

Changes in writing processes caused by post-stroke aphasia or low-grade glioma

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“A word after a word after a word is power.”
Margaret Atwood

Abstract

Background: Writing is a cognitively and linguistically complex task, therefore sensitive to impairment caused by the presence and surgical removal of low-grade glioma or presence of post-stroke aphasia.

Purposes: The overall aim of the thesis was to investigate the changes in writing processes, text characteristics and spelling caused by post-stroke aphasia or low-grade glioma. *Methods:* In study I, 20 consecutive participants with presumed low grade glioma wrote a copytask and a narrative and were tested with test of spoken lexical retrieval before and three months after tumour resection. The aim of the study was to investigate writing fluency before and after surgery and whether writing fluency was related to oral lexical retrieval difficulties. In study II, the 15 participants with aphasia and a matched reference group wrote two narrative texts and were tested with dictation tests. Texts characteristics and aspects of the writing process were compared between groups and relations between different writing processes were investigated for both groups. Relations between spelling in text and dictation tests were examined for the study group. In study III, the aim was to investigate the lexical features of two types of narrative texts, and the words with errors, written by 16 participants with aphasia and compare to texts written by a matched reference group. Corpus linguistic analysis methods were used. In study IV, 16 participants with aphasia wrote a word dictation test and were tested for phonological de-coding, reading ability and phonological spelling. Spelling ability and editing was analysed and related to reading and phonological abilities. The writing tasks in all studies were written in a keystroke logging program to enable analysis of the texts as well as the writing process behind the texts.

Results and conclusions: I: Aspects of writing fluency were affected both before and after surgery but typing speed was an important factor behind the pre-surgery differences. A decline in overall productivity and an increase in pauses before words after surgery could be related to a lexical deficit. II: All aspects of productivity in text writing were affected for the group with aphasia. There was a relation between editing and productivity for the persons with aphasia, but not for the reference group. Scores in spelling tests cannot predict spelling in free texts. III: Texts written by persons with aphasia contained a less varied vocabulary and they tended to avoid using long words. The mis-

spelled words were more likely to be content words, long words and uncommon words for the persons with aphasia than for the reference group. Lexical features in text writing were affected by aphasia, but was dependent on the type of text writing task. IV: The most common error type was omission of letter(s) and there was evidence of aphasia specific writing errors. Both spelling and editing difficulty was related to word frequency and word length. Successful editing was related to phonological spelling scores, but not to phonological de-coding or reading ability. Specific editing strategies could be identified.

Keywords

Aphasia, writing, writing process, spelling, keystroke logging, low-grade glioma

Sammanfattning på svenska

Att skriva är en kognitivt och språkligt krävande aktivitet. Personer som får någon form av hjärnskada får ofta skrivsvårigheter. I avhandlingen beskrivs och analyseras de skrivsvårigheter som uppstår när en person har och behandlas för låggradigt gliom (en typ av hjärntumör) eller afasi (svårighet att förstå och producera språk efter hjärnskada) i samband med stroke.

Syftet med avhandlingen var att undersöka förändringar av skrivprocesser (det vill säga allt arbete som ligger bakom en text), egenskaper hos texten och stavning som orsakats av låggradigt gliom eller afasi i samband med stroke.

Metod: I studie I skrev 20 deltagare med förmodat låggradigt gliom en kopieringsuppgift och en berättelse och fick göra test som undersökte muntligt ordflöde före och tre månader efter tumörresektion. Studiens syfte var att undersöka om deltagarnas skrivflyt ändrats efter operationen samt om skrivflyt relaterade till svårigheter med muntligt ordflöde. I studie II skrev 15 deltagare med afasi efter stroke och en referensgrupp två olika sorters berättelser, en kopieringsuppgift och två diktamensuppgifter. Variabler från den färdiga berättelsen och från skrivprocessen jämfördes sedan med resultat från en referensgrupp som hade gjort samma skrivuppgifter. Vidare undersöktes relationen mellan de olika skrivprocessmått i båda grupperna. Relationen mellan personernas stavningsförmåga när de skrev en berättelse och när de gjorde ett stavningstest undersöktes för gruppen med afasi. I studie III var syftet att undersöka lexikala drag, dvs. vilka ord som användes i två olika typer av berättelser skrivna av en grupp där deltagarna hade afasi och en referensgrupp. Syftet var också att undersöka och vilka av orden i berättelserna som var felstavade. Korpuslingvistiska analysmetoder användes. I studie IV gjorde de 16 deltagarna med afasi en diktamensuppgift och tester av fonologisk omkodningsförmåga, läsförmåga och fonologisk stavning. Deltagarnas stavningsförmåga och sättet de redigerade analyserades och relaterades till resultat från de olika testen. Alla skrivuppgifter i alla studier skrevs i ett tangentloggningsprogram som gör att man i efterhand kan se vilka ändringar personen gjort och var hen pausat.

Resultat och slutsatser: Studie I visade att aspekter av skrivflyt var påverkade både före och efter operationen för personerna med förmodat låggradiga gliom och att en skillnad i tangentbordshastighet var en viktig faktor bakom skillnaderna före operation. En nedgång i produktivitet, (mätt som ord per

minut) när de skrev och en ökning av pauser innan ord skulle kunna vara relaterat till en svårighet med att framplöcka ord/ordflöde. Studie II visade att alla aspekter av produktivitet var nedsatta för gruppen med afasi. Det fanns en relation mellan att göra många revideringar och att ha en lägre produktivitet för gruppen med afasi, men den relationen fanns inte i referensgruppens resultat. Resultat på stavning av isolerade ord i en diktamensuppgift kunde inte förutsäga hur deltagarna stavade i sin fria berättelse. I studie III visade resultaten att de berättelser som skrivits av deltagarna med afasi innehöll ett mindre varierat vokabulär och att de tenderade att undvika att använda långa ord. De felstavade orden var i oftare innehållsord, långa ord och lågfrekventa ord för deltagarna med afasi än för referensgruppen. Lexikala drag var påverkat i texterna för deltagarna med afasi jämfört med referensgruppen, men resultaten var delvis olika beroende av vilken typ av berättelse som de hade skrivit. I studie IV visade resultaten att det mest vanliga stavfelet för personer med afasi var att utesluta en bokstav/bokstäver och det fanns stavfel som var specifika för just afasi. Både stavning- och redigeringsvårigheter var relaterade till ordfrekvens (det vill säga hur vanligt ordet är) och ordlängd. Framgångsrikt redigerande var relaterat till resultat på test av fonologisk stavning, men inte till resultat på test av fonologisk omkodningsförmåga eller läsförmåga. Specifika redigeringsstrategier kunde identifieras och beskrivas.

List of papers

This thesis is based on the following studies, referred to in the text by their Roman numerals.

- I. Antonsson, M*, Johansson, C*, Hartelius, L, Henriksson, I, Longoni, F & Wengelin, Å.

*joint first authorship

Writing fluency in in patients with low-grade glioma before and after surgery

International Journal of Language and Communication Disorders 2018; 53:3: pp. 592-604.

- II. Johansson-Malmeling, C., Hartelius, L., Wengelin, Å. & Henriksson, I.,

Text writing and its relationship to writing processes and spelling ability in post stroke aphasia

Submitted for publication.

- III. Johansson-Malmeling, C., Wengelin, Å. & Henriksson, I.

Lexical features of narrative texts written by persons with post-stroke aphasia – analysis of word use and errors

Submitted for publication.

- IV. Johansson-Malmeling, C., Wengelin, Å & Henriksson, I.

Aphasia and spelling to dictation – analysis of spelling errors and editing

Manuscript

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Abbreviation

A-group	Group with post-stroke aphasia
BNT	Boston naming test
HGG	High-grade glioma
LGG	Low-grade glioma
PWA	Persons with aphasia
R-group	Reference group
TBI	Traumatic brain injury

Introduction

Writing in our society

Literacy is a prerequisite for participation in daily life in modern societies – the EU High Level Group of Experts on Literacy has recognised literacy as a tool required to have the power and the means to fully participate in society. Reading and writing skill is required to perform most jobs, to manage domestic finances or to obtain an education. It is also a question of democracy and human rights, since literacy is a prerequisite to partake of public information and to participate in the public discussion. In the past, reading was seen as the most common literacy activity. However, it has been suggested that, following the process of digitalisation, writing has now surpassed reading as the primary literacy activity, meaning that we have gone from an era of mass reading to an era of mass writing (Brandt, 2014). This dependence on writing skills poses a challenge to persons with aphasia or other reading and writing difficulties in a highly digitalised society such as Sweden.

