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«My Spelling is Wobbly» • Vibeke Rønneberg

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– Causes and consequences of word-level disfluencies in written composition

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Thesis for the Degree of Philosophiae Doctor (PhD)
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UNIVERSITY OF BERGEN

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Scientific environment

The research presented in this dissertation was conducted at the Department of Linguistic, Literary and Aesthetic Studies at the University of Bergen. The Research Council of Norway funded it through the CATO project; a cooperative project between the University of Bergen and the National Centre for Reading Education and Research, University of Stavanger. I am a member of the Norwegian Graduate Researcher School in Linguistics and Philology.

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Hanne, thanks for being my lunch date, support and friend. Ane, thanks for providing me with support in every possible way. Maj and Kjetil, thank you for always having open doors for the boys and me. There is a saying it takes a village to raise a child – I would say a street is all you need. Mum and dad, thank you for taking care of Jakob and Per when I have been away on conferences, and for all the support you have given me. Marianne, thank you for being the supportive big sister you are. Jakob and Per, thank you for reminding me that certain things are much more important than writing a PhD.

Foreword

My son, Jakob, started school at six, and soon learned to read and write. One day he observed, “Mum, the world is filled with text; it wasn’t when I was five”. He was on his way to becoming literate and to be able to take part in literate society. His observation is accurate, the world does indeed look different once one is able to read and write. In school and in most workplaces, being able to write accurately, efficiently and with little effort is important for participation and success. However, the importance of literacy is spreading to other areas of life as well, and being literate is important to be able to take part in everyday social life. Technological development and the electronic revolution including PCs, smartphones, texting, emailing and the use of an increasing number of apps and programs in all domains of life have made digital communication an essential aspect of our lives.

Two things in particular have inspired me, and have been important to me in writing this thesis: First, all the different writers I have met while working as a teacher. Second, my liking for maths and science. I will explain why below.

In early summer 2012, I read the description of the CATO project. The project’s aim was to find factors that aid, support and stimulate text production. In my work as a teacher, I had seen how words came easily to some students. When they are given a writing assignment, their ideas and thoughts are easily transformed into letters making up a text. For others this process is a struggle. They might have ideas they wish to express, but it is as if they cannot manage to follow up these initial ideas, and they might struggle to get these ideas down on the paper. My thought was that a PhD project that might actually be of use in helping some of these struggling writers would be well worth the effort. I became curious, and wanted to know more about text production and writing processes. To be honest I barely knew anything about this when I first read the project description, so I realized I had to find out more and I needed to find out quickly. That summer, instead of bringing a novel to the beach I brought a copy of Åsa Wengelin’s thesis *Text production in Adults with Reading and Writing Difficulties*.

I have always had a tendency to prefer quantitative research and experiments when studying humanities subjects. I think this relates to my preference for maths, chemistry and physics while studying at upper secondary school. Reading the description of the CATO project, I realized this project would involve experiments and great amounts of data. Getting to know the writing literature, I became interested in several experiments that used eye tracking and key logging. It was especially fascinating to read that development of new technology has opened for new possibilities to test and possibly rethink theories about writing and written word production.

Abstract

The aim of this PhD-project was to explore word-level processes involved in writing, and in particular word-level disfluencies. I have investigate what predicts word-level processes and disfluencies, and how word-level disfluencies can influence aspects of the final text. Two broad questions were addressed; What are the causes of word-level disfluency in written production?, and What, if any, are the consequences of word-level disfluency when the writer is composing full text?

Article 1 investigates the writing process and the written product of a group of dyslexic students and a group of control students. Results from this article indicate that students diagnosed with dyslexia have a word-level focus when writing, and that this word-level focus is related to the writing process and not them struggling to read what they have written.

Article 2 is an investigation of the spelling process and spelling accuracy in a group of 6th graders. Results indicate that the spelling process persists beyond typing onset. Moreover, word-split performance and non-word spelling accuracy predict spelling accuracy. Spelling response latency was predicted by non-word spelling response latency, and by key-finding speed. Keystroke intervals within words was predicted by word-split performance, non-word spelling RT and key finding speed.

Article 3 investigates the relationship between spelling, motor execution processes involved in keyboarding, text composing processes and text quality measures. Results indicate that the transcription measures; copying, key finding and spelling, all influence word-level processes when producing text. Moreover, results indicate that word-level disfluencies have a negative impact on measures of text quality.

Article 4 is a theoretical investigation of existing technical aids for writing support, and the general ideas underpinning these. A shift from having correction as the main element, to a writing aid having fluency as the main principle is suggested.

My conclusion is that word-level disfluencies are related to spelling, and that word-level disfluencies can influence aspects of the final text.

List of publications

Torrance, M., Rønneberg, V., Johansson, C., & Uppstad, P. H. (2016). Adolescent Weak Decoders Writing in a Shallow Orthography: Process and Product. Scientific Studies of Reading, 20(5), 375–388. http://doi.org/10.1080/10888438.2016.1205071

Rønneberg, V., & Torrance, M. (2017). Cognitive predictors of shallow-orthography spelling speed and accuracy in 6th grade children. Reading and Writing. http://doi.org/10.1007/s11145-017-9751-3

Rønneberg, V. (paper prepared for submission). An investigation of the relationship between transcription, word-level processes and measures of quality in text composition.

Rønneberg, V., Johansson, C., Mossige, M., Torrance, M., & Uppstad, P.H. (Accepted pending revision). Why bother with writers? Towards "Good enough" technologies for supporting dyslexics. In Miller, B., McCardle, P., & Connelly, V. (Eds.). Writing development in struggling learners: Understanding the needs of writers across the lifecourse. Leiden, The Netherlands: Brill.

Contents

1. Introduction

I have titled my thesis “My spelling is wobbly” – Causes and consequences of word-level disfluencies in written composition. The introductory phrase of the title sites Winnie the Pooh describing his spelling, and it is meant to draw attention to the importance that spelling has in written word production. The rather informal qualifier “wobbly” is an eye-catcher, but also illustrates my focus when discussing spelling. The focus is not on spelling errors, but instead on the process of spelling, and how this process sometimes is unstable and insecure. Next, I include the term disfluencies. I am aware that using the term in the title may be deemed an academically ‘bold’ thing to do. Researchers with a preference for more neutral, established terms may consider the term ‘disfluency’ as being either too polemic, too imprecise or simply inappropriate. The reason I have chosen to emphasize the term disfluency in the title is to draw attention to what I believe is a central aspect in written word production. To use the term polemically, or to acknowledge its polemic potential, may help to maintain a clear focus – for you, the reader – and to emphasize that disfluency as a phenomenon is a subject that deserves attention.

The term disfluency cannot be separated from the term fluency. In reading, Tønnessen & Uppstad (2015 p.75) see fluency as “thinking one’s way through a text without the written medium obstructing one’s though”. I think this view of fluency can be applied to writing as well – writing fluency is thinking one’s way through a text without the writing medium obstructing ones thought. A disfluency in word production in this context is a latency time for keys word initially or in the middle of a word that for the particular location is so long that it is expected to be disruptive. It follows from the definition of fluency that I expect these to be disruptive if they are caused by the written medium. In the present context, consequences of deletions or word-level revisions are not investigated although these actions might be considered disfluencies as well. I am aware that the term disfluency has negative connotation; however, I think this serves to pinpoint something important in that it suggests that long latency times at the word-level might disturb written language production as a whole.

In the foreword, I referred to my son‘s description of the world as “filled with text”. In such a world, it is obvious that written communication remains important and its importance is - if anything - is increasing. Therefore, it is an important task for decision makers and politicians to make sure that all groups are able to express themselves in written language, and are enabled take part in this literate society. Even more so, for educators and developers of supportive writing tools, it is essential to focus not only on the final written text, but also on the writer – the human, and the process she is involved in while writing, pulling the research fields of psychology and linguistics together. This entails a substantial challenge for me as a writing researcher – to acquire more knowledge about temporal characteristics of the writing process. In particular, this means, examining how different processes involved in writing are interrelated and investigating the mechanisms behind written word production.

A reasonable amount of research has already been done to acquire knowledge about the processes involved in writing (Bereiter & Scardamalia, 1987; Flower & Hayes, 1981; Hayes & Flower, 1980; John R Hayes, 2012; van Wijk, 1999). Less however, is known about the low-level transcription processes involved in word production. It is suggested that low-level transcription skills might influence higher level processes and possibly text quality (Graham, Berninger, Abbott, Abbott, & Whitaker, 1997; Limpo, Alves, & Connelly, 2017; McCutchen, 1996), although there is mixed evidence of this. Moreover, the literature has indicated that having a word-level focus is a characteristic of struggling or dyslexic writers (Wengelin, 2007), and that this word-level focus might be related to transcription (Sumner, Connelly, & Barnett, 2013). More information is needed to understand the mechanisms underlying low-level transcription processes, and to find out if and how processes at the word-level can influence other aspects of writing.

The work included in this thesis contributes to psycholinguistics by exploring the production of single words within the context of full text, and by unpacking some of the mechanisms behind word-level production and disfluencies. Moreover, by investigating written text production in a group of dyslexic writers, I contribute to a field of research where relatively little has been done. As such, this thesis is a study of written language production. My aim is to explore word-level processes involved in writing, and in particular word-level disfluencies. I want to investigate what predicts word-level processes and disfluencies, and find out if word-level disfluencies can influence aspects of the final text.

Linking back to education and writing support, and to my experience with struggling writers, the initial idea was that it might be more important for a writer to maintain fluency when writing, rather than ensuring that all words are correctly spelt. In the next section, I will explain the rationale behind the assumptions that fluency is important and that word-level disfluencies can be negative for text production.

1.1 Background

In Levelt's theory, language production is theorized as involving multiple, interrelated processes (Levelt, 1983, 1989). Levelt's model, describes production of spoken language as consisting of five components: message construction, formulating, articulating, parsing and monitoring. Although Levelt's model was originally designed to describe speech production, expressing an idea, whether in speech or in writing, assumes some common linguistic units before motor execution. In the message construction phase, the speaker conceptualizes what she intends to say. Next, the speaker transforms the pre-linguistic concept into a linguistic structure. The speaker formulates phonetic strings, and plans how to articulate these with motor programs. Once the message is converted into articulation, the speaker can parse and monitor the utterance. The parsing can assess information about linguistic aspects of the spoken utterance, whether all phonemes are uttered, qualities of the voice (Levelt, 1983). Finally, the monitoring component detects speech errors, and compares inner and externalised speech.

There is, however, limited agreement around exactly what the processes involved in language production are, and how they are coordinated. Starting from the 1970s, attempts were made to get closer to what goes on during written language production. The first studies concerned with process, were interested in writing behaviour and rate of writing, and involved observation, audio recording or videotaping. In general, these studies recruited small samples, Emig (1971) recorded eight twelfth graders composing aloud, Matsuhashi (1981) video recorded and studied pauses of four high school students. In the 1980s and onward, there gradually was a trend towards more research on the writing process, marked by Hayes and Flower's (1980) seminal publication attempting to experimentally identify the processes of writing and to illustrate a model describing the writing process. This model identifies three major processes: planning, translating and reviewing. The planning process consists of generating ideas, organizing them and setting goals to establish a writing plan. The translating process is guided by the writing plan, and acts to produce language that corresponds to information in the writer's memory. The reviewing process consists of reading the text that is already written and editing it. The second process: translation – the process by which ideas are converted into written language – is central to my focus in this thesis. More specifically, in Hayes terms, what I am interested in is the transcription part of translation.

Hayes and Flower identified the processes involved in their model through think aloud protocols where participants commented on what they were doing. Thus, their initial model focused on higher level, conscious processes. Studies of more low-level processes have only more recently been possible through newer methods and technological development. In his more recent model Hayes (1996, 2012), has also given more focus to low-level (tranciption) processes. Torrance & Galbraith (2006) point out that as soon as these low-level, less accessible processes are included; there is a large increase in the number of possible interactions between processes.

A more recent and independent line of writing process studies focuses largely on low-level processes. This thread of research is based in psycholinguistics, and it is important for the current thesis. Within this tradition, low-level processes in written text production are studied by using measures of written time course to test hypotheses about the writing process, and as such, the temporal processes of word production have become a central object of study (e.g. Bonin, Roux, Barry, & Canell, 2012; Damian & Stadthagen-Gonzalez, 2009).

In particular, two main strands of research can be identified in the study of written word production, one focusing on orthographic retrieval measuring word initial latencies (e.g. Bonin, Peereman, & Fayol, 2001), and the other emphasizing investigation of written production from a motor execution perspective (e.g. Van Galen, 1991). The most recent on-line studies of written production of single words, however, typically address the relationship between central linguistic processes and what is seen as a more peripheral process - motor execution (e.g. Roux, McKeeff, Grosjacques, Afonso, & Kandel, 2013).

1.2 Theoretical framework

How one understands the coordination of different writing processes, has consequences for the influence of low-level or transcription processes, on other parts of the writing process. I will present a modular and a casading model of language production, and give reasons for why I believe a casaded model better explains the coordination of writing processes.

