision of an entire paragraph, editing always aims to correct or improve the text or individual word (Lindgren and Sullivan 2002). For PWAs, the editing process is commonly both more time-consuming and less successful than for persons without aphasia. Further, when writing connected text, PWAs tend mainly to perform edits at the word level rather than at the sentence or text level, which is where writers without aphasia tend to focus their editing efforts (Behrns *et al*. 2008). Previous research has also identified a relationship between the extent of editing and the rate of text production for PWAs, but not for writers without aphasia (Johansson-Malmeling *et al*. 2020), indicating that the latter engaged in 'fluent editing' while the PWAs' editing operations hindered their text-production process.

Various individual abilities might have an impact on the editing process. For example, the ability to read the text written in order to evaluate it is obviously central to making successful edits (Lindgren and Sullivan 2002). Phonological ability and sub-lexical spelling ability may be essential to spelling revision, and real-word spelling ability may reduce the need for word-level editing. All of the above-mentioned abilities may be impaired or reduced to different degrees in post-stroke aphasia. However, spelling and editing difficulties may also be related to the length and frequency of individual words. Long and infrequent words are more often misspelled by PWAs than short and frequent ones, both in dictation tasks (Bricker *et al*. 1964, Whitworth *et al*. 2005) and in text writing (Johansson-Malmeling 2019). However, it is not known whether such word characteristics also affect editing difficulties.

Writing processes such as editing can obviously not be investigated using the final text produced by writers. Fortunately, new technology offers a variety of methods to do so. One of them is keystroke logging, which records all actions undertaken by the writer on the keyboard or with the mouse as well as their timing, enabling writing behaviour to be studied (Leijten and Van Waes 2013). Keystroke logging has previously been used to investigate writing processes, for example, in persons with Alzheimer 's disease (Van Waes *et al*. 2017), low-grade glioma (Antonsson *et al*. 2018), adolescent students with dyslexia (Torrance *et al*. 2016) and with post-stroke aphasia (Behrns *et al*. 2008, Leijten *et al*. 2015, Johansson-Malmeling *et al*. 2020).

To sum up, there is evidence showing that the spelling of single words tends to be challenging for PWAs and that editing behaviour is an important aspect of the spelling process. However, it is not known how editing difficulty relates to spelling difficulties, lexical features of words written or abilities linked to reading and writing ability. Nor have the editing operations or behaviours been studied as a process in PWAs. To treat PWAs successfully and/or develop digital tools to help them overcome their spelling and writing difficulties, it is crucial to have knowledge about the nature of their spelling and editing difficulties and about the relationships between their reading, phonological and spelling ability.

Against that background, the aim of the present study was to analyse spelling and editing processes as well as errors in a dictation task performed by PWAs and to identify any relationships between spelling and editing difficulties and lexical characteristics of individual words. Two additional aims were to investigate the relationship between successful edits and reading and writing ability, and to identify specific editing strategies or behaviours.

Research questions:

- To what extent do the participants make errors and edits in the words written in the dictation task and what types of spelling errors do they make?
- Are word length and word frequency related to spelling and editing difficulty?
- Are reading ability, phonological-spelling ability, phonological-decoding ability and word-spelling ability related to editing, and can specific editing strategies or editing behaviours be observed using writing-process data?

Table 1. Demographic information and information about aphasia type for the participants with aphasia

Code	Sex	Age when enrolled (years)	Years of formal education	Type of aphasia	Aphasia severity (based on 'A-ning' scores)	Writing-ability score (based on 'A-ning')
1	M	71	18	Non-fluent	Mild/moderate	4.36
2	M	61	11	Non-fluent	Mild/moderate	3.35
3	M	70	20	Non-fluent	Mild	4.75
4	M	58	18	Non-fluent	Moderate	2.88
5	M	72	17	Non-fluent	Mild	4.50
6	M	63	25	Non-fluent	Mild	4.38
7	M	79	20	Mixed/fluent	Mild	3.88
8	M	70	17	Mixed	Mild	4.25
9	F	72	10	Mixed	Mild/moderate	3.38
10	M	71	16	Mixed	Mild	4.38
11	F	72	9	Non-fluent	Mild	4.75
12	M	79	13	Non-fluent	Mild	3.75
13	M	69	13	Non-fluent	Mild	3.25
14	F	65	9	Fluent	Moderate	2.63
15	F	67	12	Non-fluent	Mild	4.63
16	M	67	12	Non-fluent	Moderate	2.88
$N = 16$	12 M/4 F	Mean = 69.1	Mean = 15			Mean = 3.88 Inclusion cut-off = 2.50

Notes: The 'A-ning' writing score ranges from 0 to 5, where 5 means no writing difficulties (Lindström and Werner 1995).
M, male; F, female; *N*, number.

Methods and materials

The study was approved by the Regional Ethical Review Board of Gothenburg, Sweden (reference number 525-14).