A report commissioned by the Swedish National Board of Health and Welfare (Socialstyrelsen) showed that 94% of people in Sweden older than 12 years of age are Internet users. The activities that most people engage in online are searching for information, e-mailing and using social networks and chat services (Internetstiftelsen i Sverige, 2017). People with aphasia or other language difficulties, because of their communication difficulties, are at risk of having a low quality of life (Cruice, Worrall, Hickson & Murison, 2003; Lam & Wodchis, 2010) and of experiencing social exclusion. They could benefit greatly from the opportunities offered by the Internet when it comes to maintaining social relationships. However, another report called Swedes with disabilities and the Internet [Svenskarna med funktionsnedsättning och internet] found that people with aphasia was the group where the largest proportion of survey respondents answered that they felt excluded from participation on the Internet, and reading and writing difficulties were identified as the most important factor for exclusion (Johansson, 2017). The Swedish Aphasia Association has named the right to digital participation one of its main issues (Afasiförbundet, 2019).

Aphasia

The traditional definition of aphasia is that it is an acquired language impairment caused by focal brain lesion in language areas in the language-dominant hemisphere (most often the left hemisphere) (Papahtanasiou, I. & Coppens, P., 2012). In recent decades, however, the definition has been broadened to cover brain lesions in many locations (Ahlsén, 2006). The most common cause of aphasia is stroke, but aphasia can also be caused by traumatic brain injury, tumour growth, tumour resection or other brain injury. Approximately one-third of stroke survivors are affected by aphasia (Efstratiadou, Chelas, Ignatiou, Christaki, Papathanasiou & Hilari, 2012). Aphasia entails difficulties in producing and understanding spoken and written language.

There are different types of aphasia which can roughly be divided into two groups: non-fluent and fluent aphasia. Non-fluent aphasia is characterised by anomia (difficulties with lexical retrieval) and writing difficulties with relatively well-preserved auditory comprehension and reading ability. Fluent aphasia is characterised by the fluent production of spoken and written language which may be difficult to understand, as well as by difficulties with auditory comprehension and reading. However, all types of aphasia entail difficulties in many different linguistic functions; clear lines between different aphasia types are difficult to draw.

Difficulties with communication related to cognitive functions or decline, caused by for instance lesions in the non-dominant hemisphere, can entail difficulties with lexical retrieval (anomia), narrative ability, making inferences or taking the initiative in communication contexts. These difficulties are referred to as cognitive communicative disorders (Tompkins, Klepousniotou & Scott, 2013); they can overlap with aphasia when it comes to their symptoms.

Low-grade glioma (LGG)

A low-grade glioma is a slowly growing tumour in the brain (Pallud et. al 2012). Brain tumours are classified as having different grades of severity based on histological variables; tumours rated as grade I or II are referred to as low-grade glioma (LGG). LGGs are often situated in or near ‘eloquent areas’ of the brain, i.e. areas believed to be the location of language, motor or sensory functions (Duffau & Capelle, 2004).

The issue of impaired communication has been investigated in persons with glioma, but since they usually present only with subtle difficulties, test batteries designed for persons with post-stroke aphasia have been deemed insufficiently sensitive (Papagno et al., 2012). A study by Brownsett et al. (2019) investigated

self-reported changes in communication post-surgery in tumour patients. The findings included word-finding difficulties (often in combination with fatigue), a need for more time to find or understand words, a need to ask people to repeat verbal information, difficulties engaging in conversations with several people, difficulties reading connected text and difficulties producing words using a keyboard.

Lexical-retrieval difficulties have been reported as the most common language deficit in persons with low-grade glioma both before surgery (Antonsson, Longoni, Jakola, Tisell, Thordstein & Hartelius, 2018; Papagno et al., 2012; Satoer et al., 2014) and after surgery (Antonsson, Jakola, Longoni, Carstam, Hartelius, Thordstein & Tisell, 2018; Ek, Almqvist, Wiberg, Stragliotto & Smits, 2010; Racine, Li, Molinaro, Butowski & Berger, 2015; Satoer, Vincent, Smots, Dirven & Visch-Brink, 2013). Although research based on neurolinguistic models suggests that lexical-retrieval difficulties should affect both the spoken and the written modalities (Luria, 1976), there is little research into the issue of written lexical retrieval in persons with LGG before and after tumour treatment.

Lexical retrieval in oral and written language production

Lexical retrieval is a core language function, and difficulty with lexical retrieval is a cardinal symptom of aphasia as well as a common sign of language-function decline. On the prevailing view, the process of oral lexical retrieval begins with the conceptualisation of the target word and then moves on to lexical selection. The word is then encoded at the morphological and phonological levels, and the process ends with the articulation of the word (Levelt, Roelofs & Meyer, 1999). It has been suggested that the lexical retrieval of verbs might be more sensitive to impairment (Mätzig, 2009), but a study matching verbs and nouns to psycholinguistic factors found no difference between nouns and verbs. (Alyahya, Halai, Conroy & Lambon Ralph, 2018). Also, word frequency (not surprisingly) has an impact: in an unimpaired population, the retrieval times for the written naming of nouns was longer for low-frequency words (Paesen & Leijten, 2019). When it comes to differences between oral and written retrieval, it has been suggested that written words are retrieved from the same semantic system as spoken words but that the output lexicon used is modality-specific (Kay, Lesser & Coltheart, 1996). The primary output lexicon used for written words is claimed to be orthographic in nature. There would also appear to be a difference in the reliance on motor skills in that oral lexical retrieval is dependent on articulatory motor skills whereas written lexical retrieval is dependent on graphomotor skills. An additional difference

in the retrieval process might concern the extent to which whole words are retrieved. Research into written lexical retrieval suggests that words which are to be spoken are retrieved as a single unit, whereas the full orthographical representation of a word may not yet have been retrieved when a person starts typing that word (Rønneberg & Torrance, 2019; Torrance, Nottbusch, Alves, Arfe, Chanquoy, Chukharev-Hudilainen, . . . Wengelin, 2018).

Writing with aphasia or cognitive communication disorders

People who have reading and writing difficulties due to aphasia experience this as a great loss (Kjellén, Laakso & Henriksson, 2016, Knollman-Porter, Wallace, Hux, Bron & Candace, 2015; Lynch, Damica, Abendroth & Nelson, 2013; Parr, 2007), and this loss affects their quality of life (Parr, 1995; 2007). Even so, writing difficulties have received fairly little attention in research and treatment focusing on persons with aphasia. In fact, it has not even been established to what extent persons with post-stroke aphasia have writing difficulties; however, a Swedish registry for patients with stroke reported that approximately 26% of them claimed to have writing difficulties at a follow-up three to five years after their stroke (Riksstroke, 2018).

It has been suggested that acquired spelling difficulties have specific neuroanatomical correlates: the left perisylvian regions might be of importance to phonological spelling, and the left angular gyrus might be more important for lexical spelling (for an overview, see Beeson & Rapcsak, 2002). However, while those brain locations may well be particularly important for the spelling function as such, it should be kept in mind that writing in the broader sense of a cognitive activity is dependent on both linguistic and cognitive abilities and hence on large neural networks.

Historically, the most common research procedure when investigating writing in aphasia has been to examine spelling using single-word dictation tests and then analysing the scores against the background of the dual-route model (see, e.g., Beeson & Rapcsak, 2015). The type of writing disorder is then determined based on the type of spelling errors made.

Spelling has also been investigated in persons with glioma. The types of spelling errors made by persons with post-stroke aphasia and those made by persons with spelling difficulties due to glioma surgery largely overlap (van Ierschoot, Bastiaanse and Miceli, 2018). In the aforementioned study by Brownsett et al. (2019), writing difficulties were reported for persons with glioma after surgery: 24% of them scored below a cut-off for written picture-description and 19% scored below one for writing to dictation. A review by van Ierschoot, Bastiaanse and

Miceli (2018) found that spelling difficulty was reported in 44.4% of patients with glioma before surgery and that 26.9% of those who had had unimpaired spelling before their surgery manifested spelling difficulties after it, which remained at follow-up in approximately half of those cases. However, it should be noted that both of those studies included patients with grade II–IV tumours, i.e. not just low-grade ones (which are grades I–II). Research into writing in persons with traumatic brain injury (TBI), who had cognitive difficulties caused by their TBI but had not been diagnosed with aphasia (Dinnes, 2018), found writing difficulties to be more common than spelling difficulties; the participants were reported to have difficulties with many different aspects of writing, such as spelling, punctuation and grammar as well as composing a message, organising a text, generating content and retrieving words.

As noted above, the lexical features of individual words have an impact on spelling ability and difficulty: spelling errors in a dictation test are more prone to appear in low-frequency and long words (Whitworth, Webster and Howard, 2005). However, it is not known whether this finding applies to text writing as well as to dictation. Although spelling research has contributed to our knowledge of spelling impairment, there is little research investigating how spelling-test scores transfer to more functional text writing or what types of writing difficulties are experienced in that context. Research into text writing by persons with aphasia and related language disorders remains scarce. One reason is that many people with aphasia are not able to produce written texts (meaning that there is a shortage of data for research). Another is that the writing difficulties associated with aphasia are particularly persistent, meaning that by the time a patient has recovered other abilities and left rehabilitation (where clinical studies typically take place), his or her writing difficulties often remain (Ahlsén, 1998).