Let us assume a model of writing consisting of the processes; 1) retrieval of a concept, 2) planning syntax, 3) orthographic retrieval and 4) motor execution. Syntax decisions are modelled as being decided before orthographic retrieval as studies of cerebral activation in spoken word production indicate that for example syntactic gender is retrieved before the word's phonological code (van Turennout, Hagoort, & Brown, 1998).

If the processes in this model of writing, are coordinated in a simple modular processing model (Fodor, 1983), or sequential model, each module is independent of the others. The interesting point to be made here is that if all the processes involved in writing occur in a sequence (Figure 1), one by one, a student's struggling with lower-level processes would not necessarily influence higher-level processes. Let us say a writer struggled with orthographic retrieval, trying to figure out how to spell a word (illustrated at the bottom part of the figure). In that case, the search for the right spelling would not necessarily influence any of the other processes, if all the processes involved in writing were encapsulated. If this actually were the case, it would only mean that the process of orthographic retrieval would take longer, and that this could be observed as a pause or halt in the motor execution. Intuitively, however, syntax planning needs to be maintained while orthography is retrieved, which might impose high demands on memory.

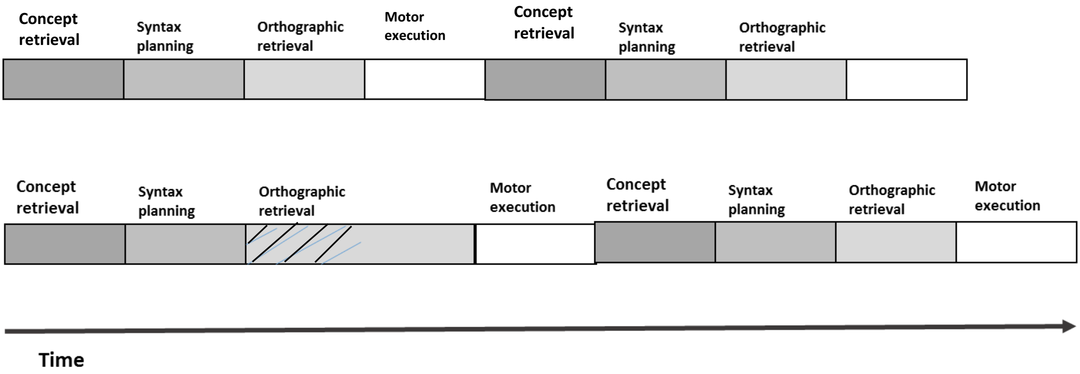

Figure 1. A modular model of writing, with writing processes occurring in a sequence. This is a model that is entirely sequential, so delay in one process will just result in slower production.

There is research, however, implying that a modular or sequential view of language is unlikely. In a sequential model, only the lemma that is selected will be encoded phonetically; however, evidence from speech and mixed errors, suggests this is not how language is produced (Dell & O'Seaghdha, 1991). Mixed errors are errors that carry both semantic and phonological similarities to the target word. Stowe, Haverkort, & Zwarts (2005) provide additional support that a modular view of language production is unlikely. They review evidence from neuroimaging, surveying evidence for linguistic processes being linked to specific brain areas. Broca's and Wernicke's area have traditionally been identified as areas specialized for language. However, Stowe et al.(2005) argue that the neurological basis for language might be more complex than previously assumed. They conclude that Broca's area serves more general functions that are part of a larger network of brain areas that work together. The evidence for this is findings showing that simple language tasks, such as processing simple sentences, do not activate Broca's area (Stowe et al., 1998), while

many other functions do. The activation of such a network is incompatible with a modular view of language (Fodor, 1983), and a model of writing like the one presented in Figure 1.
From studies of written language production there is evidence that high-level processes can occur in parallel with low-level transcription processes (Alamargot, Dansac, Chesnet, & Fayol, 2007; Foulin, 1995). Using an Eye and Pen device, Alamargot et al.(2007) instructed participants to compose a procedural text from photos. They found that writers were able to transcribe at the same time as they were encoding visual information that was distant from where the pen was writing. Seen this way, transcription is not merely executing what is already planned; planning *can* happen in parallel with transcription. Olive (2014) too comments on what he sees as a tradition of conceiving cognitive processes as occurring in a sequence or one after the other. In his opinion, it is unlikely that the processes involved in writing are sequentially organized. If they were, he claims language would only be prepared during pauses. Rather, he suggests that the different processes can work in parallel, and suggests a cascading model of writing (Olive, 2014). Such a view on writing entails that higher-level processes have the potential of being activated during orthographic retrieval and while handwriting or keyboarding.

In addition to accounting for the processes involved in writing, the structure of the language production system, and how the different processes are administered, models of writing also need to account for how more general constraints imposed by the writers' cognition represent barriers to fluent production. Although people have the ability to perform more than one task at a time, quite often, performing one task can interfere with performance of another (Creamer, 1963; Pashler, 1994). Limitations in working memory, and competition for limited resources have been used to explain why the processes involved in writing sometimes happen in parallel and other times not. Baddeley`s (1986) model of working memory influenced Hayes and other writing researchers in the 1990s, leading to more of a focus on working memory (Kellogg, 1996, 2001). To Baddeley (1983) working memory refers to the

temporal storage of information during performance of different cognitive tasks, and the central characteristics of this storage is that it has limited capacity.
Just & Carpenter (1992) suggested a capacity theory of working memory. They proposed a linguistic working memory separated from the representation of linguistic knowledge. Linguistic working memory is seen as a resource of limited capacity, and as such, it can constrain comprehension. Seeing memory as a limited recourse has had consequences for theories of writing. McCutchen (1996) investigated the issue of capacity limitations during writing. She argues that a capacity theory can provide a framework to understand writing development. According to a capacity theory of writing, transcription processes and text generation compete for the limited cognitive resources. Thus, writing can be understood as coordination of translation processes, editing and planning within the limitations of working memory. In a series of studies, Kellogg (1996, 2001) find support for the idea that planning, translating and reviewing compete for working memory resources when writing. Following capacity view of processing, Alamargot et al. suggest that the writer's cognitive capacity influences the duration and frequency of parallel processing and of pauses when writing. A pause or parallel processing thus depends on the writer's capacity, and how large demands the involved processes impose.
However, apart from working memory being a limited recourse, the concept is vague. It can be used to explain nearly all effects. This raises questions about falsifiability. The working-memory approach often applies a computer metaphor of system overload to illustrate the main insight of the theory. There are, however alternative explanations as to why the system sometimes becomes overloaded, and why, for example, certain processes can be executed in parallel and others cannot. An alternative explanation comes from a research tradition studying dual-task performance. Studies of dual-task interference, provide insight into how the brain functions. Tasks sometimes interfere with each other if they are performed simultaneously. A possible explanation for why the system sometimes gets overloaded is that some operations form bottlenecks (Pashler, 1994). According to Pashler (1994) bottlenecks can occur if two processes need one mechanism to be dedicated to only them for a period time. This can result in one or both of the tasks

being delayed. Christiansen and Charter (2016) employ the bottleneck metaphor together with the “just-in-time” metaphor in their meta theory of language production. The metaphors origin from production companies who employ what they call just-in-time production. Just-in-time production reduces the need for storage as the units you need to build the product you are producing arrive just in time for when they are needed. If a part is delayed it will create a bottleneck; not only is there a stop in production, but because of limited storage capacity, production of other parts will be put to a halt as well. Christiansen & Chater (2016) argue that the way the language production system avoids bottlenecks is by chunk-and-pass production and processing just in time, meaning that linguistic input and output must be processed here and now. Christiansen & Chater’s (2016) metaphors capture nicely how in this thesis I conceptualize how written language is produced.

Chunk-and-pass production requires incremental processing; linguistic units must be built rapidly, and then be passed on to avoid bottlenecks. The need to compress and to rapidly build linguistic structures comes from the just-in-time constraint on language production (Christiansen & Chater, 2016). Expressing an idea, whether in speech or writing, assumes some common units for encoding what happens before motor execution. In writing, chunks of higher level abstraction e.g. a lexical concept is broken down to sub-chunks of less abstract linguistic units e.g. the lemma, containing syntactic information (Levelt, 2001). As soon as selection of a lemma is complete, phonological codes are activated and orthography can be retrieved. In this way, linguistic units are broken down until arriving at a set of chunks low enough for transcription. The reason why information is passed down is that that is how the system works: As soon as a process completes processing, the information is available in a form that the next downstream process can use, and so this process is activated. This way, the lexicalization process “looks for” the syntactic frame for a phrase. As soon as a frame is provided, it can start the processing necessary to fill it.

Within each level of linguistic representation, capacity is limited, and as soon as a higher-level chunk is ready, it is passed down to the level below (Christiansen & Chater, 2016). Instead of stockpiling information – preparing and storing semantic or linguistic units well in advance of output, input to downstream processes is provided just-in-time. This is what is meant by just-in-time-processing.

In a just-in-time production system, if one process is, for some reason delayed, then this can causes a bottleneck. This means that subsequent processes will be delayed: they cannot run without input. In itself, this is not necessarily problematic. However, if there is a bottleneck, information from the level above is “buffered” and cannot be used immediately. Information that is “buffered” is prone to interference, which is why bottlenecks can result in forgetting what you wanted to say or write.

The need to break down linguistic units just-in-time leads to a bias towards choosing words that are easily accessible in the lexicon. In speech, this can be observed by speakers reusing parts of the conversation (Christiansen & Chater, 2016). For writers this might lead to a tendency to choose more frequently used words, as these are more easily available in the lexicon. For speech, Christiansen & Chater (2016) claim that because of the “Now-or Never” bottleneck, low-level phonetic decisions cannot be made too far in advance but need to be executed right away – this may be the case for writers as well.

Let us assume a model of writing different from the modular, and in line with just-in-time production. A model where where language production activates a larger network of brain areas. A model wherein processes can operate in parallel. If, a writer is in seach for the right spelling, and the low-level processes and higher level processes involved in writing can occur in parallel, this writer’s search for the right spelling could potentially interfer ond buffer other, more high-level processes. Illustrated in figure 2.

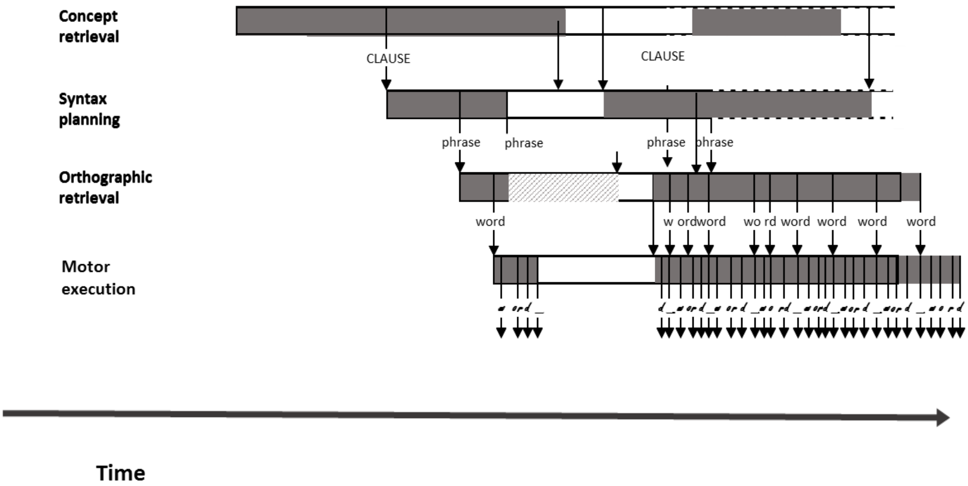

Figure 2. A bottleneck in a casaded model of writing. A delay in one process will results in a bottleneck, and will "buffer" information from the level above.

Applying this view of language to writing gives a framework for understanding how low-level processes need to be executed here and now, and how disfluencies in low-level processes may relate to other processes, and thereby possibly influence text quality measures, and how well an argument is developed. If transcription is disfluent, processes that can otherwise operate in parallel if transcription is fluent may come to a halt. In addition, a writer may run the risk of forgetting what she was going to say if transcription is disfluent.

The potential for bottom up influence in the cascaded model is well captured by Christiansen and Chater's (2016) just-in-time metaphor. According to this constraint on language processing and production, words that are not fluently broken down into chunks low enough for transcription may cause a bottleneck. Taking this bottleneck together with an understanding of written language production as a cascaded process, where higher-level processes can be activated while keyboarding (if transcription is fluent), explains why there can be an influence from the bottom up. When a disfluency occurs while executing low-level processes, higher-level processes can be buffered so that parallel-cascaded process might not take place, which again may potentially affect the final result. This line of reasoning is the rationale behind the assumption that maintaining fluency when writing is important.