Participants

The participants were recruited through local aphasia associations and through speech and language pathologists in the western region of Sweden. The criteria for inclusion were: (1) having post-stroke aphasia; (2) a self-reported ability to use a keyboard (one- or two-handedly); (3) being at least 18 years old; (4) scoring at least 2.5 on the subtests of auditory comprehension and writing of the 'A-ning' aphasia test (corresponding to the ability to understand connected speech and to produce connected writing); and (5) having Swedish as one of their first languages. The inclusion criteria related to being able to produce connected writing was because the participants were screened for inclusion to a larger study where text writing was assessed (Johansson-Malmeling *et al.* 2020). The criteria for exclusion were: (1) developmental reading and writing difficulty or other learning difficulty other than stroke and/or (2) impaired hearing or vision which could not be compensated for and/or (3) neurological disease or disorder other than stroke. The participants were screened for inclusion by the first and last author. One participant had been bilingual as a child (Swedish and a minority language), but has only ever read or written in Swedish. All persons deemed to meet the criteria ($N = 18$) were included in the study. However, one participant was later excluded owing to fatigue and consequent difficulties performing the tests and writing tasks, and another was excluded when the presence of self-reported developmental reading and writing difficulties was established after data collection. Demographic data for the remaining 16 participants are shown in table 1. All data, including the 'A-ning' scores, are from the time when each participant was enrolled in the study, one year before the collection of the data used in the present study. Aphasia type and severity were diagnosed using 'A-ning' (Lindström and Werner 1995), a standardized test used to diagnose aphasia in Sweden. Its subtests of auditory comprehension and writing ability were used to establish eligibility for inclusion in the study. The writing-ability score used for this purpose (table 1) is the mean score on the two subtests of writing ('Informational writing' and 'Writing to dictation'). Both the overall composite score on the 'A-ning' test, which is used to grade aphasia severity, and the subtest scores range from 0 to 5; an overall score of 5 means 'no aphasia'.

Tests and tasks and analyses

To analyse spelling, editing and related abilities, a variety of tasks and tests were used. Since there is no specific Swedish-language test or test battery to examine

acquired reading and writing difficulties, the tasks and tests were taken from different test batteries. The tests were chosen to examine the targeted abilities with minimal interference from other challenges related to aphasia. Descriptions are provided below. All tests and tasks were administered by the first or last author or a certified speech and language pathologist.

The *word-dictation* test used was taken from a test battery (the 'LS') designed to assess reading and writing ability in secondary-school students (Johansson 2004). The words included in the dictation test have been selected based on a qualitative analysis of common spelling errors in Swedish, but the test manual provides no information about the frequency, length, spelling difficulty, age of acquisition or other features of those words. The test was chosen due to its variety of words and spelling challenges and to the fact that norms were available for adults (18 year olds). The test administrator read the words aloud, presented as part of a sentence. The participants typed the words and their writing was recorded using a keystroke-logging tool called New ScriptLog (Wengelin *et al.* 2019). The test includes 50 words, but one of them was found to prompt the writing of digits rather than letters and so was excluded from the analysis. Of the 49 remaining words, 25 were compound words, that is, two or more words written together without a space. Errors in compounds are common in Swedish; compounds are commonly written as several words rather than one. Since the sole error of a compound word might thus be the addition of a space between the root morphemes, it might be interesting to investigate whether the participants spelled the individual component elements of compound words correctly. Hence, the analysis of word frequency and errors was performed both for the whole compound words and for their two (or sometimes three) separate root morphemes. As a consequence, there are two possible maximum scores on the word-dictation task: 49 (for whole words) and 75 (for root morphemes).

To examine *phonological (sub-lexical) spelling* skill, a dictation task consisting of nonsense words was used. Since there is no comprehensive test for acquired reading and writing difficulty in Swedish, a random selection of 18 words, two to eight letters long, from among the nonsense words included in the above-mentioned LS test was used (Johansson 2004). The nonsense words were chosen to have varying length and to be relatively few since the task was deemed quite taxing for the participants. In the original test, students read those words out loud, but in the present study the researcher instead read them out to the participants, instructing them to 'write the word as it sounds'. In the analysis, any written word that constituted a phonologically accurate representation of the corresponding nonsense word was deemed correctly spelled, even if the spelling was unusual. For example, *öta* spelled *ötah* was deemed correct although a silent *h* in final position is unusual in Swedish, whereas *ddrav* was considered an incorrect spelling of *drav* since a written Swedish word cannot begin with two identical consonants.

In both dictation tasks, the participants were able to request an unlimited number of repetitions of a word (which always prompted the repetition of the entire word—but not of its context sentence in the case of the real-word test). This was not in accordance with the instructions given in the test manual but represents an adjustment to better suit PWAs.

The written words from the word-dictation task were analysed for correctness and error types. A word could be analysed as manifesting several errors and hence as representing several error types. The errors found were divided into the categories listed in table 2.

The first four categories listed in table 2 were suggested by Kay and Handley (1994). They were also used for Swedish by Wengelin (2002), who added two categories: consonant doubling and segmentation errors. Since the present material comes from a dictation test of single words, the only possible segmentation errors relate to the *splitting* of compounds, which is why the category has been renamed accordingly. Finally, where the written word bore little resemblance to the target word and/or the error(s) made were not categorizable, or the row was left blank, the word was categorized as non-categorizable (and a note was made of whether the first letter was correct). These categories were used for the initial, surface-level analysis. The error categorization was performed by the first author. To assess inter-rater reliability, a co-author then categorized the errors made by eight randomly selected participants; 72.3% agreement was found, which would be considered as 'substantial agreement' according to Landis and Koch (1977).

As noted above, it was found appropriate in the present study to add three categories of errors, related to error types made specifically by PWAs, to the four categories suggested by Kay and Handley (1994). Whitworth *et al.* (2005) used those four categories but added a few more to better suit PWAs: morphological errors, semantic errors (called '*resembles another word in the current study*') and phonological/regular spelling errors. The present study did not make a distinction based on whether an error was made in a root morpheme or in a suffix, since that distinction proved difficult to make, but the other two categories were added as factors considered in the further analysis of spelling errors. Finally, since there was evidence of perseverations in the written words, that category was also added to the analysis.