However, some research has been carried out. Its findings include that texts written by persons with aphasia contain more spelling errors (Vandenborre et al., 2018, Behrns, Ahlsén & Wengelin, 2010), have less complex syntax and are more often perceived as vague (Behrns, Ahlsén & Wengelin, 2010) and less engaging (Mortesen, 2004) compared with texts produced by reference groups. However, their texts have been found to have relatively well-preserved text structure and lexical diversity (Behrns, Ahlsén & Wengelin; 2010).

Models for spelling, writing and writing processes

To explain writing or spelling at the word or text level, and any difficulties manifested, various models of writing tend to be used. When it comes to analysing acquired writing difficulties, diagnosing the type of agraphia and providing a basis

for writing treatment, the most commonly used model is the dual-route model. It suggests that there are two autonomous routes which can be followed when a person writes a word: a phonological (sub-lexical) route and a lexical–semantic route. Those routes may be selectively impaired, or both of them may be affected (Ellis, 1982, Hatfield, 1998). A more recent, aphasia-specific, model is the PALPA (Psycholinguistic Assessment of Language Processing in Aphasia) model (Kay, Lesser & Coltheart, 1996), which builds on the two basic routes of the dual-route model but also describes lexical retrieval in speech and reading. The dual-route model was originally developed to explain reading at the single-word level, although it has long been used to diagnose and categorise acquired writing difficulties and served as a basis for writing treatment. The research carried out into the applicability of the dual-route model to writing also relies heavily on scores on word-dictation tests, and it is not known how dictation-test scores relate to functional text-writing ability in persons with aphasia.

Against this background, Susan Parr (1991) developed an ethnographic approach to research into acquired reading and writing difficulties, where she advocated a sociolinguistic approach to writing difficulties and emphasised the importance of paying attention to pre-morbid writing ability. Among other things, Parr stressed that writing takes place in a social context and as a component of different literacy practices.

In research focusing on the cognitive aspects of text writing, models have been developed to explain the complex dynamics of the writing process as a linguistic AND cognitive activity. Those models acknowledge that writing is dependent not only on linguistic abilities but also on a range of cognitive functions, such as working memory and executive function. The most famous model of text writing was originally developed by Flower and Hayes (1981) and later revised by Hayes (2012). The original model as presented by Flower and Hayes suggests three basic sub-processes of writing: planning, translating and reviewing. They stress that a writer will continually and dynamically shift his or her attention between sub-processes. Another model of text writing, the ‘simple view of writing’ was originally developed by Berninger et al. (2002b) to explain how children develop the skills necessary for writing, but it can also be very useful in the investigation of acquired writing difficulties. The model describes how two components – (1) transcription (typing and spelling) and (2) executive functioning (planning, reviewing, editing and evaluation of the text written so far) – enable the third component: (3) text generation. The first component is typically automatised in adult writers, meaning that it requires less working-memory capacity than the second component. Research into working memory and its function in the writing process has showed how different components or sub-processes often ‘compete’ for working-memory capacity and how, since working memory is a limited resource, when one

sub-process requires more of that resource, the others receive less of it. For example, Hayes and Chenoweth (2006) showed that if an additional charge is placed on transcription, the quality of their text deteriorates. Olive, Kellog & Piolat (2008) showed that text writing places equal demands on verbal working memory and visuospatial working memory.

Since text writing is such a cognitively complex and demanding task, it has been suggested that it offers a sensitive instrument for detecting language and cognitive impairment or decline (Keenan, 1971; Rapp, 2002, Lorch, 2013) – more sensitive than the analysis of spoken production (Vandenborre, 2018).

Analysis of writing processes

Analysing text writing may involve the analysis of final texts or the analysis of the writing process behind such texts. In fact, any final text is the product of a process and of a context. Certain aspects of that process can be identified and analysed. This is useful because it cannot be seen from a final text, for example, how much its author edited it, how fast it was written or whether the writer made any major changes to its structure. Information about such aspects clearly adds knowledge that is relevant in the models of writing used. There are many methods available for examining writing processes, including think-aloud protocols, retrospective protocols and video recordings of writing sessions (Janssen, van Waes & van den Bergh, 1996). However, many of those methods are unsuitable for persons with aphasia since their writing processes tend to be easily disturbed and their texts tend to be quite short. In recent decades, software has been developed to record and log writing processes. Software for such ‘keystroke logging’ enables analysis both of the text as it emerges and of the final text. It records all actions made using the keyboard or the mouse on a timeline, which makes it possible to see, for example, where and how the writer edited the text and how fast the writer typed. Temporal aspects of the writing process can provide a useful proxy for the cognitive energy required for writing. Analysis of pause length and location also enables the measurement of fluency (Leijten & Van Waes, 2013). Keystroke logging has been widely used in research into academic writing and writing development, but it has also proved useful when investigating writing processes in persons with developmental writing difficulties (Wengelin, 2002), in second-language learners (see, e.g., Spelman Miller, Lindgren & Sullivan, 2008), in persons with Alzheimer’s disease (Van Waes, Leijten, Mariën & Engelborghs, 2017), in persons with mild cognitive impairment (Paesen & Leijten, 2017), in persons with Parkinson’s disease (Iakovakis, Hadjidimitriou, Charisis, Bostantzopoulou, Katsarou &

Hadjileontiadis, 2018), in students with hearing impairment (van de Weijer, Åkerlund, Johansson & Sahlén, 2019) and in persons with post-stroke aphasia (Behrns, 2008). Because of the fine-grained temporal data it yields, keystroke logging may enable particularly subtle changes in the writing process to be detected and analysed. A further advantage to using a computer and specifically a keyboard to investigate writing in persons with aphasia or at risk of aphasia is that, since they commonly present with brain lesions in the left hemisphere, the right side of the body, including the right hand (which they are most likely to prefer for writing), may be impaired when it comes to motor and sensory function, but they may – even before their stroke – have acquired the skill of typing with both hands.

The use of keystroke logging to investigate writing processes and text writing in persons who have aphasia or are at risk of language-function decline represents a minimally invasive method to obtain insight into the linguistic and cognitive processes underlying writing.

Aims

The overall aim of the thesis was to investigate the changes in writing processes, text characteristics and spelling caused by post-stroke aphasia or low-grade glioma. The specific aims of the studies were:

- I. To explore whether writing fluency was affected in LGG patients before and after surgery and whether writing fluency was related to performance on tasks of oral lexical retrieval.
- II. To examine and compare text writing in the production of narratives in persons with and without aphasia and to interrelate measures from the narrative output for both groups. To relate measures of writing and writing processes to scores on tests of spelling.
- III. To investigate and compare the lexical features of texts written by persons with post-stroke aphasia and by a matched reference group, and to investigate and compare the lexical features of the misspelled words in the same groups.
- IV. To analyse spelling and editing difficulties as well as errors in a dictation task performed by PWAs and to identify any relationships between spelling and editing difficulties and characteristics of individual words. Additional aims were to investigate the relationship between successful edits and reading and writing ability and to identify specific editing strategies or behaviours.

Methods

Participants

The participants in Study I were 20 consecutive patients with presumed LGG, scheduled to undergo surgery at the Department of Neurosurgery at Sahlgrenska University Hospital in Gothenburg, Sweden. The inclusion criteria for participation in Study I were (1) presumed LGG, (2) age over 18 years, (3) absence of moderate or severe developmental or language disorder, (4) Swedish as a first language and (5) absence of developmental reading or writing difficulties. Histological examination after surgery showed that eight of the participants in the study actually had a tumour of a higher grade than 2, meaning that those patients were diagnosed with high-grade glioma.

The participants in Studies II, III and IV were recruited through speech-language pathologists and local aphasia organisations in the western region of Sweden. The criteria for inclusion in the studies were: (1) aphasia due to stroke, (2) a score above 2.5 on the 'A-ning' (Lindström & Werner, 1995) sub-tests of writing or auditory comprehension, (3) ability to use a computer keyboard, (4) a minimum of six months since the onset of stroke, (5) age over 18 years and (6) Swedish as a first language. Exclusion criteria were (1) developmental reading and/or writing difficulties or other learning impairment existing prior to the stroke and (2) a hearing or visual impairment which could not be compensated for. Eighteen participants met the inclusion criteria and were thus recruited to the three studies. The inclusion criteria regarding performance in writing and auditory comprehension (based on sub-test scores from 'A-ning') yielded a group of participants with mild to moderate post-stroke aphasia. Two of the eighteen participants were excluded from the analysis in all three studies after initial participation: one owing to failure to complete the tests because of fatigue and one owing to developmental reading and writing difficulties which were identified after the tests. In Study II, one additional participant was excluded owing to technical errors. Information about the study participants is shown below in table 1.