Disfluencies at the word-level can be observed as long-lasting latency times, (as illustrated in figure 3) word initially or mid word. There are various possible explanations for these disfluencies. A long latency time in front of a word in the middle of a sentence, could be an indication that the writer is either a) reading, the previous word or text, b) considering which word to write, it has to do with planning a phrase, c) is searching for a key, the disfluency is related to motor execution d) is trying to retrieve the word's spelling, e) is planning what to say next, or f) is simply distracted.

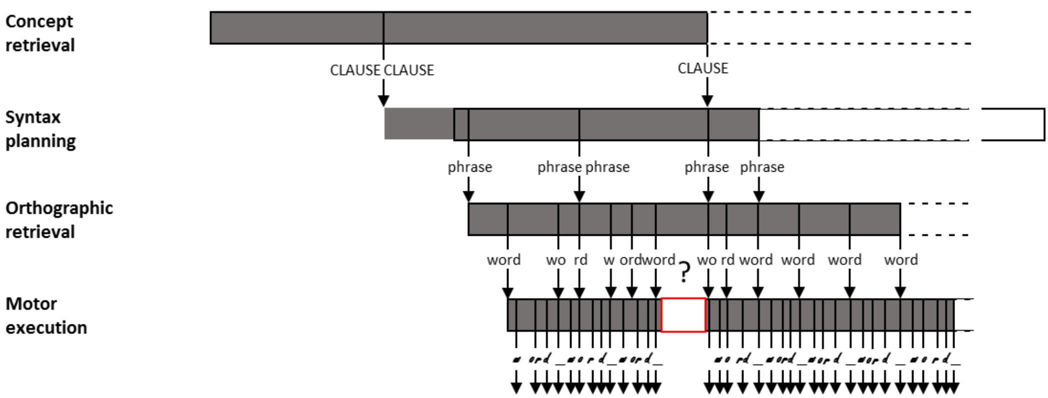

Figure 3. A long latency time observed when outputting a word.

Although word production is the focus here, it is essential to be aware that sentence production too is under the just-in-time constraint (Figure 2), and to acknowledge that words are planned within the context of sentences or phrases. Like in business, and just-in-time stock control, delivery of language components in sentence production, have to arrive just in time for when they are needed, and without the need for storage. Research on written sentence production indicate that as soon as a unit is ready it is passed down to the level below. In an experimental study by Torrance & Nottbusch

(2012) results indicated that participants only planned the first noun phrase of a sentence before they started to write, when combining objects into sentences with the form “The A and the B are above the C”. When the unit, or syntactic structure is more complex, like a subordinate subject noun phrase, more time is needed before typing onset (Nottbusch, Weingarten, & Sahel, 2007). These findings are similar to findings from spoken sentence production, showing that whole clauses are not planned in advance, rather participants start to speak as soon as they are done planning the first noun or subject noun phrase (Martin, Crowther, Knight, & Tamborello, 2010), and findings that sentences beginning with a more complex phrase takes longer to prepare (Smith & Wheeldon, 1999).

According to Christiansen & Chater (2016), just like for production, language comprehension, is dealt with by “Chunk-and-Pass” processing. This means that as soon as the human parser gets input, the syntactic analysis begins. The parser seems to make decisions as soon as possible, without keeping all possible parses open as it goes through making sense of a sentence. Christiansen & Chater (2016) describes this as a need to process here and now. Similar to in written production, the need to chunk information and pass it on means that the first part of a sentence is parsed before later parts. This parsing process follow some general principles, minimal attachment and late closure (see e.g. Warren, 2013). Minimal attachment is the idea that for each new unit, the parser goes for a parse that leads to less branching in the syntactic tree (Frazier & Fodor, 1978). Late closure is the principle that the parser is likely to remain in the same kind of phrase (e.g. verb phrase or noun phrase), and it attaches new units into the phrase it currently processes (Frazier & Fodor, 1978). These principles can cause problems when they cause sentences to be parsed and processed in a way that conflict with the intended parse of the sentence. Parsing is not always straightforward, because words in sentences can sometimes have different meanings, and can be assigned to more than one linguistic category. There is evidence from so called Garden Path sentences, that is, sentences that are grammatically correct, but that are ambiguous and often leads down a wrong path, that the comprehender does not make full analysis of the complete sentence at once (van Gompel, Pickering, Pearson, & Jacob, 2006). Rather, the reader, starting from the beginning of the sentence, interprets the sentence as being set in one context, and interprets the rest of the sentence in light of these judgements. At some later point in the sentence, new information causes confusion and the reader might fully or partly deactivate the inappropriate analysis (van Gompel et al., 2006). Thus, sometimes, the need to process linguistic input here and now, can lead to ambiguity.

1.3 Research question and outline of the thesis

In this thesis, I address two broad questions:

1. What are the causes of word-level disfluency in written production?
2. What, if any, are the consequences of word-level disfluency when the writer is composing full text?

Broken up, my research question above can be formulated as questions that are more specific, and that are addressed by different papers:

In article 1, a group of students was identified based on their struggling with decoding, and being diagnosed with dyslexia. This group of students were targeted as it has been hypothesized that students with dyslexia struggle with writing because they have a word-level focus; that is they are disfluent at the word-level. This article aimed to answer the questions:

- Do students who struggle with decoding produce poorer quality texts?
- Do students who struggle devote disproportionate resources at the word-level?
- Does word-level focus (if present) result from students experiencing decoding problems when reading the word they are currently producing or have just completed?

To answer my overall research questions, I first needed find out whether word-level disfluencies are related to the writing process itself; or whether it relates to monitoring or reading what you have written. I hypothesised that long latency times, or disfluencies at the word-level are related to production rather than monitoring (reading). By production, I mean that I expect long word-level latency times to be related to transcription rather than to monitoring or reading the word that is being written.

Next, I followed two lines of questions; I needed to find out more about the process of spelling single words, what cognitive predictors are there of spelling in a shallow orthography, and whether spelling is a cascaded process. In addition, I aimed to find out how spelling and motor execution influence written word production, and more specifically whether word-level processes influence other writing processes and measures of quality.

In article 2, spelling competence was seen as being reflected in both spelling accuracy, and in spelling fluency. By including fluency as part of spelling competence it was possible to investigate what cognitive factors affect and predict not only spelling accuracy, but also spelling response time and inter keystroke interval. This article addressed the research questions:

- What are the effects of child-level and word-level factors on spelling accuracy and time course?
- And the interaction between the two.

We expected both phoneme-grapheme encoding and orthographic recognition to be important when spelling. Moreover, we hypothesized that if orthographic planning persists beyond typing onset then we would observe differential effects for regular words and words containing what we term a challenge.

Through this article, it was important to find out whether orthographic planning persists beyond typing onset, as that is an implication that disfluencies in the middle of words can be related to spelling.

Article 3, investigates how transcription might predict latency times and disfluencies at the word-level when writing, and possible consequences of disfluencies. The research questions addressed in this paper are:

- What predicts word-level production, and in particular disfluencies at the word-level?
- Can disfluencies in word-level production influence other writing processes and text measures?

I hypothesize that word-level disfluencies are predicted by spelling ability. Moreover, I hypothesize that and word-level disfluencies have negative consequences for higher level processing, and therefore potentially a negative effect for text quality.

Article 4, discusses theoretical assumptions about how lack of flow or disfluencies might influence text writing, and practical consequences for tools developed for writing support. A shift from having correction as the main element, in a writing aid to having fluency as the main element is suggested.

1.3.1 **Outline of the thesis**

My thesis consists of four papers and a kappa surrounding these. Chapter 2 constitutes a presentation and discussion of some concepts that are particularly relevant for answering the research questions. Chapter 3 gives details on what I did to answer the research questions, and provides a commentary on the methods of the three empirical papers. Readers might want to turn to the papers and read these before reading chapter 3, 4 and 9. Chapter 4 gives a short presentation of the articles that are included in this thesis, and that function together to answer my questions. I have conducted three empirical studies, and in addition, I have included a theoretical reflection around consequences of struggling at the word-level, and possible implications for developers of writing support. The papers in their full form appear in chapters 5, 6, 7 and 8. The final chapter, chapter 9, is a general discussion of all findings.

2. Central consepts

There are four concepts that are especially central to the research reported in this thesis: transcription, pauses, and fluency and disfluency. In the following section, I will give an outline of how these are used and understood in this thesis. First, I will discuss what is meant by transcription, how transcription skills typically have been measured and various possible methodological challenges. The next concept - pauses - is related to the object of study in process studies of written language production. Finally, the notions of fluency and disfluency relate to pauses and latencies in that they are used to describe a particular distribution of pauses or latencies.

2.1 Transcription

In Hayes's terminology, the translation process concerns producing text and encoding the concepts the writer intends to write (Hayes, 1996; Hayes & Flower, 1980). In Hayes's model, transcription is part of the translation process, and is considered a sub process separate from lexical retrieval and syntactic planning. Transcription skills therefore combines spelling and keyboarding and handwriting abilities (Berninger, Abbott, Abbott, Graham, & Richards, 2002).

How transcription skill is measured bears consequences for research results. Appropriately operationalizing transcription skills has therefore been central in attempting to answer my research questions. Spelling skills have typically been measured in terms of accuracy (Alves & Limpo, 2015; Berninger, 1999; Graham et al., 1997; McCutchen, 1996). Seen this way, spelling skills can be measured as the proportion of errors in a text, or in a more controlled setting, by having subjects complete a spelling test and counting correctly spelled words. However, there is the spelling process or a fluency aspect to spelling as well. By this, I mean that two students who both correctly spell the word *lokomotiv [locomotive]*, might have done so very differently. One of them could have spelled the word quickly without any hesitation, while the other could have slowed down before the *k,* wondering whether there should be one or two k's. Possibly also slowing down before the third *o,* fearing that there might be too many o's. All of which would result in it taking longer to spell the word. These temporal differences should be included as part of what is meant by spelling skills. Thus, I argue that measures of spelling ability need to take into account not just accuracy by also the ease (fluency) with which the spelling is generated.

The spelling process involves retrieving an internal orthographic representation of the word (or part of the word, or next letter) to be produced. This is then passed to the motor planning process, which then tells your fingers how to execute the motor programs necessary for outputting a word on paper. According to a dual-route account of spelling, spelling can be achieved through two different routes, by incremental phoneme-grapheme mapping, or by directly activating orthographic lexemes (Rapp, Benzing, & Caramazza, 1997). Related to the dual-route account of orthographic retrieval is a question of whether orthographic planning is complete before the first letter is written, or if orthographic planning persists after the first letter of the word is written.

In addition to spelling, transcription involves the motor execution associated with handwriting or, like in the studies that I report in this thesis, keyboarding. Handwriting can be evaluated the basis of the product, readability or neatness, or by handwriting fluency. Handwriting fluency has typically been measured by the alphabet writing task (Abbott & Berninger, 1993; Graham et al., 1997). In this task, children are timed as they print the entire alphabet. Some studies give the score based on how many letters are written in the first 15 seconds (Graham et al., 1997). This task not only gives information about the speed by which participants are able to produce the letters on the paper, it also gives information about familiarity and accuracy of the letters and knowledge of the alphabet. So the score you get is both about motor skill and about alphabet knowledge, which may be seen as orthographic knowledge (e.g. Pontart et al., 2013). The task however, does not involve ability or speed of linking letters together.

Another way of measuring both handwriting fluency and typing fluency is to ask participants to copy one or more sentences of text (Graham et al., 1997; Hayes & Chenoweth, 2006). This way of measuring handwriting or typing fluency will capture speed of transition between letters, but also reading ability, a memory component and, to some extent, spelling ability. The inclusion of a reading element means that reading accuracy and reading speed will influence the result. Spelling processes are necessarily engaged when performing tasks of this nature. Unless the writer copies one letter at a time from the source – which would result in exceptionally slow performance – copying is likely to involve retaining a phonological representation of what is read that must then be spelt during output on the page or screen. Thus, in a copying task, spelling cannot be completely disregarded as long as the words that are written are written in the familiar orthography and constitutes real words.

A third way of measuring handwriting or typing fluency is having participants write their names repeatedly. Alamargot et al.(2007) recorded mean pause duration (times when the pen is lifted from the page) when participants wrote their names. Although, as they argue, this measure excludes more demanding conceptual and linguistic processes, the fact that writers names vary across a number of dimensions that might affect how the pen moves across the page is likely to make this a very noisy measure of handwriting (or typing) fluency.

Some studies include typing speed or transcription fluency when producing text as a production measure (see for example von Koss Torkildsen, Morken, Helland, & Helland, 2016). Medimorec & Risko (2017), in line with Strömqvist (1999), see transcription fluency as the mean keystroke interval within a word. These production measures are not intended to distinguish out spelling fluency from motor execution. For this thesis however, I attempt to investigate spelling fluency and motor execution as hypothetically separate, not to risk missing important insights about word production. Attempts have been made to better distinguish motor execution skills from the influence of orthographic skills. Pontart et al. (2013) distinguished the influence of graphomotor skills (writing ones name) and orthographic knowledge (the alphabet writing task).