Editing was investigated in the writing of the word-dictation task. There are different ways to measure

Table 2. Categorization of spelling errors in the dictation tasks

Category	Description	Examples
Substitution	Letter(s) substituted with wrong letter(s)	Example: *allmenhet* (target word: *allmänhet* 'general public')
Insertion	Insertion of additional letter(s)	Example: *energiekälla* (target word: *energikälla* 'energy source')
Omission	Omissions of letter(s)	Example: *flygtranport* (target word: *flygtransport* 'air transport')
Reversal/transposition	Reversal of letter(s)	Example: *kärnkarftverk* (target word: *kärnkraftverk* 'nuclear power plant')
Consonant doubling	Omission of consonant doubling or incorrect doubling of consonants	Example: 1: *programerare* (target word: *programmerare* 'programmer') Example: 2: *djurvänn* (target word: *djurvän* 'animal lover')
Compound splitting	Compound word written as several words with a space between them	Example: *extraförtjänst* (target word: *extraförtjänst* 'top-up income')
Non-categorizable	Word lacks resemblance to target word, row left blank and/or error(s) impossible to categorize	Example: *förset* (target word: *särskilt* 'particularly')

Table 3. Measures of editing

Measure of editing	Measured as:
Proportion of unedited text (%)	Total number of 'tokens' (alphanumerical characters, punctuation, spaces and any other visible results of key presses) in the final text divided by the total number of instances of the pressing of token keys (expressed as a percentage)
Edited words (%)	Proportion of words that have been edited
Successfully edited words (%)	Proportion of the edited words where the final result was the correct target word
Unsuccessfully edited words (%)	Proportion of the edited words where the final result was an incorrect word

editing which capture different aspects of the process. The proportion of unedited text reflects the overall amount of editing undertaken, since it is based on the total number of tokens in the final text divided by the total number of tokens pressed during the writing process. A low proportion of unedited text means that the writer deleted or changed a large proportion of the text during text composition. The proportion of edited words reflects editing at the word level and is relevant for a dictation task but cannot reveal how much a word was edited. Therefore, the present study used both of those measures along with the proportions of successfully and unsuccessfully edited words (table 3).

All measures of editing are expressed as percentages, since three of the participants did not write all 49 words—two of them discontinued the dictation task and a technical error caused data to be missing for one participant. The results are based on 33 words for participant 3, 44 words for participant 13 and 22 for participant 14. Editing behaviours and strategies were also investigated using the keystroke logs. The logs were replayed and observed by the first author.

Word frequency of the words in the word-dictation task was analysed in line with Johansson-Malmeling (2019), where Swedish words were categorized as (1) high-frequency (the 1000 most commonly used words), (2) medium-frequency (the 2000−5000 most common words) and (3) low-frequency (words less common than the 5000 most common ones). The analysis for word frequency was performed using AntWordProfiler (Anthony 2013). Word lists were obtained from a mixed and balanced corpus of Swedish texts (including both news articles, books and blogs) and provided by the Swedish Language Bank, University of Gothenburg.

Word length of the words in the dictation task was measured and defined as the number of letters in the word. Results from word frequency and length analysis were correlated to spelling scores and editing to establish possible impact.

Reading ability was tested using a cloze task taken from the DLS test battery for primary-school students (Järpsten 2002) which involves reading a text and filling in gaps by choosing one correct word from among four options. Designed to assess reading speed with retained reading comprehension, this task has a time limit of 5 min which was applied in the present study. This test was chosen since it examines both reading speed and comprehension, but does not require reading aloud, which would present a challenge to PWAs.

Phonological decoding skills were assessed using a test called 'Which word sounds right?' taken from the Duvan dyslexia-screening tool (Lundberg and Wolff 2003). In that test, words are presented in rows with three columns. Each row contains one real word which is spelled in a phonetically appropriate but

Table 4. Proportion of correctly written dictation words and root morphemes, proportion of unedited text, proportion of edited words, and proportion of edited words that were edited successfully

Participant ID	Whole words correct (%)	Root morphemes correct (%)	Proportion of unedited text (%)	Edited words (%)	Successfully edited words (%)
1	81.63	88	82.66	73.47	77.78
2	12.24	33.33	71.96	61.22	13.33
3*	51.61	68.89	91.63	29.03	22.22
4	22.45	40	95.42	24.49	16.16
5	85.71	92	98.84	12.24	66.67
6	63.27	72	51.21	95.92	55.32
7	57.14	70.67	86.42	40.82	50
8	65.31	77.33	89.8	34.69	41.18
9	24.49	44	63.09	73.47	11.11
10	81.63	86.67	88.15	38.78	68.42
11	85.71	89.33	97.74	10.2	100
12	28.57	40	80.72	63.27	25.81
13**	20.45	40.91	93.28	43.18	0
14***	13.64	28.57	59.49	82.61	10.53
15	95.92	97.33	87.22	34.69	88.24
16	6.12	18.67	80.46	59.18	0
Mean/median	49.74/54.38	61.73/69.77	82.38/86.82	48.58/42.00	40.42/33.50
Minimum–maximum	6.12–95.92	18.67–97.33	51.21–98.84	10.20–95.92	0–100

Note: A total of 76.4% correct is the norm value indicated in the test manual (for whole-word dictation). Results from the dictation test: *based on 31 words, **based on 44 words and ***based on 22 words (out of 49).

orthographically incorrect manner (e.g., *tjips* instead of the correctly spelled *chips* 'crisps/potato chips') and two nonsense/pseudo-words. The participants were asked to mark the word that sounded like a real word, although it was misspelled. The test was used to assess phonological decoding skills in writing only, without requiring auditory processing or verbal responses, which made it suitable to PWAs. The test was administered in accordance with the manual, including a time limit of 2 min, but the instructions given were simplified and a practice item where the researcher provided help as needed was performed before the actual test.

Results

The results will be presented in the following order: descriptive results from the word-dictation task (correctness and editing), analysis of spelling errors, analysis of impact of lexical variables, analysis of relationships between abilities related to spelling and editing, and finally analysis of editing strategies and behaviour.

Dictation performance

The descriptive results from the word-dictation task are presented in table 4. Correctness was measured as the proportion of whole words and root morphemes, respectively, with the exact spelling of the target word/morpheme.