A reference group matched for age and educational level was used in all studies except Study IV. The reference group was assembled from a larger group of 52 participants, which was a convenience sample recruited through different community organisations as well as through the personal networks of the thesis author and of her supervisors. The inclusion criteria for the reference group were (1) age

over 18 and (2) Swedish as a first language. Exclusion criteria were (1) neurological disease or disorder, (2) developmental reading and writing difficulties or other learning impairment and (3) hearing or visual impairment which could not be compensated for. The data from the reference group were collected by two final-year speech-language pathology students, an assistant researcher and the author of the thesis.

Table 1. Participants in the thesis

Study	Participants	Sex	Age in years (mean)	Educational level (mean)
I	20 participants with presumed LGG	12 m, 8 f	25–62 (45.8)	9–22 (15.0)
	31 participants (reference group)	14 m, 17 f	26–62 (45.5)	11–21 (16.1)
II	15 participants with post-stroke aphasia	11 m, 4 f	58–79 (69.1)	9–25 (15.1)
	26 participants (reference group)	15 m, 11 f	58–79 (68.0)	9.5–21 (15.65)
III	16 participants with post-stroke aphasia	12 m, 4 f	58–79 (69.1)	9–25 (15.0)
	26 participants (reference group)	15 m, 11 f	58–79 (68.0)	9.5–21 (15.65)
IV	16 participants with post-stroke aphasia	12 m, 4 f	58–79 (69.1)	9–25 (15.0)

Notes: Except that one participant was excluded from Study II owing to technical errors, the participants with post-stroke aphasia were the same in Studies II, III and IV.

One reference group was assembled for Study I to comprise participants within the same age range and with the same average age and educational level, resulting in a group of 31 participants. A second reference group was assembled in the same manner to match the group of participants with aphasia in Studies II and III, resulting in a group of 26 participants.

Tests and writing tasks

Tests

All participants in all studies were tested for presence and severity of aphasia. The participants in Study I also underwent a battery of tests measuring their naming ability and verbal fluency. The participants in Studies II and IV underwent tests relating to reading and writing ability. All tests used are listed in the table below and described in the text following it.

Table 2. Tests used and abilities measured

Tests	Ability measured	Studies
'A-ning' (neurolinguistic aphasia examination)	Type and severity of aphasia	I, II, III and IV
Dictation, LS	Spelling in test	II and IV
	Editing in test	IV
Non-word dictation, LS	Phonological (sub-lexical) spelling in test	II and IV
Reading, DLS	Reading speed with retained comprehension	II and IV
Which word sounds right? Duvan	Phonological decoding	IV
Naming (BNT)	Lexical retrieval	I
Letter fluency (FAS)	Verbal fluency, lexical retrieval, executive function	I
Semantic fluency, animals	Verbal fluency, lexical retrieval, executive function	I
Semantic fluency, verbs	Verbal fluency, lexical retrieval, executive function	I

Aphasia type and severity were measured using 'A-ning', a neurolinguistic aphasia examination (Lindström & Werner, 1995). A-ning consists of seven sub-tests measuring different aspects of language function. The overall score, which gives a measure of aphasia severity, is the average score on all sub-tests. A-ning a standardised test in Swedish and is commonly used in Swedish clinics and aphasia research. A-ning overall scores are used to describe the participants in all studies, and the scores on the sub-tests of writing and auditory comprehension are used as inclusion criteria for the participants with post-stroke aphasia (Studies II, III and IV). The average score on the writing sub-tests is used to describe participants' writing in Study IV.

Since there is no spelling test for acquired writing difficulties in Swedish, word spelling (lexical spelling) was measured using LS dictation (Johansson, 2004) and a non-word dictation test (sub-lexical spelling). LS dictation is a word-dictation test commonly used in Swedish schools. The words were presented in a sentence read aloud by the examiner. The participants could have a word repeated if they so wished. The non-word dictation test encompassed 18 nonsense words from a non-word decoding sub-test included in the LS test. The words were two to eight letters long and had plausible Swedish phonology, but no actual meaning. There was no time limit to any of the dictation tests.

Reading ability was measured using a cloze task from DLS (Järpsten, 2002), which is a test battery for screening reading and writing difficulties in primary-school children. The task is to fill in missing words by choosing from four options;

it is designed to measure reading speed with retained reading comprehension. It was deemed suitable for use for the present purposes since it did not require the participants to read aloud or to answer any questions orally, in which case what would have been measured might instead have been difficulties in speech production related to aphasia. The test has a time limit of five minutes.

Phonological decoding ability was measured using a reading task from the Duvan test battery, which is designed to screen for developmental dyslexia in adolescents and adults (Lundberg & Wolff, 2003). The task is called 'Which word sounds right' and requires participants to choose among three nonsense words, one of which is a possible but incorrect spelling of a real word.

Naming (lexical retrieval) was measured using the digitalised version of the Boston Naming Test (BNT) (Kaplan et al. 2001). Administration and scoring were performed in accordance with Tallberg (2005).

Verbal word fluency was measured using three word-fluency tests: Letter fluency (FAS) (Spreen and Benton 1969), Semantic fluency (animals) and Semantic fluency (verbs). The task is to produce as many words as possible in different categories within a time limit; the categories are words beginning with the letters F, A and S for the letter-fluency task and animals and verbs for the semantic word-fluency tasks. Those tests are considered to measure not only verbal word fluency but also executive functions. The verbal word-fluency tests were administered and scored in accordance with Tallberg, Ivachova, Jones Tinghag and Östberg (2008).

Writing tasks

A number of writing tasks and measures were used in the various studies. They are listed in the table below and described in the text following it.

Table 3. Writing tasks, measures or variables and their description

Writing tasks	Measure or variable	Description	Studies
<i>Copy task (CT)</i>	Typing speed	Median time in seconds between characters within a word.	I, II, IV
<i>Picture-elicited narrative (PE)</i>	Writing fluency – burst length	Mean number of characters pressed between pauses >2 sec.	I
	Word-level pauses	Pauses (>2 sec) before, within or after a word.	I
	Word-level errors, proportion	Words not found in a Swedish dictionary (SAOL) or words not corresponding to the target word (in the dictation test).	I
<i>Picture-elicited and free narrative on a set theme (FN and PE)</i>	Production rate	Number of words in final text divided by minutes of total production time (words/minute).	I, II, III and IV
	Editing (proportion of un-edited text or words)	Proportion of characters or tokens first pressed remaining in final text or proportion of words which have been edited.	II and IV
	Text length	Number of words in final text (correct and incorrect).	
	Word-level errors (proportion and type)	Words not found in a Swedish dictionary (SAOL) or words not corresponding to the target word (in the dictation test).	II and III
	Lexical diversity	Word-variation ratio (OVR) $\log(\text{types})/\log(\text{tokens})$.	III
	Lexical density	Proportion of content words among all words in final text.	III
	Word frequency	Categorised as high, medium and low frequency in a frequency-band analysis.	III and IV
	Word length	Proportion of long words (>6 letters) or number of letters (in the dictation test).	III and IV
	Proportions of nouns and verbs	Proportion of nouns/verbs among content words.	III

Copy task

The rationale behind the use of a copy task is to measure typing speed in a task which requires a minimum of linguistic abilities or cognitive effort (Grabowski, 2008). The copy task used was based on an overlearned Swedish proverb, which was also shown on the screen for support, so as to minimise the lexical-retrieval

and spelling effort. The participants wrote the proverb 5–12 times, whereupon the median transition time (time in seconds between two characters within a word) was retrieved. This has proved to be a stable measure of basic typing speed.

Picture-elicited narrative

A picture-elicited narrative task was chosen to elicit a narrative with a story-telling structure, which is a type of structure that is well-known to most people. In addition, the pictures function as narrative and memory support during writing. A further reason for choosing a picture-elicited writing task was to have some control over vocabulary and to make the narratives more comparable, both within the study group and with the reference group. Two different sets of six pictures were used. They were taken from two children's picture books: *Frog, where are you?* (Mayer, 1969) and *One frog too many* (Mayer & Mayer, 1975). The picture sets had been tested and found to elicit comparable stories (Egevad, 2009; Lindström, 2009). The first story was used before surgery in Study I and in Studies II and III. The second story was used after surgery in Study I and in Study III.

Free narrative on a set theme

A free-narrative task on a set theme was included to elicit a text where the participant was free to write what he or she wanted; the theme was deemed to help the participant find ideas. The three themes used had a similar emotional tone so as to elicit comparable narratives. They were: *Last time I made someone happy*, *Last time I made someone surprised* and *Last time I was happy*. The retelling of an event or a personal memory was chosen for reasons of ecological validity, in that this represents a common form of narrative. The first theme was used in Study II and all three themes were used in Study III.