In this thesis, I attempt to distinguish three transcription measures: spelling fluency measured by speed of spelling and latency time before spelling initiation, speed of writing when performing a practiced copying task, and key board familiarity. The spelling measures are more influenced by the speed with which participants are able to retrieve orthographic knowledge, while the practiced copying task is influenced by whether or not a child has broad spelling knowledge to a lesser extent, and will be more influenced by motor programs. Finally, the keyboard familiarity measure is a measure of key-location knowledge. It is a measure of ability to mentally map the relation between the name of a letter and the location of that letter on the keyboard. It is not a merely a measure of how quickly fingers are able to hit single keys on the keyboard, such a test would be more like hitting a single key as many times as you can within for example 20 seconds, or hitting two keys as many times as possible within a time limit.

2.2 Pauses

Psycholinguistic literature has a long tradition of considering temporal aspects of language production from the perspective of spoken language. Goldman-Eisler (1968) found that people pause nearly fifty percent of the time when speaking, and she suggested that these pauses function as periods of planning, execution and monitoring. The pauses in speech can be either filled – a gap in speech that filled with a sound or word- or silent pauses. A main point to make when studying pauses is the assumption that pauses are not arbitrary, but can be studied to gain information about cognitive processes during writing. Although think-aloud protocols (Hayes & Flower, 1980) and video recordings (Matsuhashi, 1981) have made temporal studies of writing possible, keystroke logging has made the study of temporal aspects of written language production relatively straightforward. Keystroke logging gives accurate recordings of writing behaviour, and larger groups can be tested simultaneously.

Faced with temporal data, however, the challenge is how to operationalize the notion of pause in a valid way. When typing, each key press takes some time to prepare, and so it is preceded by a delay – a "keypress latency". When keyboarding, moving from one letter to another on a keyboard necessarily involves a short period of inactivity or a latency. However, not all of these short periods of inactivity should be or are considered pauses, some of them are merely transitions. The challenge arises when one needs to discern what is a pause and what is merely a transition. How long does the period of inactivity have to last to be considered a pause? Wengelin (2006 p.111) suggests a working definition of a pause as "a transition time between two keystrokes which is longer than what can be expected to be necessary merely for finding the next key". She continues to point out that most research stipulates a criterion that best suits the research (Wengelin, 2006). Two common pause thresholds are 1 second and 2 second pauses (Alves, Castro, & Olive, 2008; Strömqvist, Holmqvist, Johansson, Karlsson, & Wengelin, 2006). These thresholds are much longer than the time to find a key.

When looking at latency times or pauses, it is not very interesting averaging across all keystrokes. Keys need to be sorted according to where they appear. Foulin (1998) show that rhetorical features of the text partly determine pause location. Thus, as Wengelin et al. (2009) point out, this suggests that pause location and duration are indicative of cognitive activities that the writer engages in during the writing process.

Pauses are therefore only interpretable in the context of the specific text locations in which they occur, whether the key appears at the beginning of a word, in the middle of a word, at the beginning of a sentence or a t-unit, at the beginning of a paragraph, before a full stop and so on. Latency times for keys that are sentence initial are typically longer than for keys that are word initial, and keys that are paragraph initial typically have longer latency times than keys that are sentence initial (Wengelin, 2006). The longer sentence initial latency times are often explained by writers typically planning what to write next, or by writers looking back at what they have written. Pause probability at a particular location, allows different pause thresholds to be used. A one-second pause at a sentence boundary means something quite different from a one-second pause within a word.

When discussing the writing process, some researchers apply terms like bursts and burst length (e.g. Alves & Limpo, 2015; Baaijen, Galbraith, & Glopper, 2012). Burst length, if simply measured as the number of words written between pauses, is the same as pause frequency controlling for text length (e.g., number of pauses per 100 words), only that the characters and the pause take opposite positions in the equation. That is, burst length = the number of characters / number of pauses, while pause frequency = number of pauses / number of characters. Pause frequency is pauses per characters at a particular location, while burst length is characters per pause. Pause frequency and burst length control for the total length of the text; however, these measures do not take into account where in the text the pause occurs. Pause probability at a particular location, takes into account where in the text the pause is. Pause probability at a particular location is the number of keys in these locations that involve a pause / number of keys in these locations.

Hayes & Chenoweth (2006) argue that transcription processes are not the cause of pauses or bursts. The reason for this, they argue, is that during a copying task performed by skilled typists, they found that bursts were practically absent. However, a copying task involves reading and motor execution; it minimalizes the influence from retrieving a spelling. My argument is that transcription can cause pauses and bursts, and that the inclusion of the spelling process as part of transcription is important.

2.3 Fluency and disfluency

I have already used the term fluency several times, handwriting fluency, spelling fluency and simply fluency. In the following section, I will make clear how the terms fluency and disfluency are used by others, and how I use these terms.
Different researchers have different way of understanding and operationalizing the idea of «fluent text». When considering fluency of the final written text, the judgement of whether a text is fluent or not is based on what the reader considers makes a text fluent or not (Palvianinen, Kalaja, & Mäntylä, 2012). Thus, the process under which the text was written and the writer are ignored. There are different ways

to define writing fluency when considering fluency in relation to the writing process. Fluency of production may entail absence of cursor moves, deletions and insertions, or it can entail speed of production. Some studies include words written per minute as a measure of fluency (e.g. Chenoweth & Hayes, 2016). This way of measuring fluency, gives information about average speed across all keys in all locations. One might say that this way of measuring fluency entails quicker is better in all locations. Thus, measuring fluency this way would exclude long latency times or pauses as part of fluent writing because pauses would affect fluency negatively according to the way it is measured. However, findings from studies of the writing process, suggest that writing includes pauses, and that writing typically goes on as an alternation between bursts of inscription and pauses where nothing is written (Wengelin et al., 2009).

As a starting point here, writing fluency is seen as a behaviour characteristic for writing coherent texts with relative ease (Kellogg, Krueger, & Blair, 1991). Such a conception of fluency entails that fluent writing also has its hesitations and pauses, simply because skilled writing involves reflection, planning and revision - resulting in pauses (T. Olive & Kellogg, 2002). The central question then is not whether fluent writing includes pauses; rather it is a question of the distribution and duration of these pauses.

If fluency is not the absence of pauses, what then is it? In reading, fluency is described by Harris and Hodges as “freedom from word identification problems that might hinder comprehension” (1985 p.85). Relating to this view is the definition I introduced in the beginning of this thesis; Tønnessen & Uppstad’s (2015) view that reading fluency is “thinking one’s way through a text without the written medium obstructing one’s thought” (p.75). I apply this notion of fluency for writing as well, as it carries an implication of what disfluency might be. Following a theory of flow, (Csikszentmihalyi, 1997), flow can be seen as a threshold that need to be passed in order to be fluent. Beyond this threshold, thoughts can proceed without being interfered by for example considerations about spelling. If we combine the concept of fluency with Christiansen and Chater's (2016) just-in-time constraint of language processing and production, fluency in written production would imply that the process of breaking down concepts into words, and further into chunks low enough for transcription happens here and now.

One might say that fluent writing at least involves fluent transcription, and that fluent transcription refers to no unexpectedly long keystroke intervals at the word-level; that is, word initially and mid word. Following the argument I made in the introduction, fluent writing thus opens for higher-level processes to operate in parallel with lower level processes.

I start using the term disfluencies in the final article of this thesis, I no longer use the term pause. The way disfluency is used here, in written text production, is not to be confused with disfluencies in spoken language, which may refer to filled pauses, repetition, repair, false start. There is an extensive literature with contributions from a range of fields concerned with disfluencies in speech which I will not go into here (see Eklund, 2004; Shriberg, 1999). A disfluency here is a latency time that for the particular location is so long that it is expected to be disruptive. It is disruptive if transcription does not happen here and now, and creates a bottleneck. What I define as disfluencies are word initial latencies longer than two seconds (but shorter than ten seconds), and mid word latencies longer than one second. The term disfluency has a negative connotation as opposed to the word pause. As I said in the introduction, that is intentional; as I hypothesize that word-level disfluencies can disturb written language production as a whole.

2.3.1 Consequences of the applied notion of fluency

Most previous research has found evidence that increased transcription fluency improves written text quality (Alves, Castro, de Sousa, & Stromqvist, 2007; Connelly, Dockrell, & Barnett, 2005; Thierry Olive, Alves, & Castro, 2009; Sumner et al., 2013). However, it seems that the relationship between transcription fluency and text quality is not linear. In a group of university students decreased transcription fluency was found to be beneficial for certain aspects of writing (Medimorec & Risko, 2016; Medimorec, Young, & Risko, 2017). In their study, Medimorec & Risko (2016) define transcription fluency as motor execution. They interfered with skilled typists’ transcription fluency by asking them to type only with one hand, thus constraining motor execution and slowing down transcription speed. Results showed that texts written with one hand showed higher lexical sophistication they included more diverse vocabulary and less frequent words. This study adds new insights to the study of fluency in transcription. In studies where increased transcription fluency have improved text writing quality, participants have typically struggled with spelling in addition to motor execution. In Medimorec's study, subjects were proficient typists, and their slowing down did not involve thinking about how to spell a word, instead participants were given more time to, for example, choose a more low frequency word. Following Christiansen and Chater's (2016) view of language production, this might not be a surprising finding. According to them, in language production, discourse level chunks are broken down into sub chunks like words and phonemes or graphemes, and the higher-level chunks are passed down as soon as they are ready, leading to a tendency to choose the word that is more fluently retrieved over a word that is harder to access. Thus, forcing proficient typists to produce language not just-in-time, but by forcing them to minimally slow down, might explain the result of producing more low frequency words. In another study, Medimorec & Risko (2017) find that pauses at word boundaries predict word frequency. Increased pauses gave decreased word frequency. It has not been determined whether the pauses prior to less frequent words are linked to lemma selection or to retrieving a less frequent spelling.

3. Methods

This section includes information about what I did to get closer to an answer to my research questions:

- What are the causes of word-level disfluencies in written production?
- What, if any, are the consequences of word-level disfluencies when the writer is composing full text?

The three empirical studies were conducted on two different samples. I will describe these in more detail in below. However, before describing these, I will give a schematic overview of the studies; sample, design, and the measures involved. See Table 1.

Study	Sample	Design	Measures
Study ONE	26 weak decoders and 26 control students Mean age: 16 years 11 months Weak decoders were identified by having a dyslexia diagnosis, and by scoring below the 15th centile on a word-split test Weak decoders and controls matched for age, sex, and performance in mathematics	Students wrote two argumentative texts on keyboard. One in a normal condition and one in a masked condition. Counterbalanced across order and topic. Given 45 minutes to write each text.	**Text quality** - Organization - Theme development - Vocabulary **Text based measures** - Length - Spelling errors - Type-token ratio - Ratio of open-class to closed-class **Process measures** - Editing - Time on task - Within word latencies - Word end latencies - Pre-word latencies - Pre-sentence latencies - Pause-bins within word and pre-word
Study TWO	100 students Mean age: 11 years 10 months	Students completed a spelling-to-dictation test, consisting of 32 items. They wrote on computers.	**Spelling measures** - Accuracy - Response-onset latency - Inter-keypress interval **Cognitive ability measures** - Nonverbal ability - Rapid automatized naming - Word-split test - Short-term memory - Key finding - Non-word spelling - Raven
Study THREE	100 students (The same students as in study 2) Mean age: 11 years 10 months	Student wrote an argumentative text on keyboard. Given 20 minutes to write each text.	**Text quality** - Organization - Theme development - Vocabulary - Holistic score **Text based measures** - Length - Lexical density **Process measures** - Word initial latency - Mid word latency - Word initial disfluency - Mid word disfluency - Sentence initial latency **Transcription measures** - Spelling - Practiced copying - Key finding **Cognitive ability measures** - Short-term memory - Raven - National reading test

Table 1. Overview of design, sample and measures in the empirical studies.

All three empirical studies involve temporal writing processes with a particular focus on the word-level.

Study 1 enabled us to identify whether a word-level focus in production, seen as longer word-level latencies, results from decoding problems or from production. In addition, it provided knowledge about weak decoders.

Through study 2, we were able to identify child-level cognitive factors that predict spelling accuracy and process. Moreover, this study yielded information about how and when the spelling of a single word is planned, and if mid-word disfluencies can be related to spelling.

Study 3 identified how transcription skills influence the word-level processes during text writing. Finally, this study enabled me to model the relationship between word-level processes and measures of text quality.

In addition to the three studies, resulting in three empirical papers, this thesis includes a fourth paper that illustrates possible consequences for developers of supportive tools, of accepting the idea that disfluencies at the word-level can disturb other processes, and that writing support should aim for fluency in writing.