Although the participants all had mild-to-moderate aphasia and were all able to write at a textual level, their scores on the dictation task ranged from 6.12% to 95.92% correct words. All participants undertook some editing when writing, as could be expected. They kept between 51.21% and 98.84% of the characters first typed, and the proportion of edited words varied between 10.20% and 95.92%. Their editing success rate varied even more: the proportion of successfully edited words actually ranged from 0% to 100%.

Surface analysis of spelling errors

The results of the spelling-error analysis are presented descriptively in table 5. The numbers given indicate the number of words affected by each category of error. A single word could be analysed as manifesting several errors and might therefore represent several error types. The entire corpus of words written by the participants in the dictation task consists of 734 words, of which 365 (49.73%) were misspelled. The most common error types were omission (160 words affected), substitution (127) and consonant doubling (99). Omission included both the omission of single letters within a word and, commonly, the omission of the final letters of a word or the entire second root morpheme of a compound.

Table 5. Distribution of errors in error categories of aphasia-specific errors

	Spelling errors (proportions of words written in total in parenthesis)									Aphasia-specific errors		
Participant ID	Number of incorrect words	Substitution	Insertion	Omission	Reversal	Consonant doubling	Compound splitting	Non-categorizable	*Initial letter right*	Perseveration	Resembles another word/semantic errors	Phonetic spelling
1	8	4 (8.16)	1 (2.04)	4 (8.16)	3 (6.12)	3 (6.12)	1 (2.04)	0	*0*	0	0	0
2	43	11 (22.45)	7 (14.29)	21 (42.86)	4 (8.16)	1 (2.04)	1 (2.04)	16 (37.21)	*4*	1 (2.04)	10 (20.41)	1 (2.04)
3*	15	3 (9.68)	0	5 (16.13)	0	0	9 (29.03)	0	*0*	0	0	1 (3.23)
4	39	17 (34.69)	13 (26.53)	7 (14.29)	1 (2.04)	7 (14.29)	0	11 (22.45)	*3*	11 (22.45)	5 (10.20)	0
5	7	1 (2.04)	2 (4.08)	2 (4.08)	2 (4.08)	5 (10.20)	1 (2.04)	0	*0*	0	0	2 (4.08)
6	21	4 (8.16)	1 (2.04)	15 (30.61)	2 (4.08)	5 (10.20)	1 (2.04)	0	*0*	0	0	0
7	21	8 (16.33)	2 (4.08)	3 (6.12)	0	12 (24.49)	0	0	*0*	0	1 (2.04)	3 (6.12)
8	17	3 (6.12)	4 (8.16)	5 (10.20)	1 (2.04)	7 (14.29)	0	0	*0*	0	0	1 (2.04)
9	37	21 (42.86)	11 (22.45)	14 (28.57)	5 (10.20)	4 (8.16)	0	4 (8.16)	*2*	0	0	2 (4.08)
10	11	4 (8.16)	6 (12.24)	2 (4.08)	0	3 (6.12)	0	0	*2*	0	2 (4.08)	0
11	7	3 (6.12)	0	3 (6.12)	0	4 (8.16)	0	0	*0*	0	0	0
12	35	11 (22.45)	0	22 (44.90)	9 (18.37)	14 (28.57)	1 (2.04)	0	*0*	0	0	1 (2.04)
13**	35	6 (13.64)	6 (13.64)	20 (45.45)	9 (20.45)	13 (29.55)	0	1 (2.27)	*1*	0	4 (12.90)	1 (2.27)
14***	20	6 (27.27)	10 (45.45)	9 (40.91)	3 (13.64)	5 (22.73)	0	3 (9.10)	*3*	9 (40.10)	4 (18.18)	0
15	2	1 (2.04)	1 (2.04)	0	0	0	0	0	*0*	0	0	0
16	47	24 (48.98)	9 (18.37)	29 (59.18)	10 (20.41)	8 (16.33)	0	10 (20.41)	*7*	0	10 (20.41)	0
Total:	365	127 (17.30)	73 (9.95)	161 (21.93)	49 (6.68)	91 (12.40)	14 (1.91)	44 (5.99)	*22*	21 (2.86)	36 (4.90)	12 (1.63)

Note: Results from the dictation test: *based on 31 words, **based on 44 words and ***based on 22 words (out of 49).

Furthermore, the words containing errors were analysed for aphasia-specific errors and for which word in the compound was affected.

Analysis of aphasia-specific errors

The results of the analysis of errors specific to aphasia are shown in table 5. Perseverations, defined as words that were influenced by a word or word element from an earlier item, were infrequent: no more than 2.86% of words manifested them; only three participants had any perseverations at all, and two of those accounted for the vast majority. The nature of the perseverations varied, but the most common type was the repetition of an incorrect suffix (such as a plural ending) with several target root morphemes.

Further, some of the words in the corpus might be word paraphasias, that is, unintended words. In some cases, participants produced a word identical to or resembling a word other than the target word. Of all 365 words containing errors, 4.90% of words were (or strongly resembled) real words other than the target. For example, one participant wrote the English word for the Swedish target word (*guitar* instead of *gitarr*) and another wrote *från* 'from' instead of *framåt* 'forward'. However, given that a relatively minor spelling error could accidentally yield another word rather than reflect a paraphasia, these words were interpreted as manifesting a spelling error. There was no evidence of clear semantic paraphasias (such as writing *chair* instead of *table*).

Finally, there was evidence of 'phonetic' spelling errors, that is, cases where a word was spelled in a way which correctly reflected its sound structure but violated a spelling rule. For example, one participant wrote *snappt* instead of *snabbt* 'fast', which is phonetically correct in that the/b/loses its voicing in normal pronunciation. In all, 1.63% of words with this type of spelling error were found; the most commonly affected one included an uncommon spelling of the/ŋn/phoneme combination: some participants spelled it <ngn> or <ng> rather than <gn> in *regnskyddet* 'the rain shelter'.