The New ScriptLog keystroke-logging tool (Wengelin, Frid, Johansson & Johansson, 2019) was used to collect data in relation to all writing tasks and dictation tests. The writing environment in ScriptLog looks similar to that in an ordinary word processor.

Measures from writing

Writing-process measures

The theories underpinning the analysis of pauses are derived from studies of spoken language, where a pause has been found to indicate that the speaker requires time to think, for example about what to say next or which word to use (Kaufert, Hayes & Flower, 1986). Pause analysis of speech has shown that pause length increases with the size of the output planned, meaning that pauses between clauses are typically longer than pauses within words. Similar patterns have been reported

for writing, where writers tend to make longer pauses between paragraphs and around clause barriers than between words in a clause (Nottbusch, Grimm, Weingarten & Will, 2005; Spelman Miller, 2000). Pauses within words are rare in skilled adult writers but common in persons with developmental writing difficulties, where they are interpreted as reflecting uncertainty about spelling (Wengelin, 2002). To describe how fluently a writer produces text, a variety of fluency measures can be used. Abdel Latif (2012) suggested that fluency should be measured on the basis of bursts of text production between pauses, resulting in a measure of the mean or median burst length in letters.

Another interesting aspect of the writing process may be how fast the text was produced. The most common way to measure basic typing speed is to measure the time between two keystrokes when a person is writing. This is called the transition time or interkey interval (IKI). Transition times can be measured for different writing tasks which typically require more or less cognitive and linguistic effort, which captures different aspects of typing speed. In Studies I and II, typing speed was measured as the median transition time within a word.

An overall measure of text productivity can be obtained by combining measures relating to the final product and to the time required for producing it. Such a measure can also in some cases be seen to reflect one aspect of writing fluency. In Studies I and II, the production rate was measured as the number of words produced per minute of total writing time.

Another important part of the writing process is the editing or revision of the text, which can be defined as any alterations made to the text while it is being produced or after the text is produced (Faigley & Witte, 1981). Edits in text writing can be local (the editing of a spelling error or a typo in words that are currently being produced) or global (edits made to move entire paragraphs or clauses) (Lindgren & Sullivan, 2002). All writers edit their texts, and there is no simple relationship between the amount and quality of editing. However, an editing operation pertaining to the spelling of a specific word (provided that the target word is known) can be classified as successful or unsuccessful depending on whether it yielded the correctly spelled target word or not. In Study IV, editing behaviour was investigated on the basis of observation of the participants' editing operations in the dictation tasks.

Measures of text characteristics

Measures from the final texts were used to analyse text length, the proportion of word-level errors and various lexical features. For the analysis of the measures of lexical features, any spelling errors in the final texts were corrected manually. Words which were not possible to correct were removed from the analysis. Then the words containing errors were analysed for lexical features. All lexical analyses

were performed using software provided by Språkbanken at Gothenburg University.

Spelling in texts and tests

Word-level errors in texts were defined as any word not found in a Swedish dictionary (SAOL, 2015). Morphological errors and words not fitting the context were not regarded as errors if they resulted in a correctly spelled word.

Word-level errors in the dictation tasks were defined as words not corresponding to the target word. A categorisation of the spelling errors made in the dictation-test words was performed in Study IV. The categories used reflected findings from research into spelling difficulties associated with developmental writing difficulties (Wengelin, 2002), common types of misspellings in Swedish (Nauclé, 1980) and types of spelling errors associated with aphasia (Whitworth, Webster and Howard, 2005).

Procedure and data analysis

Data collection

Data collection for Study I was carried out between 2014 and 2016 by Dr. Malin Antonsson, the other joint first author of Study I. The patients were tested for changes in language function on four occasions: before surgery, soon after surgery, at a three-months follow-up and at a one-year follow up. The purpose of data collection was to examine language function in patients with LGG before and after surgery (Antonsson, 2017). Before surgery and at the three-months follow up, the patients were tested using language tests, including the tests of oral lexical retrieval and oral word fluency. They also performed two writing tasks in ScriptLog: the copy task and the picture-elicited narrative task. The narratives used were *Frog, where are you?* (Mayer, 1969) before surgery and *One frog too many* (Mayer & Mayer, 1975) after surgery. Information about patients' tumour location was collected from medical records at the Department of Neurosurgery at the Sahlgrenska Hospital, Gothenburg, Sweden.

For Studies II, III and IV, data collection was a collective enterprise undertaken between 2014 and 2017 as part of a larger research project where data were collected from the sixteen participants on three occasions, one year apart. The participants underwent comprehensive testing for that large longitudinal study; not all test results were analysed for the purposes of this thesis. After initial testing using A-ning to determine inclusion in the study, the remaining language tests and writing tasks were performed during two half-days. The narrative-writing tasks and

the copy task were administered during the first half-day. The copy task was presented first and then the order of the two narratives was randomised. The dictation tests, reading test and phonological tests were performed during the second half-day, also in randomised order. Data from the first round of data collection were used in Study II, data from the second data-collection round were used for Study IV and data from all three data-collection rounds were used in Study III. All 16 participants took part in all three data-collection rounds. However, the results for one participant in the third data-collection round were disregarded owing to the overall deterioration of that participant's physical health.

Analysis

Final texts, basic statistical measures and information for the pause analysis were retrieved from ScriptLog files. For Studies III and IV, lexical analysis was performed using corpus-linguistic methods and software provided by Språkbanken, Gothenburg University. The scoring of tests for Studies II–IV was performed by the thesis author in accordance with the respective test manuals. The scoring of the tests of lexical retrieval and word fluency for Study I was performed by the other joint first author of that study, in accordance with the respective test manuals.

Statistics

Statistical tests and methods were used to analyse data in all studies. The groups were rather small in all studies, and the variables were not evenly distributed. Indeed, many temporal aspects of written production are not expected to be evenly distributed; for example, writers tend to have many short pauses and fewer long ones. For these reasons, all group comparisons were made using non-parametric statistical tests: the Mann–Whitney U-test for independent samples for comparisons between study groups and reference groups, and the Wilcoxon signed-rank test for all paired comparisons. For correlations, the non-parametric Spearman's correlation coefficient was used. In Study I, logistic-regression models were used to analyse the difference between the study group and the reference group with regard to the proportion of pauses at the word level after controlling for typing speed. Those calculations were performed in the SAS statistical software, version 9.3. All other statistical calculations were performed in IBM SPSS statistics, version 20.

Reliability was assessed for the categorisation of spelling errors in Study IV. The first author first categorised all spelling errors, whereupon a co-author categorised words containing errors from eight randomly selected participants. The rate of agreement was 72.3%, which represents 'substantial agreement' according to Landis and Koch (1977).

Ethical considerations

The studies were approved by the Regional Ethics Committee of Gothenburg. The participants with post-stroke aphasia in Studies II, III and IV were informed about the studies both orally and in writing to ensure that they understood the information. Written informed consent was collected before inclusion. The participants were encouraged to ask questions, which were answered by the first author of those studies. In Study I, the question about participation was asked by the neurosurgeon with whom the patient had been in contact prior to surgery, and any questions were answered by Dr. Antonsson, the other first author of Study I.

Study I was covered by two ethical-approval decisions (Ref. Nos. 625-14 and 524-14). Studies II, III and IV were covered by a single such decision (Ref. No. 525-14).

Results

Study I: Writing fluency in patients with LGG before and after surgery

The aim of this study was to explore whether writing fluency was affected in LGG patients before and after surgery and whether writing fluency was related to performance on naming or word-fluency tests (tests of oral lexical retrieval).

Research questions:

1. Were there any differences in writing fluency and word-level pauses between LGG patients before surgery and a reference group?
2. Did the LGG patients' writing fluency and word-level pauses at follow-up three months after surgery differ from their pre-operative performance?
3. Was the patients' writing fluency related to their performance on tests of oral lexical retrieval before and after surgery?

Results

The results from Study I showed that the LGG group had lower writing fluency, lower production rate and lower typing speed (in both the narrative task and the copy task) and made proportionally more word-level pauses (pauses before, within and after words) than the reference group. However, there was no statistically significant difference in the proportion of word-level errors between the groups.

Since there was a difference in basic typing speed, an ANOVA was performed to analyse whether the difference in typing speed accounted for the differences in burst length and production rate. The results showed that there was no effect of group on burst length or production rate after controlling for typing speed. Logistic regression showed that the LGG group was significantly more likely to make pauses within words than the reference group (odds ratio=2.526; 95% CI=1.336–4.775; $p=.004$), but the other differences seen in word-level pauses could be attributed to the LGG group's slower overall typing speed.