3.1 Sample

As mentioned, two different samples were recruited. This section provides details about the two samples and the process of recruiting them. The first sample, recruited for study 1, is a group of upper secondary weak decoders diagnosed with dyslexia, and a group of control students. The second sample, recruited for study 2 and 3, consists of whole classes of 6th grade students. All included students in both samples spoke Norwegian as their first language. The two samples shown in table 1 are recruited from southwest Norway, in Rogaland County. The first from 12 upper-secondary schools, the second from four different primary schools. I chose to include two different samples, as these would serve to answer different questions relating to my hypothesis. The sample that included the students diagnosed with dyslexia was included in the study to get information about writers known to have a word-level focus. The second sample was targeted as relatively little research is done when it comes to writing and this age group. Moreover, by recruiting full classes, the whole range of students present in the current classrooms in these public schools in Norway were included. This way, by recruiting students this age and including all abilities, and we expected both students who struggle with transcription and students who transcribe more or less fluently to be included in the sample.

3.1.1 Sample 1

The reason we targeted weak decoders diagnosed with dyslexia in their first year of secondary school is that we wanted a sample of students with a dyslexia diagnosis who had reached an age where transcription normally should be automatized. In addition, several studies of dyslexic students are based on data collected from university students. We wanted a sample that included both students who would not go to university, and at the same time, a sample that included some students who potentially would go to university. Therefore, students were recruited from their first year in upper secondary school. The first year of upper secondary school is the first year where students choose to go to either a vocational or a university-preparatory school. In addition, we targeted the first year of upper secondary school because all students (apart from a small minority of students going to private religious schools or who get Steiner education) would have gone through the same curricula by this time, but not from then on. This guaranteed that students had followed the same curricula, and had been offered nearly the same schooling.

For sample one, originally, we set a strong inclusion criterion of being diagnosed as dyslexic, however, this criterion for identification for a struggling sample turned out to be difficult for several reasons. First, the process of getting in touch with these students was hard. Schools are not allowed to give information identifying students who have been diagnosed with dyslexia. Therefore, our source of information was The Norwegian Educational and Psychological Counselling Service (the PPT). This is the service that typically tests students and diagnoses dyslexia. PPT contacted potential participants who had to give their consent and their parents' consent for us to contact them. Next, we were able to contact students, and students and parents, and the student's respective schools had to agree to take part in our study, meaning students had to give their consent twice. Second and more importantly, all students identified with dyslexia did not perform poorly on the decoding test they were given, a standardized Norwegian version of the word split task (Jacobson, 2001; Miller-Guron, 1999). They did not seem to struggle the way we expected students with dyslexia to do. Based on comments from reviewers and our own considerations, this made us question whether it was meaningful to treat all students who attracted the label dyslexia as a coherent group. Because of this variation in our sample of dyslexic students, we had to change the criterion for including students in our struggling group. Instead of targeting students with a diagnosis, we asked teachers to identify struggling students, and next we asked the students if they had been given a dyslexia diagnosis. These were in turn tested by us, and included in the sample based on their decoding ability scores. When the original sample was adjusted, 7 dyslexic students and their controls were removed from the sample, adding 8 new dyslexic/control pairs (16 students). It is important to note that scores on the dependent variables were not considered when adjusting the sample. The final sample ended up being more clear-cut with the deficit group having a mean word-split (decoding) score below the 15th centile and the controls above 60th centile, with no overlap between groups. Although all the students in the deficit group were diagnosed with dyslexia, we relabelled them "weak decoders". This was done to acknowledge that some students with a dyslexia diagnosis had been excluded, and to reflect that the deficit group was now defined more narrowly.

The variability within the sample, and the "lack of struggling" described above, can possibly be explained by the way the Norwegian system defines and gives the diagnosis dyslexia, and by the fact that some students were given the diagnosis during the first years of schooling (age 9/10) and some got the diagnosis much later (age 15+). Moreover, it serves to illustrate that students with dyslexia vary in degrees of academic struggle, and in how well they succeed in developing strategies to cope with their difficulties.

3.1.2 Sample 2

Seven whole classes of 6th grade students were invited to take part in what I presented to them as a "Writing week". The writing week was designed to include writing assignments that students would work with in a normal week, so that teachers would not having to worry about working with other things than what the curricula tells them to. It was essential that the students got useful input, and a goal was to conduct good research and at the same time provide good quality education. It was important for me as a researcher that as many students as possible agreed to take part in the study, at the same time I had to design the writing week in such a way that students who opted out were not stigmatized. During writing week, I as a researcher wanted to give something back to the schools. Therefore students were not only tested, but classes received a lesson in writing, were given materials to work with, took part in a reading and writing dance and were given an opportunity to reflect around writing and the research they took part in.

It was easy to recruit classes for participation, and teachers were very positive. The writing weeks took place between mid-February and April in 6th grade. In four of the classes, all students agreed to take part in the study. In the other three, some opted out. The teachers reported that these represented a mixture of academic skills. Prior to the writing weeks, I visited all schools, informed the teachers and drew up a schedule in consultation with them. All students took part in classroom activities, and the ones who gave consent to take part in the study were tested individually. I conducted all classroom testing and instruction, and was responsible for teaching the students the dance, for the individual testing two trained research assistants assisted me.

Giving something back to schools in terms of lessons about writing, material and the dance contributed to the research in several ways. First, teachers saw the writing week as an opportunity to get input – both for themselves and for their students. For them it meant less planning and no additional organizing. Meeting the teachers in advance and making sure they were excited about the writing week, meant that they would talk warmly about the research to their students and work harder to motivate students and parents to give their consent to take part. Second, by giving a lecture prior to the writing assignment, I made sure all students knew how to argue and give reasons while writing. Finally, by the time students were tested individually, they had met the researcher and research assistant in a normal classroom setting. In addition, they had seen the researcher in a more fun and relaxed setting during the reading and writing dance. The dance served a second function as well; it served to train the students to follow specific instructions given by the researcher. I made every attempt to ensure that all students felt comfortable with me –the researcher, and the assistant. I think all research involving children should strive to create a memorable and positive experience to participants.

3.2 The Norwegian context

3.2.1 Norwegian phonology and orthography

Norwegian is a North-Germanic language. There are two written norms in Norwegian, however only Bokmål will be commented on here as this is the norm the participants used when writing. Kristoffersen (2000) points out that there is no spoken norm in Norwegian, though Bokmål is best reflected by the dialect used by the middle-class in urban areas of southeastern Norway. When describing Norwegian phonology, I will follow Kristoffersen's (2000) description of southeastern Norwegian. In Norwegian, there are nine vowels that can be realized as either long or short vowel phonemes. There are 20 consonants, eight stops [p, b, t, d, ʈ, ɖ, k, g], four nasals [m, n, ɳ, ŋ], five fricatives [f, s, ʂ, ç, h], four liquids [r, l, ɽ, ɭ], and three approximants [v, w, j]. The retroflex are not common in the southwestern part of Norway where the participants in this study came from.

Alphabetic orthographies vary in orthographic depth (Frost, Katz, & Bentin, 1987). Orthographic depth concerns how consistently the mapping between letters and phonemes is. In shallow orthographies, phonemes are represented by graphemes in a direct manner. In deeper orthographies, the relationship between sound and spelling is more complex, one phoneme can be represented by different letters, and one letter can represent different phonemes (Frost et al., 1987). The process of assembling orthography from pronunciation (letter-by-letter mapping of phonemes onto graphemes) is more reliable in orthographies that are shallow. Learners of a more shallow orthography gain more in phoneme awareness, word recognition and spelling compared to learners of deep orthographies during the first years of schooling (Seymour, Aro, & Erskine, 2003). The Norwegian orthography has a relatively regular phoneme-grapheme mapping, and is considered a more shallow orthography (Seymour et al., 2003), or as semi-transparent.

The Norwegian alphabet consists of 29 letters, and all the letters are represented with one key on the keyboard - Norwegian keyboards include keys for the special characters "æ, ø and å". With a few morphological exceptions, most Norwegian words can be accessed and spelled phonetically (Hagtvet, Helland, & Lyster, 2006, p. 21). Still, there are some challenges in the Norwegian orthography. One phoneme can be represented by several graphemes; [ʃ] can be represented by skj and (ŋ) is represented by ng, or one phoneme [ç] can be represented by different sets of graphemes kj or tj. Moreover, during the past few decades the [ʃ] has begun to be a prevalent substitute for [ç]. It has become a tendency, particularly among younger people, not to distinguish between [ʃ] and [ç], pronouncing everything as [ʃ] (Akselberg, 1999). Hagtvet et al. (2006) also point out that consonant clusters like *nifst* (scary) are difficult to spell. In addition, some consonant clusters are often reduced in colloquial speech, like *marsjerer* is often pronounced without the r in the first-syllable position. There is considerable variation between Norwegian dialects, a fact that results in some of them being closer to the written norm than others are.

3.2.2 Education

Children in Norway start school in the year when they turn six years old. They are introduced to reading and writing as soon as they start, typically being introduced to one new letter a week. The national curriculum describes the skills students should have acquired after two years of schooling. They should be able to "demonstrate an understanding of the relationship between speech sound and letter", and be able to "connect sounds to form words" (Kunnskapsdepartementet, 2006). These quotes from the Knowledge Promotion, the Norwegian curriculum for the 10-year compulsory school, indicates an emphasis on phoneme-grapheme mapping when children start school. Moreover, after two years of schooling, children should be able to "write sentences with upper and lower case letters and full stops in own handwriting and on a keyboard" and after seven years they should "write fluently in a personal and functional handwriting and use a keyboard in an appropriate manner" (Kunnskapsdepartementet, 2006). This demonstrates that Norwegian students are introduced to both handwriting and keyboarding during the first years of school, and are expected to master both. Finally, from an early age children are required to write meaningful texts. After year two, children should be able to "write simple descriptive and narrative texts" (Kunnskapsdepartementet, 2006).

3.2.3 Students diagnosed with dyslexia

Difficulties with reading and writing are the main symptoms of dyslexia. A focus on reading and spelling of words is reflected in many definitions of dyslexia. Rose 2009 constructed this working definition of dyslexia: "Dyslexia is a learning difficulty that primarily affects the skills involved in accurate and fluent word reading and spelling". There has generally been more focus on the reading problems people with dyslexia face, than on the problems with writing, although writing problems to a larger extent seem to persist (Berninger, 2006).

According to the "phonological deficit hypothesis" a phonological deficit is the main reason for the struggle students with dyslexia experience (Goswami & Bryant, 1990; Rack, 1994; Snowling, 1998). Referring to this hypothesis is a dominant way of describing the cause of dyslexia. In in schools and education, it has led to a focus on phonological awareness when teaching students with dyslexia reading. Students diagnosed with dyslexia in Norway are typically assigned lessons with a specially trained teacher each week. These lessons are typically reading-focused but can also involve spelling practice and occasionally written composition. Students diagnosed with dyslexia are typically provided with a personal computer and assistive software to support spelling and text planning.

3.3 Materials and procedure

I made all arrangements and schedules prior to data collections. Participants had been informed I was coming, and were prepared. The participants completed the text writing and all the tests at their respective schools.

3.3.1 Study 1

Participants in study 1were asked to write two expository texts. They were given 45 minutes to write each of these texts. In addition they completed a word split task (Jacobson, 2001; Miller-Guron, 1999). The text writing assignments and word split task are described in more detail below.

Text writing

In study 1, participants wrote two texts in different conditions, a normal condition and a masked condition. In the masked condition, all letters were replaced with x'es. That is, if a participant wrote, "Hi my name is Vibeke", what would appear on the screen was "xx xx xxxx xx xxxxxx". By masking letters with x'es, it was possible to investigate what happens if it is impossible to read what you have written. Both texts were about topics we expected the participants to have knowledge about, and that were part of public discussion that year. In topic A, the students were asked to write a text where they discussed the pros and cons of homework. The task statement was: *"Bør lekser avskaffes? Skriv en sammenhengende tekst der du argumenterer for og mot dette."* ("Should teachers cease to give students homework? Write an essay arguing the pros and cons of giving students homework."). In topic B, they were asked to discuss the pros and cons of having free public transportations for people 15-21 years old. The task statement was: *"Bør Ungdomskortet være gratis? Skriv en sammenhengende tekst der du argumenterer for og mot dette."* ("Should public transportation for young people be free? Write an essay arguing the pros and cons of having free public transportations for young people.”). Order and topic were counterbalanced across the normal and blind or masked-text condition. Before writing in the masked condition, students were assured that it is possible to write in this condition, and again they were urged to try to approach the writing as they normally do.

My colleague Margunn Mossige and I collected these data. Two students sat together at a time. These were the matched pairs, meaning they were students from the same class and knew each other. In assessing these students, it was important to make the setting safe and relaxed. This was particularly important as half the students in our sample were targeted because we expected them to struggle with writing, and now we wanted them to do exactly that, write. At the same time we wanted to maintain an experimental setting, that is, we wanted to make the experience as uniform as possible for all participants, by controlling variables that might otherwise influence performance. For example we allowed no music in the background, no mobile phones, no talking, no eating or drinking, writing in a room with closed doors, etc. Students were asked to approach the writing tasks as they normally would in a classroom setting. They were assured that their texts would not influence their grades, but that they took part in important research and that it was essential that they did their best. They were informed that the person testing them, together with another researcher, would read their text. Participants were explicitly informed that the researchers would read their masked text even if the text was blocked from their view. We saw it as essential that students knew this so that we did not risk their revealing things about themselves that they did not want us to know, or just write nonsense words. In addition writing a text without a purpose or without any readers is demotivating.