Analysis of compounds

It was more common for an error to affect the second (or third) morpheme of a compound than the first one: out of 117 compound words containing errors, only 21.37% (25 words) had an error in the first morpheme whereas 78.63% (92 words) had an error in the second or third morpheme (table 6).

Table 6. Analysis of misspelled compounds

ID	First morpheme affected	Second/third morphemes affected
1	1	2
2	6	10
3*	0	3
4	1	12
5	1	3
6	1	6
7	1	5
8	1	6
9	4	8
10	3	3
11	0	0
12	3	7
13**	2	9
14***	1	8
15	0	1
16	0	9
Total:	25	92

Note: Results from the dictation test: *based on 31 words, **based on 44 words and ***based on 22 words (out of 49).

Impact of word frequency and length

To examine whether there was a link between word frequency and word length, on the one hand, and the tendency for participants to produce correctly spelled words on the dictation test (for both whole words and root morphemes) and the percentages of successfully and unsuccessfully edited words, on the other, Spearman's Rho was used to analyse the correlations (table 7).

No statistically significant correlation was found between correctness (measured as the proportion of participants who spelled a word correctly) and the frequency of that word for the dictation results using whole words, but there was a significant negative correlation between word frequency and dictation results for root morphemes—meaning that the participants were more likely to produce the correct spelling for common words than for uncommon ones.

Further, there were significant negative correlations between word length (measured as the number of letters) and correctness for both whole words and root morphemes, but the correlation was stronger in the latter case. Hence, longer words are more commonly affected by errors than shorter ones.

Finally, there was no significant correlation between the proportion of successfully edited words and either word length or word frequency, but there were significant correlations between the percentage of unsuccessfully edited words and both word length and frequency. Hence, words causing greater spelling difficulty seem more difficult to edit.

Table 7. Correlations between correctness and editing outcomes and word frequency and length

Variables	Word frequency (levels 1–3)	Word length (number of letters)
Correctness (whole words)	–0.201	–0.460**
Correctness (root morphemes)	–0.380**	–0.726**
Successfully edited words	–0.159	0.019
Unsuccessfully edited words	0.394**	0.496**

Note: **Significant at $p = 0.001$.

Table 8. Scores on tests of reading, phonological decoding, non-word dictation and real-word dictation

Participant ID	Reading (total: 35)	Phonological decoding (total: 60)	Non-word dictation (total: 18)	Dictation (whole words correct,%)	Dictation (root morphemes correct,%)
1	8	4	2	81.63	88
2	7	4	2	12.24	33.33
3*	12	7	17	51.61	68.89
4	5	4	2	22.45	40
5	15	11	10	85.71	92
6	22	11	8	63.27	72
7	11	7	13	57.14	70.67
8	12	5	8	65.31	77.33
9	5	9	7	24.49	44
10	10	11	5	81.63	86.67
11	9	16	12	85.71	89.33
12	5	6	7	28.57	40
13**	9	13	4	20.45	40.91
14***	12	7	0	13.64	28.57
15	13	7	10	95.92	97.33
16	13	11	2	6.12	18.67
Mean/median	10.50/10.50	8.31/7.00	6.81/7.00	49.74/54.38	61.73/69.77
Minimum–maximum	5–22	4–16	0–17	6.12–95.92	18.67–97.33

Note: Results from the dictation test: *based on 31 words, **based on 44 words and ***based on 22 words (out of 49).

Table 9. Correlations between scores on tests of real-word dictation, non-word dictation, phonological decoding and reading, the proportion of edited words and the proportion of successfully edited words

Variables	Real-word dictation (whole words)	Non-word dictation	Phonological decoding	Reading	Proportion of edited words	Proportion of successfully edited words
Real-word dictation (whole words)	1	0.612**	0.219	0.313	–0.445	0.894**
Non-word dictation		1	0.305	0.334	–0.513*	0.521*
Phonological decoding			1	0.397	–0.155	0.059
Reading				1	–0.088	0.194
Proportion of edited words					1	–0.364
Proportion of successfully edited words						1

Note: *Significant at $p = 0.005$; and **$p = 0.001$.

Impact of various abilities related to spelling and editing

The scores on the tests of reading ability, phonological decoding, non-word dictation and real-word dictation (whole words and root morphemes) are presented descriptively in table 8.

Table 9 shows the results of a correlation analysis where the variables presented in table 8 were correlated with each other as well as with the proportion of edited words and the proportion of successfully edited words.

Scores on the real-word dictation test correlated significantly with scores on the non-word dictation test but not with the proportion of edited words. There was

a strong correlation between the proportion of successfully edited words and scores on the real-word dictation test. Furthermore, a high score on the non-word-dictation task was significantly correlated to a lower proportion of edited words and a higher proportion of successfully edited ones.

The proportions of edited and successfully edited words did not correlate significantly with the scores on the reading test or on the test of phonological decoding.

Editing behaviour as observed using writing-process data

The investigation of the participants' editing behaviour yielded the strategies or behaviours described below. Note that since the task is a word-dictation task, all editing is necessarily at the word level. Further, the choice of editing strategies or behaviours seemed more related to the idiosyncrasies of the individual participant than to aspects of the words edited, and different editing behaviours often overlapped, making it difficult to categorize editing operations.

(1) *Multiple editing of the same letter(s)/trial and error*: a writer repeatedly revises the same letter(s). This strategy was often applied to consonants and is time-consuming. It was also the most common strategy and was used by all participants. In the example (target word: *landsbygd* 'countryside'), the participant starts off writing the first word of the compound, *lands*, then types *bys* with pauses (pause duration given in seconds) between letters. The participant then deletes two letters (noted as 'BACKSPACE2', where the final digit indicates the number of key presses), then types *y* and *n*, then deletes the *n* and types *d* and *g*, then deletes *d* and *g*, then types *d* and *g* again. Finally, the last letter *g* is deleted.