Paired comparison between performance before and after surgery showed that, three months after surgery, there was a reduction in production rate ($Z=-3.360$, $p=.001$) and typing speed in the narrative ($Z=-2.053$, $p=.040$) as well as an increase in pauses before words ($Z=-1.008$, $p=.016$). The results showed that the patients had an overall lower productivity after surgery, and that typing speed was reduced only when the task carried linguistic weight, as in the narrative task. The increase in pauses before words suggested that written lexical retrieval had been affected by the surgery.

Before surgery, there was a strong positive correlation with the semantic word-fluency measure of Verbs. This relationship shows that patients who wrote in long bursts produced many verbs, and vice versa. After surgery (at the three-months follow-up), however, all measures of oral lexical retrieval (BNT, FAS, Animals and Verbs) showed strong positive correlations with burst length. Also, the measures of oral lexical retrieval had a moderate to strong correlation with typing speed in the copy task.

Study II: Text writing and its relationship to writing processes and spelling ability in post-stroke aphasia

The aim of this study was to examine and compare text writing in the production of narrative texts in persons with and without aphasia and to inter-relate measures from the narrative output for both groups. Measures of writing and writing processes were also related to scores on tests of spelling for the persons with aphasia.

Research questions:

1. How do measures of the writing process (typing speed, production rate and editing) and text characteristics (spelling and text length) distinguish writers with post-stroke aphasia from writers without aphasia in narrative writing?
2. What are the relations between typing speed, production rate and editing for both groups?
3. What are the relations between spelling in dictation tests, spelling in text and editing for the participants with aphasia?

Results

The results from Study II showed that there were significant differences between the group with aphasia and the reference group in all writing-process measures both in the narrative tasks and in the copy task. The group with aphasia had a lower production rate and a lower typing speed, they edited their texts more, and they also wrote shorter narratives. In addition, there was a difference in the proportion of spelling errors in the picture-elicited narrative, but not in the free narrative ($U=146,00$, $p=.158$).

A significant correlation between typing speed and production rate was found in the free narrative, but not in the picture-elicited one, for the group with aphasia. Also, significant correlations were found between production rate and the proportion of un-edited text for both narratives (Spearman's rho, PE: .561; FN: .569), meaning that there was a relationship between more editing and a lower production rate.

For the reference group, the production rate did not correlate with the editing rate in any narrative. Significant correlations were found between typing speed and production rate in both narrative tasks, but the relationship was negative in the free narrative and positive in the picture-elicited narrative. There was also a correlation between typing speed and editing in the free narrative, meaning that reference-group participants who typed faster edited their texts more.

Correlation analysis for the group with aphasia showed correlations between scores on the two dictation tasks (word dictation and non-word dictation). There was a strong correlation between scores on the word-dictation task and the proportion of spelling errors in the picture-elicited narrative but not in the free narrative (Spearman's rho: -.315). The proportion of un-edited text did not correlate significantly with spelling in tests or spelling errors in texts for any of the text-writing tasks, meaning that there was no relationship between how much the participants edited their texts and how many errors they made in the texts or on the dictation test.

Study III: Lexical features of narrative texts written by persons with post-stroke aphasia – analysis of word use and errors

The aim of this study was twofold. The first aim was to investigate and compare the lexical features of texts written by persons with post-stroke aphasia and by a matched reference group. The second aim was to investigate and compare the lexical features of the misspelled words in the same groups.

Research questions:

1. What are the lexical features of texts written by persons with post-stroke aphasia compared with texts written by a reference group?
2. What are the lexical features of the words misspelled by persons with post-stroke aphasia compared with the words misspelled by a reference group?

Results

The results from the group comparisons showed that when it came to lexical diversity, the group with aphasia had significantly lower diversity in both narratives than the reference group. Lexical density was higher for the group with aphasia than for the reference group in the free narrative ($U=87.00$, $p=.002$), but not in the picture-elicited one, where no significant difference could be found. The reference group used a higher proportion of long words in the free narrative ($U=123.00$, $p=.028$), but there was no such difference in the picture-elicited narrative.

In the group comparisons of the proportions of nouns and verbs in the narratives, there were no differences in the free narrative, but the group with aphasia

used a higher proportion of nouns in the picture-elicited narrative ($U=67.00$, $p<.001$).

The results from group comparisons of word frequency showed no differences between the groups in the free narrative. In the picture-elicited narrative, however, the group with aphasia used a lower proportion of high-frequency words and a higher proportion of medium- and low-frequency words.

Analysis of the lexical features of the words containing errors showed that the group with aphasia had a higher proportion of long words among the words containing errors for both narratives (PE: A(phasia) group: 42.14%, R(eference) group: 31.82%; FN: A-group: 54.84%, R-group: 45.83%), and this was also the case for the proportion of content words among the words containing errors (PE: A-group: 85.71%, R-group: 68.18%; FN: A-group: 85.48%, R-group: 80%). In both cases, the difference between the groups was larger for the picture-elicited narrative than for the free narrative. Hence the words containing spelling errors were more likely to be long words and content words in the texts produced by the group with aphasia than in the texts produced by the reference group.

Word-frequency analysis of the words containing errors showed that the reference group was more likely than the reference group to misspell high-frequency words in both narratives, whereas the opposite was the case for low- and medium-frequency words. However, the difference was smaller in the free narrative.

Study IV: Aphasia and spelling to dictation – analysis of spelling errors and editing

The aim of this study was to analyse spelling and editing processes as well as errors in a dictation task performed by persons with aphasia and to identify any relationships between spelling and editing difficulties and the 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:

1. To what extent do the participants make errors and edits in the words written in the dictation task?
2. What types of spelling errors do the participants make?
3. Are certain characteristics of words more or less related to spelling and editing difficulties?
4. What skills/abilities are related to editing and successful editing?
5. Can specific editing strategies or editing behaviours be observed using writing-process data?

Results

Although all participants had mild to moderate aphasia, the results from the word-dictation test showed large variation in the group: the proportion of correct answers ranged from 6% to 95% and the scores on a non-word dictation test ranged from 0 to 17 (max score: 18). On average, the participants edited 48% of the words and had an editing-success rate of 40%, but the proportion of successfully edited words also manifested great variation: 0–100%. The participants had a mean of 82% un-edited text in the dictation test, but they ranged between 10% and 99%. Surface analysis of the spelling errors showed that the most common error types were omissions of letter(s) (160 words affected), substitution of letter(s) (127 words affected) and consonant doubling (99 words affected). In cases where a word or an error in a word could not be categorised, the initial letter was most often correct.

Analysis of compounds showed that it was more common for the second or third root morpheme of the compound to be affected by errors (21% errors in first morphemes but 69% in second or third morphemes).

Analysis of aphasia-specific errors showed that the most common feature was that a word strongly resembled, or was in fact identical with, another word. Perseverations were seen in 21 words in the corpus, most commonly the repetition of the wrong suffix attached to multiple words. Only two participants made more than occasional perseverations. Phonological spelling was uncommon: only 12 words were affected.

Correlation analysis showed a significant correlation between word length and correctness for both whole words and morphemes. Word frequency showed no correlation with correctness for whole words, but it did for root morphemes. The proportion of successfully edited words was not related either to word frequency or to word length. By contrast, unsuccessful editing correlated significantly with both word frequency and word length, meaning that long and uncommon words are both difficult to spell and difficult to edit.

Analysis of skills related to successful editing showed that successful editing correlated significantly with scores on both dictation tests (words and non-words) but was not related to scores for reading or phonological decoding. The proportion of edited words did not correlate with the proportion of successfully edited words. Five different types of editing strategies or behaviours could be observed in the material: (1) multiple editing of the same letter(s)/trial and error, (2) instant editing, (3) edits after finishing the word, (4) provisional splitting of compounds and (5) editing large chunks at once. The first two strategies were used by all participants whereas the latter three were more individual in nature.

Summary of results

For the participants with LGG, aspects of writing fluency were affected both before and after surgery, but the results indicate that typing speed is an important factor behind the pre-surgery differences. After controlling for the differences in typing speed between the LGG and reference groups, only the difference in pauses within words remained significant. The decline in overall productivity and the increase in pauses before words found after surgery may be related to a decline in lexical-retrieval ability, a hypothesis which is supported by the finding that oral lexical-retrieval scores correlated strongly with writing fluency. The differences seen in typing speed depending on the task type suggest that linguistic processes required greater effort after surgery.

For the participants with (mild to moderate) post-stroke aphasia, Study II showed how all aspects of productivity in text writing were affected. Both the group with aphasia and the reference group edited their texts, but in the group with aphasia, more editing was associated with lower productivity. Correlation analysis showed that scores on real-word spelling tests could not predict spelling performance in free narratives for the participants with aphasia.

The results of Study III showed that texts written by persons with aphasia contained a less varied vocabulary and seemed to indicate that those persons tended to avoid using long words. The words misspelled were more likely to be content words, long words and low-frequency words in the group of persons with aphasia than in the reference group. Hence it was shown that lexical features of texts were affected by aphasia but also that those features were dependent on the levels of vocabulary control and narrative support in the different text-writing tasks.