After finishing the first text, all students were given a five-minute break and were offered a chocolate and something to drink.

Word-split task:

A standardized Norwegian version of the word-split test (Jacobson, 2001; Miller-Guron, 1999) was administered to the students when they had finished writing the second expository text, as a measure of decoding ability. Even though we knew we ran the risk of having to exclude participants based on this test, we wanted students to complete the writing tasks first. The rationale for this was to make sure motivation was optimal when writing. In addition, we knew that some of our students were likely to struggle with the word-split task and we did not want this experience to influence their writing performance.

Students were given three practice tasks; i.e. three chains of 4 words without spacing, where the student should identify the word-boundaries with a vertical line. This gave the researcher a chance to ensure that all participants knew what to do. The participants were given five minutes to solve as many word-chains as possible, with a maximum score of 74.

The word-split test provides a measure of decoding ability with a fluency focus in addition to an accuracy focus. For students as old as ours, and reading in a transparent orthography, this test gives better discrimination among pupils than single-word reading accuracy measures (Wimmer, 1993). Means for the weak decoders were below the 15th national-norm centile, and for the control students it was above the 60th centile.

Word recognition in this task will be affected by the word frequency effect (Smilek, Sinnett, & Kingstone, 2014), meaning that words that are more frequent will be more easily recognized. However, as words are presented without spacing, the surrounding words and the location of the word in the string will also influence word recognition.

Once they had finished writing both texts, and had completed the word-split task, they were asked some questions about their experiences and thoughts about writing the texts.

3.3.2 Study 2 and 3:

Two opposite forces drove the process of selecting which tests to include in our test battery. First was our wish to get many and accurate measures, with several measuring points or measures. Second, the demands of doing the testing in real schools, in authentic settings – meaning that we needed to be able to do as much as possible in a classroom setting and with real children – meaning we did not want to run the risk of exhausting the participants. We wanted to include a test of general cognitive abilities, short-term memory, orthographic recognition, phoneme-grapheme encoding, typing skills and a measure of how familiar the students were with the keyboard in addition to a text writing and spelling assignment. I will describe the spelling test that was used in study 2, and then the text writing assignment that was used in study 3, before describing the cognitive measures included in both or one of the studies.

Spelling test

The 6th grade students completed a standardized, 32 item spelling-to-dictation test (Skaathun, 2007 see appendix article 2). The words in the test were included to cover the variety of spelling in Norwegian. In the test, there were words with a straightforward phoneme-grapheme mapping, words with a word initial challenge, and words with a mid word challenge. What we term challenge included consonant doubling (e.g., tatt / taken), consonant clusters where all consonants are not clearly pronounced (marsjerer / marches), failure to differentiate similar phonemes (e.g., [ʃ], [ʂ], and [ç] in the word kjole / dress), and silent letters (the letter g in gjort / done). We got information about word frequency from the Norwegian Newspaper Corpus (NNC, 2013).

Small groups of students completed the spelling test on individual computers. Target words were presented to students through headphones. First, the students got to hear the words within a sentence, and next they were told which word to write. The participants could not infer which of the words in the sentence they were going to write, as the target word could appear anywhere in the sentence. No time limit was set. However, students were told to start spelling the target word as soon as possible after hearing the target word. All keys were logged. The spelling test gave measures on accuracy, response onset latency and inter keypress interval for study 2, for study 3 spelling speed was used instead of individual key latencies. Spelling speed included misspelled words and deletions or revisions, it is a measure of how long it took participants to spell a word irrespective of whether they spelled the word correctly.

Text writing

When collecting data during writing week, our participants wrote three or four texts, one by hand, one on a computer, one in a masked text condition and part of the sample wrote a text in English. Only data from the text written on computer is included in this thesis; however, the rationale for assigning children different writing tasks was that this would allow us to counterbalance and compare tasks and writing conditions at a later point. Thus, participants were randomly assigned to write an argumentative text around one of three topics:

"Du er en vitenskapsmann som har bygd en tidsmaskin som faktisk virker, men du kan bare bruke den til en reise. Tenk deg nøye om. Hvilken tid i fortida eller framtida ville du reist til? Begrunn hvorfor du vil reise til akkurat denne tiden.". ("You are a scientist, and you have built a time machine that actually works, but you can only use it once. Think carefully. To what time in the past or in the future would you go? Give reasons for your choice.")

"Forestill deg at du skal på en reise til en øde øy. Du får lov til å ta med deg tre ting. Tenk deg nøye om. Hvilke tre ting du ville tatt med? Begrunn hvorfor du vil ta med deg akkurat disse tingene." ("Imagine you are going to a deserted island. You are only allowed to bring three things Think carefully. What three things would you bring? Give reasons for your choice.")

"Tenk deg at du kunne få oppfylt tre ønsker og alt hva mulig. Tenk deg nøye om. Hvilke tre ønsker skulle det vært? Begrunn hvorfor du ville ønsket akkurat dette." ("Imagine you could get three wishes fulfilled, and everything was possible. Think carefully. What three should it be? Give reasons for your choice.")

Students wrote the text on individual computers. An experimental setting was maintained. They were given 20 minutes to complete the text writing. If they were done before time ran out, they were asked if they were sure they wanted to finish. If they responded yes, they were given a text to read.

Measures of cognitive abilities.

In addition to writing texts and completing the spelling task, the students in sample 2 were tested on several cognitive skills. Some of these were conducted in a classroom setting, others individually. Throughout, it was important for me to ensure that the dignity and self-respect of the students were maintained. One of my personal goals when conducting the individual testing was that the students should leave the room feeling confident and if possible better about themselves than they did when they entered. To achieve this, they all got positive feedback when they were done, and aspects of their performance were highlighted to support the praise.

Word split task

Same as for study 1.

Nonverbal abilities.

All participants completed Raven (Raven, 1981) as a measure of general nonverbal cognitive abilities. The test was conducted in group of 12-15 students working at the same time. Procedures from the manual were followed. Students were given a raw score varying from 23 to 53 points.

Rapid automatized naming (RAN).

Participants were given two RAN tasks, the letters and digits subtests from the CTOPP (Wagner, Torgesen, & Rashotte, 1999). For these tests, participants were presented with two printed pages of 36 randomly arranged objects and letters. They were urged to name the letters and numbers as quickly as possible while the researcher timed their performance and scored it for accuracy.

National reading test

We were given access to the scores their children got on the National reading teat the previous year. This is an obligatory test designed to measure reading comprehension. The test includes texts of different genres. These texts are followed by questions, mainly multiple choice.

Keyfinding.

A keyfinding exercise was given to get a measure of how quickly and accurately students were able to find single keys and trigrams on the keyboard in response to spoken letter-name prompts. Students were given four practice tasks, 2 monograms and 2 trigrams. The test itself consisted of 14 monograms, each presented two times and twenty trigrams, of which ten were cvc and ten ccc. For monograms, students heard 14 different consonant names, each occurring twice, with randomized order. On hearing a letter name students were required to press the corresponding key, being as quick and as accurate as possible. Students completed the exercise in small groups, on individual computers with letter names played through headphones. Both accuracy (the total number of correctly chosen keys, with a maximum of 28) and speed were recorded. There was a correlation between trigrams and short-term memory, and we suspected trigrams measured something other than keyboard familiarity. In the analysis, only monograms were used. The keyfinding task measures something more than just familiarity with keyboard and motor execution. The score is also influences by how quickly students are able to go from phoneme to its corresponding grapheme.

Short term memory

Students were given a letter-span task as a measure of short-term memory. Strings of letter names varying between two letters, and up to six letters were presented to the students through headphones. After hearing the string, students were required to repeat all the letter names of the string in the correct order. If all the letters of a string were recalled correctly, the student was given a score equal to the number of letters in the string.

Practiced copying task

Participants were given a practised copying task to assess typing speed when words and spellings were practised, that is, the influence from spelling is minimized. In addition, as this was a practised copying task, it meant the students did not have the text in front of them and therefore reading speed did not influence the result. The task was introduced in the classroom where students were asked to memorize two sentences; "Jeg gleder meg til bursdagen min. Da får jeg en fin gave" [I am looking forward to my birthday. I am going to get a nice present]. These sentences are easy to remember, and there are no challenging spellings. We did not attempt to control or manipulate how many different keys the students had to type. Prior to testing, the sentences were written on the blackboard and all the students repeated them orally in unison three times. Next, students opened the assignment on their individual computers. The assignment consisted of three blocks. First, a practice block where students had to type the sentences twice. Next, a neat block where they were instructed to copy the sentences as accurately as possible. For both these blocks, the participants had the printed sentences in front of them. Finally, participants completed a timed block. This time, the print was no longer available. Students were told to type the sentences as many times as possible in 1 minute. This gave us the practised copying measures median word initial latency and median mid word latency.

3.4 Analysing the written product

Two independent scorers identified all spelling errors in all texts, both for study 1 and 3, manually. This was necessary, as a lot of spelling errors in Norwegian are real word substitutions, meaning another word than the intended is written and spell checkers do not always recognize these as errors. For example, students sometimes write *vis* meaning 'knowledgeable' instead of *hvis* meaning 'if'. In addition, two scorers were necessary to agree on the word the students intended to write. After error correction, the texts were typed without any errors so that the raters of text quality would not be influenced by spelling errors. The original syntax and punctuation were retained. As some texts were written in a blind condition, capitalization was corrected to prevent raters from identifying which texts were written in which condition.

3.4.1 Text based measures

To process the written product of all texts, for both study 1 and study 3, a word count was conducted using Microsoft Word. For study 1, the number of spelling errors were counted, type-token ratio was calculated as a measure of lexical diversity, and ratio of open class to closed class was calculated as a measure of lexical density; in addition, word length and frequency was retrieved for open class words. For study 3, lexical density was calculated in addition to text length. Lexical diversity was calculated for study 3, but not included in the analysis because it correlated strongly with text length.

Lexical diversity measures how many different words there are in a text (Johansson, 2008). The way we measured lexical diversity was by calculating the ratio of types to the number of tokens; that is, number of different words in the text to total number of words. Johansson (2008) points out that a challenge with this measure is that it is longer texts generally gets lower lexical diversity, a possible solution might be to use only parts of texts to compare texts of equal lengths. For our purpose, we included entire texts. Variability in text length was large, however, we concluded that including only the first 50 or so words to make texts equal in length, would mean that for some participants only the introduction would be included, which would not give an accurate picture of lexical diversity.

Lexical density gives a measure of the proportion of lexical items in a text (Johansson, 2008). Lexical items are nouns, verbs, adjectives and some adverbs. Explicitly naming subjects and objects, rather than using for example pronouns will make a text more lexically dens. Thus, lexical density is a measure of how much information a text contains; it is not a measure of complexity. Higher lexical density implies that more information is packed into the text, and that it is less vague than a text with low lexical density, illustrated by the examples below:

Sentence	Lexical density
He loves them.	33%
He loves the dogs.	50%
Per loves the dogs.	75%

3.4.2 Reader based measures

We scored the texts for quality following an adapted version of the criteria for the Wechsler Individual Achievement Test (WIAT) –Second UK Edition essay task (Wechsler, 2006). The spelling corrected texts were scored for organisation, theme development and vocabulary. In addition, the texts written by the younger sample were assigned a holistic score. Sentence structure, the use of topic sentences, logical sequencing of ideas within paragraphs, the use of linking words, signposting to make the text clear for the readers, and whether the text included an introduction and a conclusion, and whether structure was used as a rhetorical device made up the organization score. We included signposting as a criterion because reader awareness is highly valued in the essays students normally write. One of the criteria that is included in WIAT was excluded, as it is only relevant if writers are answering the WIAT assignment. Theme development was scored according to the number of reasons or arguments for the position or stance the writer had taken, whether the text included evidence or examples to support the arguments, inclusion of a counter argument (only for sample 1 as this was not appropriate for sample 2), an evaluation of whether the content was on topic and finally if the text merely answers a question. According to the scoring criteria, three supports are needed to score the maximum number of points, however for Norwegian students who are not as used to the five-paragraph essay, this was reduced to two reasons for the first sample. For the vocabulary score, credit was given if the writer used specific words, making meaning clear and unambiguous; it was credit was given if vocabulary was varied and rich, and finally, a bonus point was awarded for including unusual or vivid words or phrases.