Example:<8.453>**lands**<3.912>**b**<2.547>**y**
<6.805>**s**<4.387><BACKSPACE2><2.538>**y**
<3.306>**n**<2.517><BACKSPACE1><9.150>**d**
<2.506>**g**<BACKSPACE2><17.304>
<14.247>**d**<5.392><20.305>**g**<4.157>
<MOUSECLICK><BACKSPACE1>
<MOUSECLICK

(2) *Instant editing*: editing is undertaken on the letter last written, which makes the production very linear. This strategy is often seen together with multiple editing and frequently used by the participants. In the example (target word: *känt* 'felt'), the participant writes *kän* and a *d*, then deletes the *d*, types a *t*, deletes the *t*, types *nt*, deletes *nt* and finally types *t*.

Example:<13.875>**kän**<4.514>**d**
<BACKSPACE1>**t**<10.237>
<BACKSPACE1>**nt**<2.369><BACKSPACE2>
t<9.813>

(3) *Edits after finishing a word*: the writer types the whole word and then undertakes editing using the mouse or the arrow keys to move backwards in the word. This strategy was quite common, but most evident in participant 7. In the example (target word: *bråttom* 'in a hurry'), the participant first writes *brotton*, then presses the enter key twice, then deletes the two line breaks and *otton*, and finally types *åttom*.

Example: <6.903>**brotton**<2.546><ENTER1>
<6.760><ENTER1><2.803>
<BACKSPACE7> <8.028>**å**<2.996>**ttom**<2.

(4) *Provisional splitting of compounds*: compound words are written 'open' to facilitate spelling and editing, and then put together when the component words are correct (or deemed correct by the writer). This strategy was primarily used by participants 1 and 6. In the example (target word: *cykelkedjan* 'the bike chain'), the participant first writes the word *cykel* 'bike' and starts to write *käe*, and then tries to edit this a few times. The first bold mouse click is where the cursor is moved and a space is inserted between the first and second components of the compound word. After that, the word *kedjan* 'the chain' is written with a great deal of editing. Then the second bold mouse click is when the cursor is finally moved into position to delete the space between the two component words.

Example: <5.810>c<2.331>y<2.065>ke<6.938>r
<BACKSPACE1>l<4.336>käe<BACK
SPACE2><6.525>ej<BACKSPACE1>l<4.591>
j<BACKSPACE1><2.905><**MOUSECLICK>**
<8.925>
<MOUSECLICK>an<2.078>
<MOUSECLICK>r<BACKSPACE1><3.655>
<MOUSECLICK>j<2.071><MOUSECLICK>
<BACKSPACE1>ä<BACKSPACE1>
<2.201>e<BACKSPACE1>
<6.598>e<4.774>
d<7.161><BACKSPACE1>
<2.426>d<10.708>
<MOUSECLICK>
<10.271>
<MOUSECLICK>

<BACKSPACE1><2.271>
<BACKSPACE1>d<6.448>
j<3.089><MOUSECLICK>
<MOUSECLICK><BACKSPACE1><17.505>
<MOUSECLICK><5.093>
k<2.015><BACKSPACE1><11.186**>**
<MOUSECLICK><BACKSPACE1>
<3.119><MOUSECLICK><

(5) *Editing large chunks at once*: the writer writes a word, deletes three or four letters, fluently writes three or four new letters, evaluates the new word and then deletes a large chunk again. This behaviour was found to be the most prominent in the participants with a fluent aphasia type, above all in participant 14. In the example (target word: *telegram* 'telegram'), the participant writes *temm*, then deletes three letters, then types *remm*, then deletes two letters. Then the letters *famin* and *g* are written, and then as many as six letters are deleted. Finally, the participant writes *gramming* and *ar*, yielding the word *tregrammingar*.

Example: <13.650>**temm**<2.626>
<BACKSPACE3><4.292>**remm**
<4.053><BACKSPACE2><2.715>
famin<2.779>
g<12.940><BACKSPACE6><2.516>
gramming<6.354>**ar**<

For one of the participants (participant 2), the process data showed evidence of additional perseverations, phonetic spelling and/or semantic errors which were later edited out. In the example (target word: *påskkycklingarna* 'the Easter chickens'), the participant begins by writing *ägg* 'egg' three times, alternating between two different spellings—'egg' is semantically related to Easter and chickens, but not phonetically or orthographically similar to the target word(s). Later on, the participant connects the word *ägg* to the beginning of the word *kyckling* 'chicken' before deleting it and starting to write the right word: *påsk* 'Easter'.

Example: <16.897>**ägg**<3.997>
<BACKSPACE3>**ägg**
<4.709><BACKSPACE3>**kyl**<7.228>
<BACKSPACE3>**äggky**<2.265>**li**
<BACKSPACE1>
<6.926><BACKSPACE6>**påskkyl**<2.816>
n<2.770><BACKSPACE1><6.367>
n<3.567><BACKSPACE1>**aa**<BACKSPACE1>
<2.079><BACKSPACE1><5.515>**n**<12.101>
<BACKSPACE2>
nl<BACKSPACE2><4.782>
lnn<BACKSPACE3><2.159>
ln<4.820>**i**<2.134>**s**
<2.902><BACKSPACE3><3.609>

Discussion

The aim of this study was to analyse PWAs' spelling and editing difficulties in a dictation task and to relate those difficulties to various aspects of the words written. Two additional aims were to relate successful editing operations to reading and phonological decoding ability as well as to investigate whether any specific editing strategies or editing behaviours could be observed in the keystroke logs.