Finally, the categorisation of spelling errors carried out in Study IV showed that the most common error type was the omission of letter(s), and there was evidence of aphasia-specific writing errors. Spelling difficulty often entailed editing difficulty, and both spelling difficulty and editing difficulty were related to word frequency and word length. Editing success was associated with scores on the non-word dictation test, meaning that the participants who edited more successfully had better phonological-spelling skills. By contrast, editing success did not correlate with phonological de-coding ability or reading ability. Specific editing strategies could be identified in the keystroke logs. Some strategies were individual (such as the provisional splitting of compounds), while others were more commonly used (such as multiple editing of the same letter(s)/trial and error).

Discussion

Writing involves large neural networks and is dependent not only on language functions but also on other cognitive functions such as working memory and executive function. The focus in aphasiology has traditionally been on investigating the linguistic representations of the impairment, but there is now growing interest in investigating processes that underpin linguistic abilities and difficulties, entailing a shift of the focus from linguistic performance to cognitive processing relating to language function. As expressed in a presentation by Code (2018), '[t]he focus is on the processes and mechanisms responsible for the construction of representations, not the building blocks themselves'.

In this thesis, the aim was to examine both the 'building blocks' or linguistic representations (such as spelling errors and text features) and the underlying processes (writing processes).

In this section, the following topics from the thesis will be discussed: (i) How spelling cannot, and should not, be equated with writing and how tests of aphasia or reading and writing difficulty cannot capture the full extent of acquired writing difficulty. (ii) How the investigation of writing processes proved to be more sensitive to change and impairment than the measurement of spelling in text. (iii) How models of text writing can be useful when interpreting results from the investigation of the writing process in populations with aphasia or other related difficulties. (iv) How complex linguistic and cognitive activities, such as writing, are difficult to examine in persons with aphasia and related difficulties, because of those activities' dependence on especially working memory and but also executive function. (v) How more research into spelling and editing in persons with aphasia and related difficulties in languages other than English is warranted, since differences in orthographic transparency may make the challenges faced by such persons different.

Tests vs. texts

The focus on spelling ability as measured in tests, which tends to characterise current research into writing in persons with post-stroke aphasia fails to capture the full extent of the difficulties seen in text writing. The results from Study II show that scores on a word-spelling test do not even transfer to spelling in free writing.

Even so, it is evident from Studies II, III and IV that spelling difficulty is an important part of the writing difficulties of persons with post-stroke aphasia. Further, since the results of Study II showed that more editing was associated with lower productivity in persons with aphasia, it is also clear that editing difficulty is a vital part of their writing difficulties and so should be addressed in treatment and in research.

However, not all persons with writing difficulty due to aphasia or related cognitive difficulties experience or present with spelling difficulty. The word-dictation test used in Studies II and IV was designed to be taken by Swedish students and was standardised based on scores of 18-year-old students. In Study IV, four participants with aphasia scored above the standard average but still experienced substantial writing impairment. In fact, the participants with post-stroke aphasia also exhibited many of the symptoms reported by Dinnes et al. (2018) for persons with traumatic brain injury. For example, one participant with mild post-stroke aphasia performed above the standard average on the word-dictation task and also performed well on the non-word dictation task, but when writing the free narrative he only produced a few (correctly spelled) words and the result was not a narrative, only a short reference to a date (which, presumably, was when he had last made someone happy/made someone surprised/been happy). His text did not reveal any information that could be linked to the set theme without an explanation or prior knowledge. The participant himself reflected on this discrepancy in performance, commenting: 'I still know HOW to write, I just don't know WHAT to write'. In relation to the model proposed by Flower and Hayes (1981) and Berninger (2002b), this participant had difficulties with the planning and idea-generating aspect of text writing. If spelling or written naming is used as the primary method to investigate writing ability in aphasia, such a person could be categorised as having no difficulty writing although he is not able to write a short, self-generated narrative about a personal memory more or less of his own choice.

In Studies I and II, the proportion of spelling errors proved to be a less sensitive indicator of language impairment than writing-process measures. In Study I, no difference was found in the proportion of errors between the group with LGG and the reference group, and nor was there a difference in the LGG group's proportion of errors before and after surgery, even though temporal aspects of the writing process were found to be affected in both comparisons. For the participants with aphasia in Study II, differences in the proportion of errors were found only when the vocabulary was controlled in the picture-elicited narrative task, not in the free-narrative task, where the participants could avoid using difficult words. This shows that temporal aspects of the writing process (such as pausing behaviour, production rate and typing speed) might be more sensitive measures of changes or impairments than spelling in text.

Aphasia test batteries developed for persons with post-stroke aphasia have been regarded as not sufficiently sensitive to capture subtle changes in language function in persons with LGG (Brownsett, et al., 2019, Papagno et al., 2012). For this reason, attempts have been made to find more subtle signs of language dysfunction, using more sensitive language tests (see Antonsson et al., 2018). However, in this thesis, such potentially insufficient test sensitivity was seen in the studies of participants with post-stroke aphasia as well. Aphasia test batteries (such as A-ning) include a range of sub-tests intended to test different aspects of language function, but those sub-tests might be insensitive to subtle impairments even in persons with post-stroke aphasia. The sub-tests of reading and writing do not fully capture temporal aspects of reading and writing function or changes in the effort required to complete tasks – and, it should be emphasised, those sub-tests are not designed to capture such aspects. For example, one participant in Studies II, III and IV who attained the maximum score for reading in A-ning reported that he did not read in everyday life because he no longer enjoyed doing so – it was too time-consuming and made him too tired. In line with this, Kjellén, Laakso and Henriksson (2016) reported that participants regarded reading as both more effortful and more time-consuming than before their stroke, meaning that they engaged in literacy activities less often. The same authors also reported that their participants read or wrote as practice more often than for enjoyment, but that the aim of their practice was to be able to use reading and writing functionally again.

Models of text writing

Models of the writing process are typically developed to describe the writing process in unimpaired writers (Flower & Hayes, 1981; Hayes 2012) or to describe writing development (Berninger, 2002b), and they are usually based on writing experiments involving unimpaired university students. This raises questions about their applicability when it comes to analysing the writing process of persons with aphasia or lexical-retrieval difficulties. In fact, such models tend to assume lexical retrieval to be quick and effortless, typically categorising lexical retrieval as an automatised low-level sub-process requiring little or no cognitive effort. This did not pose a challenge in Study I, where the participants' writing was quite similar to that of the reference group and the focus of the study was on finding subtle changes in writing processes compared with the reference group or with the situation before surgery. However, in Study II this became more of a challenge, for example in using commonly used measures of the writing process. The commonly used measure of writing fluency (production bursts between pauses) could not be used, since the participants with aphasia typed too slowly and wrote too disfluently

for that measure to give reliable results. It was expected that there would be large differences between the study group and the reference group on all measures of the writing process – as was also shown by the results of Study II. However, the applicability of the writing-process models and writing-process measures is rooted in the theoretical framework underpinning those models and measures, which describes the interaction of low-level and high-level processes, both of which are dependent on working memory. The models can be used to describe the changes and its consequences when formerly automatized low-level processes becomes impaired and therefore de-automatized. It is evident from Studies I and II that when low-level sub-processes (such as lexical retrieval or spelling) which used to be automatized before surgery (Study I) or before stroke (Study II) are de-automatized, this has a detrimental impact on text generation and productivity in text writing. Hence theoretical frameworks such as the ‘simple view of writing’ (Berninger, 2002b) and the writing-process model proposed by Flower and Hayes (1981) proved immensely valuable in understanding and interpreting the results of the studies included in this thesis.

Working memory

As mentioned in the introduction, working-memory capacity is limited in all humans and there are reports of impaired working-memory function in persons with aphasia (see, e.g., Lang & Quitz, 2012; Mayer & Murray, 2012). It follows from the ‘simple view of writing’ (Berninger, 2002b) that when, for example, spelling requires much effort, less capacity is left to be used for idea generation or editing beyond the word level. One participant in Study I gave up on his free narrative even though he had not finished it because of the huge cognitive effort required for spelling and editing at the word level. This participant felt that he had to stop writing although his narrative was incomplete, commenting: ‘My head is only filled with spelling’. Such a tendency to quit could be observed in other participants as well – it seemed as though they ‘hit a wall’ of effort while writing a text. The finding of Study IV to the effect that the second or third root morpheme of compounds is more likely to contain errors than the first root morpheme might also be attributable to the strain on working memory (Berninger, 2002b) or ‘graphemic buffer’ (Kay, Lesser & Coltheart, 1996). It could also be attributable to difficulties of written lexical retrieval in that the orthographical representation of a word may not have been fully retrieved when the person starts typing and is then lost or never completed owing to the strain on working memory/the graphemic buffer. One participant reflected himself 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 well be an account of experiencing strain on verbal working memory.