However, and generally acknowledged in the research community, how to evaluate text quality is challenging. By following a premade scoring scheme, it might be concluded that I took the easy way out. Though, this was necessary, considering all the texts that needed to be scored. However, it is important to be aware of the fact that scoring texts according to such premade criterion always runs the risk of missing something important. For example, the experience and emotions the reader got during reading are largely ignored. After having scored more than 200 texts, only one in particular sticks to my memory. I would say this text made a lasting impression on me. Following the scoring scheme, this text got one of the lowest scores. It was only remotely an appropriate response to the prompt. It lacked structure. There was no introduction or conclusion. There were no linking words, and some sentences were simply impossible to understand. Nevertheless, it communicated something. This text, written by one of the students in the dyslexic sample described the feeling of not being able to finish ones homework because reading took forever. It described years of sitting inside, struggling alone, while hearing the other children playing outside. In a way, the incomprehensible sentences and chaotic style of writing added a touch of realism. Should the text be deemed to be of bad quality? Possibly. Probably. Nevertheless, it had potential.

3.4.3 Text process measures

All key presses were logged using EyeWrite, an in-house software (Wengelin et al., 2009), and process analysis are based on keystroke latencies. In working with the articles that make up this thesis, both latency times, pauses and disfluencies have been used. Moreover, different pause criteria have been used. In study 1, latency times were used when modelling the writing process for the two groups of students. In addition, pause bins were identified so that we got information about all raw latencies and about long latencies or pauses. In study 3, latency times and disfluencies were used.

The way we defined locations in the text also varied for some locations. When investigating sentence boundaries in study one. We were interested in whether or not dyslexic students are poor writers because they are poor readers or if their struggling with writing is related to the writing process itself. We were interested in detailed information about what happened in sentence boundaries, and therefore three different locations in relation to sentences were identified; *a._^a* sentence initial after full stop and space, before first letter in sentence, *a.^_a* sentence initial after full stop before space, and *a^._a* sentence end before full stop. All these series of keys had to be produced fluently, that is without any cursor moves, deletions or insertions, in order for the unit to be identified as a sentence boundary. As we were interested in whether students looked back in their text, we wanted to identify possible loci points for when this happened. The sentence boundaries in the third study were identified differently. For this article, we were only interested in a latencies sentence initially. Moreover, several of these young students did not press space after full stop. Others always made a line shift after full stop. Thus, our criterion for what was included as a sentence initial key was different. All paragraph initial keys were included as these definitely are also sentence initial keys, in addition all letters following full stop, whether or not these were preceded by space were identified as sentence initial; *P^a* *._^a* *.^a* . By including full stops not followed by a space, we ran the risk of including cases where abbreviations or numbers were followed by a full stop; these were few, however.

3.5 Statistical methods

For the three empirical papers, I have used different statistical methods. I will comment on some of these below.

3.5.1 Weighted Kappa

Weighted Kappa was used to evaluate the degree of inter-rater agreement for the different quality scores. As our categories were ordered we could assign different weights according to how much raters differed for a particular subject, so that if a participant could get a score between 0 and 7 points, the level of agreement is larger if the raters gave 3 and 2, than if they could only get a score between 0 and 3 points.

3.5.2 Linear mixed effects models

Linear mixed effects models were used for process data for studies 1 and 2. A mixed model allowed us to include both fixed and random effects. Our data from study 1 were keystrokes nested within texts that were nested within students; for study 2, the data were keys nested within words that were nested within students for study 2. In other words, in study 1 we assume all keys within a text have something in common, and all texts produced by the same individual have properties in common. A mixed linear effects model allowed us to assume that different subjects had different baselines or intercepts, and that writing condition would influence subjects differently. That is, we had a random intercept for subjects and a random by-subject slope for the masked vs. the normal condition. For binary outcome variables –spelling correct or not, we used logistic mixed effects regression models, and the glmer command in R.

3.5.3 Piecewise SEM

For study 3, I used a different method. For this study, I wanted to model multivariate relationships, where variables influence each other both directly and indirectly. As the data is nested – keystrokes nested within participants, I did not want to limit the sample size by the variables at the highest level, and thus limit the sample size to number of participants. By using piecewise SEM, I tested separate regression models for each dependent variable, and these were then put, or in Lefcheck's (2016) word, 'pieced' together, meaning each path was represented by a linear equation, and the linear equation is then tested separately (Lefcheck, 2016). Goodness-of-fit was tested by Shipley's test of directed separation (Shipley, 2000). Analyses were performed using the R lavaan package (Rosseel, 2012) and the piecewise SEM package (Shipley, 2000).

3.6 Ethical considerations

Ethical considerations have been important throughout the research. When the project started, the Norwegian social science data services were informed about sample, tests and methods, and approved both data collections. Letters of consent were also approved by the Norwegian social science data services, before being sent to participants (see appendix).

Both the samples are vulnerable groups. One group because it consisted of students diagnosed with dyslexia, in addition these students were under 18. The other group because it involved children. We provided participants with information about the purpose of the research, and about who would have access to their texts. It was important that the information was understandable for the age group. Both samples needed consent from their parents as students were under eighteen. In addition to signing the consent form, participants were told that they could withdraw from the study if they felt like it at any point.

The students diagnosed with dyslexia were targeted because of their diagnosis, in addition they were asked to do something many of them reported to be a struggle. We strived to maintain their individual dignity, and focused on encouraging them in advance and value their effort.

Confidentiality was important for us in two respects. First, students were given a number so that it would not be possible to identify individuals. The key giving information about which student had what number was kept separate from the data. Second, being allowed into schools meant that we sometimes were allowed into the staffroom. As teachers in Norway do not have individual offices, exchanging information about students is often done in the staffroom. My research assistants and I strived to avoid getting information that was not meant for us – we informed staff that we were outsiders, and if student names were mentioned together with conferential information, we left the room.

4 Presentation of the articles

4.1 Article 1

Torrance, M., Rønneberg, V., Johansson, C., & Uppstad, P. H. (2016). Adolescent Weak Decoders Writing in a Shallow Orthography: Process and Product. Scientific Studies of Reading, 20(5), 375–388. http://doi.org/10.1080/10888438.2016.1205071

This paper investigates the writing process and the written product of a group of dyslexic students and a group of control students. It has been suggested that writers with dyslexia have a word-level focus and that this might result from their difficulty with reading. The paper is an attempt to falsify the word-level hypothesis, and the monitoring hypothesis – that this word-level focus is due to reading. Dyslexics are known as having difficulty reading, and because of this, they may struggle more during writing. We therefore hypothesized that the students with a dyslexia diagnosis' struggling with writing is mediated through reading, i.e. because of their reading issues, they cannot exploit visual feedback from reading what they have written, which in turn causes them to have writing problems. If this is the case, dyslexic writers struggle at the word-level because they are poor readers, and they cannot recognize whether a word is spelled correctly or not. The other possibility is that writing difficulties at the word-level are related to the writing process itself. Dyslexic writers spell less well, they have difficulties coding phonemes into graphemes and therefore they produce text less fluently, which again affects the product. If spelling words is very resource-demanding rather than automatic, then this demand is assumed to take resources away from other processes. Dyslexic writers will then have fewer resources to enable them to maintain a more global representation of the current and future text. Thus, if their struggling with writing is not mediated through reading we could say that dyslexia is both a reading and a writing difficulty. In order to distinguish the two, we tested what happened if we took away the opportunity to read during text production, we called this the masked condition.

If dyslexia is primarily a reading difficulty, then the strong case would be that the masked condition would even out any differences between dyslexic students and control students. If this were the case, we would find the same error rate and text quality for all students when writing in this condition.

Results indicated partial support for the word-level focus hypothesis, but no support for the monitoring hypothesis. Although the monitoring hypothesis was falsified in this article, a new link between reading and spelling becomes visible – decoding skills predict written quality.

4.2 Article 2

Rønneberg, V., & Torrance, M. (2017). Cognitive predictors of shallow-orthography spelling speed and accuracy in 6th grade children. Reading and Writing. http://doi.org/10.1007/s11145-017-9751-3

In the second article, spelling accuracy and time course was investigated in 100 Norwegian 6th graders. We aimed to access what cognitive factors predict spelling outcome, and what predict spelling process. Spelling was thus measured as spelling accuracy, spelling response latency and mean inter-key latency. We hypothesized that both grapheme-phoneme encoding ability and orthographic recognition would be important for spelling. Moreover, we predicted different effects for words that contained a spelling challenge than for words with no such challenge, expecting orthographic ability to be particularly important for spelling challenging words. In addition, we wanted to test the extent to which the spelling process persists beyond typing onset. We hypothesized that inter-keypress intervals immediately in front of a spelling challenge would be longer than elsewhere in the same word, indicating that orthographic planning persists beyond typing onset.

Results indicate that word-split performance and non-word spelling accuracy predicted spelling accuracy. In addition, students who were quicker at key finding, and who had greater memory span tended to spell more accurately. Spelling response latency was predicted by non-word spelling RT, and by speed on the key-finding task. Inter-keystroke interval was predicted by word-split performance, non-word spelling RT and key-finding speed. In addition, results indicate that the spelling process persists beyond typing onset.

4.3 Article 3

Rønneberg, V. (paper prepared for submission). An investigation of the relationship between transcription, word-level processes and measures of quality in text composition.

The third article investigates the relationship between spelling, motor execution processes involved in handwriting or keyboarding, text composing processes and text quality measures. The study is innovative in its attempt to distinguish spelling fluency from typing fluency, measured by keyboard familiarity and a practised copying task. By using piecewise structural equation modelling, I tested a model predicting word-level processes and disfluencies, and next a model predicting different text quality measures directly, or through text length and lexical density.

Results indicate that process measures from a practised copying task, key finding task and spelling task all influence word-level processes when producing text. For word-level disfluencies, the path from spelling process measures is the strongest predictor. Moreover, results indicate that word-level disfluencies influences text length negatively. Word-level disfluencies also have a negative impact on measures of text quality, indirectly through text length, and for one measure there is a direct effect.

4.4 Article 4

Rønneberg, V., Johansson, C., Mossige, M., Torrance, M., & Uppstad, P.H. (Accepted pending revision). Why bother with writers? Towards “Good enough” technologies for supporting dyslexics. In Miller, B., McCardle, P., & Connelly, V. (Eds.). Writing development in struggling learners: Understanding the needs of writers across the lifecourse. Leiden, The Netherlands: Brill.

The fourth article is a theoretical investigation of existing technical aids and the general ideas underpinning these. Further, it is a reflection on what support writers with Specific Learning Disabilities and dyslexia need, based on what is characteristic of their writing. It is suggested that a shift from having correction as the main element, to a writing aid having fluency as the main principle might be more beneficial for these writers. We suggest that as an essential part of meaning construction takes part during writing, while writing words letter by letter, and that interruptions in the meaning-making process can cause the writer to lose the plot, or hinder further meaning construction. The solution that is suggested is to separate revision from transcription, and that feedback should aim to be nonintrusive.

5 Article 1

6 Article 2

Read Writ
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Cognitive predictors of shallow-orthography spelling speed and accuracy in 6th grade children

Vibeke Rønneberg[1,2] · Mark Torrance[2,3]

Abstarct Spelling accuracy and time course was investigated in a sample of 100 Norwegian 6th grade students completing a standardized spelling-to-dictation task. Students responded by keyboard with accurate recordings of response-onset latency (RT) and inter-keypress interval (IKI). We determined effects of a number of child-level cognitive ability factors, and of word-level factors—particularly the location within the word of a spelling challenge (e.g., letter doubling), if present. Spelling accuracy was predicted by word reading (word split) performance, non-word spelling accuracy, keyboard key-finding speed and short-term memory span. Word reading performance predicted accuracy just for words with spelling challenges. For correctly spelled words, RT was predicted by non-word spelling response time and by speed on a key-finding task, and mean IKI by non-verbal cognitive ability, word reading, non-word spelling response time, and key-finding speed. Compared to words with no challenge, mean IKI was shorter for words with an initial challenge and longer for words with a mid-word challenge. These findings suggest that spelling is not fully planned when typing commences, a hypothesis that is confirmed by the fact that IKI immediately before within word challenges were reliably longer than elsewhere within the same word. Taken together our findings imply that routine classroom spelling tests better capture student competence if they focus not only on accuracy but also on production time course.

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Introduction

Both practitioners and researchers typically understand spelling competence as ability to spell words accurately. Spelling success is, however, only partly about whether or not the word that the child produces is accurately spelled. Students also need to spell fluently, without excessive hesitation and effort. Factors that affect children's spelling fluency—the time course of single-word production—are not well understood. Understanding the full complexity of a student's spelling ability arguably requires information about both the product and production time course.