Error types and categories

To classify the spelling errors found, a number of categories were borrowed from research into developmental writing difficulties and supplemented with other categories designed to suit PWAs, in line with the claims of Whitworth *et al.* (2005). However, in some cases it was difficult to apply those categories to the errors made by the participants. The errors made by those with the most severe spelling difficulties often had to be categorized as 'non-categorizable', meaning that the most severe errors were difficult to interpret and hence to analyse. This finding suggests that the surface analysis of spelling errors might be difficult to apply to a group with more severe agraphia. The relatively few errors being categorized as 'aphasia-specific' errors might also be attributed to the groups' aphasia severity level. However, the words categorized as 'non-categorizable' should also be seen as aphasia-specific since writers typically do no produce unrecognizable words. At group level, the most common type of error was the omission of letters, presumably often the part of a word that a participant did not know how to spell. However, the participants also made errors which are very common among writers of Swedish without aphasia, such as those involving consonant doubling. Given that it might be expected that many participants would use the lexical route (Ellis 1982 and Hatfield 1989) and thus draw upon a visual, not auditory, representation of a whole-word 'image', where doubled consonants would be a salient feature, this type of error was surprisingly common.

The common phenomenon of compounding in the Swedish language also has implication for the function of the lexical route. Only one participant made more than the occasional compound splitting error. However, there was evidence of participants using the strategy of provisional splitting of compounds to aid or strengthen the function of the lexical route in editing.

The fact that errors were often difficult to categorize is interesting from the perspective of the question as to whether PWAs can benefit from using apps or digital

spellcheckers developed for persons with developmental writing difficulties. Spellcheckers or word predictors are more likely to be of benefit if the word produced is close to the target. There seem to be certain differences in categorizable error types associated with the difference in aetiology. Persons with developmental writing difficulties seldom omit large parts of words or have perseverations. In Swedish adults with developmental reading and writing difficulties, the most common errors were substitutions (commonly of vowels) and consonant doubling (Wengelin 2002).

Further, there are reports of 'visual errors' in dictation writing by PWAs (e.g., Rapcsak and Beeson 1991), but during the error analysis in the current study it proved difficult to establish with certainty that a given error is visual as an amount of subjective judgement would be required. For example, any minor error will, by definition, result in a word which closely resembles the target word. Hence, there is a risk that categorization as a visual error would incorrectly exclude other factors that might explain the error just as well. For this reason, no errors have been categorized as visual errors in the present study.

Spelling and editing difficulty

Although the participants all had mild to moderate aphasia and all were able to write connected texts, their scores on the dictation tasks show great variation: between 6.12% and 95.92% correct words on the real-word-dictation task and between 0 and 17 (maximum score of 18) correct ones on the non-word-dictation task. This variation exists despite the group's limited variation in severity and type of aphasia and agraphia.

Four participants actually scored above the norm value on the real-word-dictation task. This could be taken to mean that they have no spelling difficulties. However, if information about editing is also taken into account—that is, if editing difficulty or a need for substantial editing is seen as part of spelling difficulties—it is evident that at least some of those participants do have spelling difficulties and show evidence of uncertainty about spelling. Those four edited between 10.2% and 73.5% of their written words, meaning that there was great variation. The participant who edited 73.5% of their words might not have been able to attain a high score on a dictation task performed by hand or with a time limit. It is also worth noting that a writing process where almost three-quarters of the words in a text are edited is a time-consuming and effortful process, and this is highly likely to affect functional aspects of text writing, as reported in Johansson-Malmeling *et al.* (2020), where more editing correlated with a lower production rate. This result is supported by the finding that correctness of spelling did not correlate with the amount of editing undertaken by a participant but did correlate with the quality of the editing. Hence, strong or weak spellers do not edit more or less, they edit better or worse. However, extensive editing by definition exerts a negative impact on productivity in text writing (Johansson-Malmeling *et al.* 2020) potentially by adding cognitive 'weight' onto the working memory and the graphemic buffer (Berninger *et al.* 2002b).

Using keystroke logging to investigate writing makes it possible to analyse the process leading up to the finished text. However, it unfortunately does not provide any insight into the participants' brains that might identify their intentions or thoughts while writing. Hence, the analysis of spelling strategies must be limited to what is visible in the logs, but that analysis should be informed by what is known about PWAs' writing and their writing difficulties. The most common editing strategy was the multiple editing of the same letter(s), which might also be referred to as trial and error. This strategy was also reported as commonly used in text writing for PWAs, where 13.8% of edits were categorized as trial and error (Behrns *et al.* 2008). The writers appear to try out different spellings for a word, primarily, it would seem, using the lexical route to evaluate the result. In cases of unsuccessful editing, it seems that the phonological processes required for editing on the grapheme/phoneme level do not work properly, suggesting a failure of the *sub-lexical* route. And phonological spelling was indeed related to successful editing. But it is clear from the logs that participants using this trial-and-error strategy may also have difficulty knowing when a word is correctly spelled, since they sometimes edit out the correct spelling, suggesting a failure in the *lexical* route. However, it is not possible to tell from the logs whether, in a given case, the participant actually thinks that the word is correctly spelled even though it is not or whether he or she simply gives up because the task has become too tiresome.

To return to the issue of the usefulness to PWAs of spellcheckers and word predictors, it can be noted that many of the words found to have non-categorizable errors and to bear little resemblance to the target word still had a correct first letter. This would seem to suggest that a digital word-prediction tool might actually work to some extent for PWAs, as used in the studies by Behrns *et al.* (2009) and Thiel *et al.* (2017). In addition, this finding might indicate that the lexical-retrieval process remains functional and that the orthographical representation is preserved to some extent even though the person is not able to spell the word correctly. Caramazza *et al.* (1987) suggested that difficulties manifesting themselves towards the end of a long word might be a sign of difficulties in the graphemic buffer.