In Study I, the picture-elicited narrative may actually have placed too little strain on the linguistic and cognitive aspects of the participants' writing processes for their difficulties to become evident. An alternative method could have been to use a more challenging writing task, such as producing an argumentative text, or simply to remove the pictures, which functioned as narrative support throughout the task, once the participants had had a look at them, so that they would have had to perform more text planning. However, a freer task could also have yielded less comparable texts, rendering comparisons between the situation before and after surgery and between the LGG group and the reference group more difficult; the pictures used to elicit the narratives did provide a certain level of control over the vocabulary used by the participants. Another option would have been to increase the strain on working memory by adding an articulatory suppression task (Hayes & Chenoweth, 2006) or a dual task (see, e.g., Olive, 2004) to be performed by the participants while writing.

Spelling, editing and the dual-route model

The dual-route model is often used to diagnose agraphia in aphasia. However, as noted by Thiel, Sage and Conroy (2014), many persons with aphasia and writing difficulty do not fit into any of the diagnoses based on that model. Beeson and Rapsak (2002) therefore proposed using those diagnoses together with a description of the person's writing difficulties. This suggests that the dual-route model can be used to understand spelling ability at the word level but not to comprehend the full range of a person's writing impairment.

The categories used for errors in Study IV were based on categories used for spelling errors made by adults with developmental writing difficulties (Wengelin, 2002), on common Swedish misspellings (Nauc ler, 1980) and on aphasia-specific errors (Whitworth, Webster and Howard, 2005). When the dual-route model is used as a theoretical starting point, it is common to categorise all misspellings yielding a word which is visually similar to the target word as 'visual errors' (see, e.g., Rapsak & Beeson, 1991). However, all minor spelling errors would then be regarded as 'visual', which may entail a risk of excluding other explanations for an error. A further difficulty when categorising spelling errors made by persons with aphasia is that a fairly large proportion (12%) of the words containing errors were non-categorisable since they lacked any resemblance to the target word.

The results from Study IV suggest that the routes used when writing (lexical and sub-lexical) are also continuously used while editing. One might speculate

that the lexical route could be seen as the primary route and the phonological route as a subordinate support system; both routes might be used dynamically while writing, even at the word level. When the lexical route fails in editing, the phonological one is used instead, as is supported by the finding from Study IV of a correlation between sub-lexical spelling ability and editing propensity and success. The lexical route might then be used continuously to evaluate editing results.

It might be added that the dual-route model was developed for English and that most research into spelling difficulties in aphasia is based on data regarding English-speaking patients. English has a non-transparent orthography, while that of Swedish can be categorised as fairly transparent (Seymore, Aro & Erskine, 2003). This difference in transparency might make the dichotomy between sub-lexical and lexical spelling less evident in the case of Swedish.

Studies III and IV found word frequency and word length to be significant factors for spelling and editing difficulty both in tests and in texts, suggesting that those factors should be taken into account when measuring spelling in persons with aphasia. Word frequency and word length might be significant factors in text writing because they contribute both to spelling difficulty and to lexical-retrieval difficulty (Paesen & Leijten, 2019).

Limitations

One limitation affecting all studies included in this thesis related to the fairly small number of participants, both in the study groups and in the reference groups. The participants showed great variation on all measures of the writing process and in their text writing, which affected the statistical tests. In the case of patients with LGG, a large group would have enabled results to be analysed against the background of tumour location. For the persons with aphasia, results could have been related to aphasia type. However, it should be added that the number of participants with post-stroke aphasia is larger in this thesis than in previous research into writing processes in persons with aphasia (see, e.g., Behrns, Ahlsén and Wengelin, 2008) and that the persons with aphasia participated on three occasions over a period of two years.

An additional limitation of the studies relates to the shortness of the texts produced by the participants. Even though the picture-elicitation task tended to yield longer texts than the free-narrative tasks, even the picture-elicited texts were short. This limited the range of methodological options available, especially in Study III. It also made the proportions reported more difficult to interpret in Studies II and III. However, it is important to keep in mind that shortness is in fact a striking and important feature of texts written by persons with aphasia.

The lack of standardised and validated tests to measure writing and spelling ability in persons with acquired reading and writing difficulties is a limitation which potentially affects the results of Studies II and IV. Although adjustments were made to better suit the persons with aphasia, the complicated nature of the instructions may still have affected the results. Moreover, it was not possible to compare scores across tests. Additionally, the standards used to interpret scores were not adjusted to suit the age of the persons with aphasia. However, the tests used in Studies II and IV were carefully chosen to test reading- and writing-related abilities without requiring the participants to produce speech (in which case the severity of their spoken impairment related to aphasia would have been likely to affect their results).

The copy task (copying an overlearned phrase written on the screen) was designed in accordance with Grabowski (2008) and intended to provide a measure of basic typing speed with low demands on lexical retrieval and cognitive effort. However, for the participants with post-stroke aphasia, the task was actually both challenging and tiresome. Even the copying of an overlearned sentence proved linguistically and cognitively challenging to them, and it became clear how de-automatised their writing had become. For the patients with LGG, by contrast, the copy task was not that demanding, but differences could still be seen between them and the reference group even before surgery. In the LGG group, a battery of copy tasks, as used in Van Waes et al. (2017), would have enabled investigation of whether the differences were attributable to motor, linguistic or cognitive functions. However, two measures of typing speed were in fact used in Study I (typing speed in the copy task and typing speed in the picture-elicited narrative). Only the LGG patients' typing speed in the narrative differed after surgery, suggesting that typing speed was affected only when the task carried linguistic weight (self-produced content).

Conclusion

Measuring temporal aspects of writing processes can be useful to detect subtle changes in language function in persons with low-grade glioma, but temporal patterns are also sensitive to changes in other cognitive functions such as working-memory decline or the presence of fatigue. At a group level, measures of temporal aspects of the writing process proved more sensitive to change or impairment than measures of spelling errors in texts.

To fully comprehend the challenges involved in writing for persons with post-stroke aphasia, investigations must include analysis of the processes behind the text, not only of the final text, or else there is a risk that difficulties will be masked or indeed present as lexical difficulties in text writing. Spelling difficulties may cause excessive editing, which is associated with a lower production rate. All aspects of productivity in text writing are affected by mild to moderate post-stroke aphasia. In a free narrative, writers with aphasia may avoid words which are difficult to spell and edit, meaning that the lexical features of texts written by persons with aphasia may reflect difficulties in spelling, in editing and/or in lexical retrieval. Less frequent and long words are both difficult to spell and difficult to edit for persons with aphasia. Analysis of different tasks involving the writing of narrative texts suggests that results vary depending on the amount of narrative support provided and on the level of control over vocabulary.

Future Perspective

The insightful reflections made by the participants with post-stroke aphasia during testing suggests that it might be fruitful to use keystroke logging in combination with retrospective interviews for this group. Then the participants would write a text in a keystroke logging tool. After completing the writing task the writing log would be replayed for them and they would be asked to reflect on the writing process in retrospect. The reflections on one's own writing ability might also function as treatment for writing difficulty and for identifying successful editing behaviour.

Additional research is warranted when it comes to functional aspects of writing for persons with aphasia. As mentioned in the introduction, writing takes place in different settings and through different types of literacy acts. In this digital era, more research is needed in how persons with aphasia write emails (see Thiel, Sage & Conroy, 2017) texts, messages online and chats for example, and how this type of writing can be facilitated through use of aids or through treatment.

Since editing ability proved crucial to productivity in text writing, intervention studies involving digital writing support and training of efficient editing strategies should be evaluated and clinically applied if successful.

The knowledge in how different language functions interact during writing is limited; therefore research in for example how persons with aphasia read during writing could contribute with valuable information. To use eyetrackning during writing for persons with aphasia to examine the use of reading during text composition and editing might contribute to the development of treatment or the development of aids.

Since working memory is an important function for writing, research in how aids or treatment might limit strain on working memory is warranted. The use of spellcheckers or word predictors could be used to limit working memory demands on lower level processes. Evaluation could then prove if a reduction of strain put on working memory could potentially result in an improved functional text writing ability.

The development of a test for acquired reading and writing difficulties to be used clinically and in research would enable more valid examinations of reading and writing ability for persons with aphasia or cognitive communicative disorders. Such a test could prove valuable as a basis for treatment as well as in research.

Tests of written lexical retrieval in a keystroke logging tool could be developed for use in the clinical evaluation of changes to cognitive functions due to tumourresection for persons with LGG or for evaluation of interventions for persons with aphasia or cognitive communication disorders. Since verbs might be more sensitive to impairment than nouns, both should be included. Temporal aspects

could then be measured, such as both the time for lexical retrieval and the time for finishing the word.

To conclude, more research in the different aspects of writing impairment and its impact on functional writing for persons with aphasia or cognitive communication disorders is warranted.

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