Further, in compound words, it was more common for the second or third morpheme to be affected by an

error. This might be due to the above-mentioned factors relating to lexical retrieval and orthographical representation, but it might also be related to the function of the graphemic buffer in the verbal working memory, which would theoretically support the ability to retain and manipulate verbal information (such as words and their orthographical representation). It is well established in research that different aspects of writing are dependent on the limited capacity of the working memory (e.g., Berninger *et al*. 2002b, Olive 2004), and there are reports of impaired working-memory function in PWAs (e.g., Lang and Quitz 2012, Mayer and Murray 2012). An impaired or strenuous spelling process could also be expected to require additional working memory capacity, since the process is no longer automatized (Berninger *et al*. 2002b). One participant made the following comment on the writing of compounds: 'When I work so hard on spelling the first word [morpheme] I sort of forget about the second one,' which might be an anecdotal indication of strain on the graphemic buffer of the verbal working memory.

Word length and word frequency in relation to spelling and editing difficulty

The results show that word length and word frequency are related to spelling difficulty in a dictation task, which is expected and in line with the findings of Whitworth *et al*. (2005) and Bricker *et al*. (1964). It is also in line with previous research into errors in text writing by the same participants as in the present study (Johansson-Malmeling 2019). According to the PALPA model, if the participants' errors are related to word length, it might be a graphemic buffer deficit but if the errors are related to frequency it is more likely a semantic lexical deficit (Kay *et al*. 1996). The present study adds that the same aspects (word length and word frequency) are also related to editing difficulty. However, there was no correlation between word length and frequency on the one hand and successful editing on the other. Hence, short and familiar words were not easily edited, they were simply more often written correctly initially. There is evidence of the influence of 'age of acquisition on spelling' (Hirsh and Ellis 1994, Weekes *et al*. 2003) and ideally, the possibility to include age of acquisition as a lexical variable in this study would contribute to the knowledge on lexical influence on spelling ability. However, data of age of acquisition is not yet available in Swedish word data bases. Still, this study is a step forward in characterizing the impact of lexical variables on spelling and editing in Swedish speakers with aphasia.

Neuro-psychological models of writing such as the dual-route model (Ellis 1982, Hatfield 1989) and the PALPA model (Kay *et al*. 1996) suggest that it might be interesting to investigate the relationship between spelling errors and editing difficulty on the one hand and different types of agraphia and/or aphasia on the other. However, owing to the relatively small size of the sample studied here and the fact that the majority of the participants were categorized as having a non-fluent aphasia type, it is not possible to investigate statistically whether different spelling and editing difficulties are related to different aphasia types. Still, it is worth noting that only two of the participants made more than occasional writing errors reflecting perseverations—one who had fluent aphasia and one who (albeit acutely diagnosed as having global aphasia) had non-fluent aphasia. Perseverations in speech are typically associated with fluent aphasia types, but it should be noted that those two participants are among the three persons in the present study with the most severe aphasias.

Abilities useful for spelling and editing

Phonological decoding ability and reading ability were hypothesized to be useful for spelling and editing while writing. Previous research has found an underlying phonological deficit related to both reading and spelling ability (Rapcsak *et al*. 2009) and that the results from tests of spelling and reading of non-words could predict word reading and word spelling in PWAs (Rapcsak *et al*. 2007). Tainturier and Rapp (2010) showed how reading and writing draws upon the same graphemic buffer resources and how nonsense words are more demanding to both spell and read. Somewhat surprisingly, no significant correlations were found between successful editing on the one hand and reading or phonological decoding ability on the other. However, as Rapcsak *et al*. (2009) has showed that spelling ability was more severely impacted by the phonological deficits than reading, there is a possibility that the participants (having mild to moderate aphasia) had preserved reading ability sufficient for editing. Hence, the analysis showed no significant correlation, but might have with participants with more severe aphasia. Here it should be noted that, in the absence of a specially designed Swedish-language test for acquired reading and writing difficulties, the tests of reading and phonological decoding used were taken from screening tests for developmental reading and writing difficulties. Although the instructions for those tests were modified to some extent to suit the needs of PWAs, both the reading test and the phonological decoding test had a time limit. The dictation tasks did not, meaning that the presence or absence of a time constraint may have influenced the correlation findings. In future studies it would be beneficial to include tasks which are similar in such respects and which have been validated for use in PWAs. The significant

correlation between results of non-word spelling and successful editing establishes the importance in phonological spelling skills for editing.

Limitations

One of the limitations of this study is the relatively small sample size. The participants all had mild to moderate aphasia and the vast majority of participants had non-fluent aphasia, which limits the generalizability to persons with post-stroke aphasia as a group.

Another limitation is the lack of a comprehensive test for reading and writing difficulties for adults with aphasia in Swedish. Additional studies are warranted using data from a larger number of participants with more variation in severity and type of aphasia.

Future research

Future research should compare errors made in dictation tasks with errors made in free-narrative texts by PWAs to investigate whether, and to what extent, error types are similar across task types. It would also be useful to compare error types and editing behaviour between persons with acquired and developmental writing difficulties, respectively, to assess the appropriateness of having PWAs use digital writing aids originally developed for persons with developmental writing difficulties. Finally, some of the compound words in the dictation task are lexicalized, for example, *sjuksköterska* 'nurse' (literally 'sick nurseress') while others are not, for example, *innetemperaturen* 'the indoor temperature'. It might be interesting to know whether the lexicalization status of compound words affects spelling and editing difficulties.

Conclusions and clinical implications

When spelling tests for PWAs are developed, word length and word frequency should be taken into consideration. When spelling difficulties are assessed, both correctness of spelling and the presence of editing difficulties should be taken into account, to obtain a fuller picture of the person's spelling ability. Treatment for writing difficulties in aphasia should include training in successful editing strategies. Finally, since editing strategies and behaviour turned out to be individual, the fitting of PWAs with digital writing aids should be individual as well.

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Supporting Information

Additional supporting information may be found online in the Supporting Information section at the end of the article.

Appendix. Words from the word-dictation task with frequency level and word length