There are both educational and theoretical reasons for developing an understanding of factors that predict spelling fluency. A child who struggles in an attempt to spell all words correctly is probably more disadvantaged when composing text than a child who writes all words quickly, but makes a few mistakes. At a global level, struggling with spelling production may result in students being demotivated, running out of time, having less time for planning or writing a shorter text. At a local level, difficulty with specific words tends to slow output. For example, copy-typists tend to slow down when they type irregular words (Bloemsaat, Van Galen, & Meulenbroek, 2003). Struggling to spell a word—regardless of whether the word is then spelled correctly—risks damage to higher level, conceptual, rhetorical or even syntactic structures in the text. Language processing operates under a stringent "now-or-never" constraint (Christiansen & Chater, 2016). If spelling is attention demanding, and therefore draws processing resources away from higher-level processes, the writer may, in a literal sense, forget what they were going to say. This trade-off between transcription (spelling and handwriting) and higher-level conceptual or rhetorical processing has frequently been argued (e.g., Berninger, 1999; McCutchen, 1996; Torrance & Galbraith, 2006; von Koss Torkildsen, Morken, Helland, & Helland, 2016), although evidence of a causal relationship between spelling competence and text quality (spelling accuracy aside) is not yet established (see, for example, Babayiğit & Stainthorp, 2010; Graham & Santangelo, 2014).

From a theoretical perspective, exploring spelling time course addresses issues around the nature and scope of the planning processes necessary for written production of a single word. In principle at least, spelling can be achieved either by assembly—incremental phoneme-letter mapping—or by activation of orthographic lexemes directly from their associated concepts (e.g., Rapp, Benzing, & Caramazza, 1997). This suggests a dual-route account of orthographic retrieval (Barry, 1994; Martin & Barry, 2012; Perry & Ziegler, 2004; Rapp, Epstein, & Tainturier, 2002). The extent to which different routes are used (or the probability that a particular route will win the horse-race, cf. Paap & Noel, 1991) is likely to be language-dependent. Share (2008) argues in the context of single-word reading that the dual-route model as a whole is not a good representation of reading in a shallow orthography. Similar arguments may apply to shallow-orthography spelling—the focus of the present study. A related issue is the scope of lexical and motor planning in single word production. Specifically, is all orthographic processing complete prior to output (before the writer makes their first pen stroke or key stroke; e.g., Logan & Crump, 2011) or does orthographic planning persist beyond output onset? Again, it is possible that the answer to this question is dependent on the orthographic depth of the language that is being written. In developing writers both processing route (assembly vs. direct) and planning scope (lexical or sublexical) are likely to be dependent on various dimensions of the writer's literacy skills.

Both orthographic and phonological processing ability are likely, therefore, to play a role in children's spelling performance. A number of studies have explored cognitive factors that predict early spelling performance, where performance is measured just on the basis of accuracy. In early primary school children there is, as might be expected, a strong correlation between single-word reading accuracy and spelling accuracy. This effect is present in both shallow and deep orthographies (Babayiğit & Stainthorp, 2011; Caravolas, Hulme, & Snowling, 2001) but in German it disappears in early-secondary students (Landerl & Wimmer, 2008). This is because the regularity of letter-to-sound mapping in German mean that in older students, word reading errors are very rare, while spelling mistakes remain relatively common as sound-letter mapping is less regular. Spelling accuracy is also consistently predicted by phonological awareness (e.g., Muter, Hulme, Snowling, & Stevenson, 2004) although these effects also decrease with age in typically-developing students (Furnes & Samuelsson, 2011; Landerl & Wimmer, 2000). In English, rapid automatized naming (RAN)—the number of stimuli (letters, numbers, colours, objects) that a participant can name in a fixed period of time—has also been found to predict spelling accuracy, even after control for phonological ability (Savage, Pillay, & Melidona, 2008; Strattman & Hodson, 2005), although Landerl and Wimmer (2008) failed to find similar effects in German in 8th grade students. While RAN may play a role in predicting spelling accuracy, the shared mechanisms are not well understood. It may be that RAN taps speed of phonological processing (Vellutino, Fletcher, Snowling, & Scanlon, 2004). Alternatively, slow naming may indicate impaired learning of mental orthographic representations, at either word or sub-word level (Bowers & Newby-Clark, 2002; Wimmer, Mayringer, & Landerl, 2000; but see Moll, Fussenegger, Willburger, & Landerl, 2009). Moll et al. (2014) found that RAN measures involving naming digits and objects (i.e. with no letter-to-phoneme processing component) predicted spelling accuracy in English but not French (deep orthographies), and German but not Finnish (relatively transparent orthographies, although with some asymmetry in German, noted above). These phonological and orthographic theories make different predictions about the extent to which RAN will predict spelling accuracy and/or spelling speed for regular and irregular words (i.e. words with and without predictable letter-sound correspondence) and, more generally, spelling in shallow and deep orthographies. However McGeown, Johnston, and Moxon (2014) found that even in English where spelling is highly irregular, spelling accuracy in mid-primary children is predicted both by pseudo-word reading—a test of phonological decoding—and by orthographic ability (based on a word/pseudo homophone discrimination task). Finally, there is some evidence that verbal short-term memory span predicts spelling accuracy for early-primary spelling in Norwegian (Lervåg & Hulme, 2010), and early- and mid-primary children spelling in English (Caravolas et al., 2001), although it is not clear whether these effects are independent of phonemic awareness (Landerl & Wimmer, 2008).

The present study investigated effects of various child-level and word-level factors on not just spelling accuracy but also production fluency. In general terms, this examined accuracy/speed trade-off in spelling-to-dictation: Are accuracy and fluency predicted similarly by students' orthographic and phonological skills, or do effects diverge? More specifically, analysis of how student skill interacts with word regularity provides insight into the cognitive processes that underlie upper-primary students' performance on spelling-to-dictation tasks. There is considerable evidence from research with adult writers that spelling processes and their motor execution interact in single word production (Bertram, Tønnessen, Strömqvist, Hyönä, & Niemi, 2015; Delattre, Bonin, & Barry, 2006; Kandel & Perret, 2015; Lambert, Kandel, Fayol, & Espéret, 2007; Roux, McKeeff, Grosjacques, Afonso, & Kandel, 2013; Scaltritti, Arfé, Torrance, & Peressotti, 2016). Delattre et al., for example, found that in French (a deep orthography), both word frequency and orthographic regularity affected onset latency (time from stimulus presentation to output-onset, measured as onset of first pen stroke) and output duration (time from onset to word end, controlling for word length). Kandel and Perret (2015) found similar effects in 8-year-old children, an age at which most are likely to have achieved handwriting automaticity. They concluded that orthographic processing persists beyond output onset. Scaltritti et al. (2016) in a study of adults typing picture names in Italian (an orthographically transparent language) found frequency effects and other lexical effects on response latency. They found, however, that orthographic neighbourhood —a word-level orthographic effect—did not affect onset latency but did affect production duration. Torrance et al. (2017) studied typed picture naming in a number of alphabetic languages. Spelling difficulty, indexed by cross-subject spelling agreement and controlling for name agreement, only affected writing timecourse in some languages, including French but not including Norwegian (the focus of the present study). In almost all cases, effects were exclusively in production duration and not onset latency. There is evidence that extended production time is specifically associated with slowed output around the location of the irregularities within the word (Roux et al., 2013).

In general terms, therefore, findings suggest (a) individual (student-level) differences in orthographic and/or phonological processing ability predict spelling accuracy in early primary students, and (b) orthography and orthography/phonology regularity affect processing timecourse—both response latency and output duration —in adults and also late-primary students. Correlational studies exploring student-level predictors of spelling performance however give quite mixed findings which may, in part, be explained by differences in orthographic depth of the languages in which the research was conducted. Most obviously, the role of word-level orthographic knowledge is likely to be greater in deep orthographies in which spelling by assembly is relatively unreliable. In a cross-language comparison of students beyond second grade using nationally standardised spelling tests (i.e. without attempt to control regularity across language), Moll et al. (2014) found that phonological awareness predicted spelling accuracy in German and Finnish (relatively transparent orthographies), but not in English and French (deep orthographies), but also not in Hungarian, which is relatively transparent. It may also be that the orthography in which a student learns to spell affects the extent to which direct or assembled routes dominate their spelling processes: independently of the regularity of the specific word being spelt students with a shallow-orthography language may prefer spelling by assembly.

The study that we report in this paper explores the effects of Norwegian 6th grade students' performance on RAN (letter), phonological (non-word) spelling, and a word-split reading task that emphasises orthographic recognition, on their spelling performance, measured in terms of both accuracy and fluency. Students completed a spelling-to-dictation task and typed their responses. We also measured, as control variables, key-finding ability as an index of typing skill, and non-verbal ability and RAN (objects) as a measure of general cognitive skills and short-term memory. Norwegian, like German, is typically understood as somewhat asymmetrical in terms of orthographic transparency (e.g., Hagtvet & Lyster, 2003; Lervåg & Hulme, 2010). Grapheme-phoneme mapping is very regular, making reading by assembly accurate. Phoneme-grapheme correspondence is less predictable, meaning that for a subset of Norwegian words spelling by assembly alone is insufficient, and success also requires retrieval of orthographic knowledge. Spelling in the present study was assessed via an existing, standardised spelling task (Skaathun, 2013) comprising both regular words with a simple 1-to-1 phoneme-letter mapping, and words that contained some form or irregularity or complexity (henceforth "challenge") for which spelling would necessarily need to go beyond incremental letter-by-letter assembly.

Writing, unlike speech, has two main output modalities—handwriting and keyboarding (typing). There has been a tendency to for researchers to theorise these independently (e.g., Gentner, Larochelle, & Grudin, 1988; van Galen, 1991). We know of no direct comparison of spelling processes in the two modalities. Arguably, however, it is reasonable to assume that processes upstream of motor output that is required for the generation of spelling is very similar in both modalities. Our choice of typed output in the present study was therefore expedient rather than principled: Writing time course data are more easily collected by keyboard, and give more clearly demarcated character onset times. Although students in Norwegian schools, with a small number of exceptions, learn handwriting before typing, students are expected to also have a reasonable level of typing competence by upper primary.

Our research addressed questions about the effects of child-level and word-level factors on spelling accuracy and timecourse, and the interaction between the two. After statistical control for general cognitive skills (object RAN and non-verbal ability), we predicted effects for both phoneme-to-grapheme encoding ability (non-word spelling-to-dictation) and orthographic recognition. That is, in a more shallow orthography we expected both phoneme-grapheme encoding and orthographic recognition to be important when spelling. More specifically, we predicted divergent effects for regular words and words that contain a spelling challenge; with students with good orthographic ability performing particularly well when spelling challenging words. We determined effects on accuracy but also, for correctly spelled words, effects on production fluency, and particularly the extent to which spelling processes persists beyond typing onset. If planning is prepared fully in advance of typing onset then both response latency (RT, time from stimulus presentation to typing onset) and production speed should be unaffected by whether the spelling challenge occurs at the start of the word or in the middle of the word. If orthographic planning persists beyond typing onset then we predicted differential effects of challenge location. We also predicted that, if orthography is prepared incrementally (on a letter-by-letter basis) then inter-keypress interval (IKI) immediately prior to a spelling challenge would be longer than elsewhere in the same word.

Methods

Participants

Whole classes of Norwegian 6th grade students from four different schools were invited to take part in a "writing week" during which they completed a battery of measures including all those reported in this paper. Data collection was between mid-February and mid-April, 2015. Students were excluded from the sample if they did not speak Norwegian at home, they had behavioural difficulties that prevented successful completion of tasks, and if they were absent for part of the test period (20 students in total). 100 students (61 females) with a mean age of 11 years and 10 months made up the final sample. Students varied in keyboarding skill but all used computers regularly as part of normal classroom activities, including free writing tasks. Mean within-word inter-key interval on a free-writing task completed by the same sample (not reported in this paper) was 380 ms. This compares to 167 ms for Norwegian upper secondary students (Torrance, Rønneberg, Johansson, & Uppstad, 2016).

Materials and procedures

All tests were given to the participants at their respective schools. Some tests were administered in a group setting, while others were given individually, as detailed below. Group tests were all completed under "examination conditions". The first author administered all group tests. The first author and a research assistant administered individual tests.

Spelling assessment

Participants completed an existing spelling-to-dictation test, standardized for students writing by hand, and consisting of 32 items designed to cover different features of Norwegian orthography. The test was designed to measure spelling ability across a wide age range and had previously been standardised with large samples of Norwegian children (Skaathun, 2007, 2013 see "Appendix"). In our study, students wrote on a keyboard. The test comprises a combination of words with a straightforward phoneme-grapheme mapping (7 words), words with a word-initial challenge (8 words), and a larger group of words with mid-word challenges (17 words). Challenges included consonant doubling following a short vowel sound (e.g., *tatt*/taken), consonant clusters (*marsjerer*/marches) these have been found to be difficult to spell (Hagtvet, Helland, & Lyster, 2005), failure to differentiate similar phonemes (e.g., [ʃ], [ʂ], and [ç] in the word *kjole*/dress), and silent letters (the letter *g* in *gjort*/done). Word frequency (surface form) was calculated from the Norwegian Newspaper Corpus (NNC, 2013). Word frequencies varied between 966 and < 1 per million, with a mean of 225. The spelling test was completed by small groups of students on individual computers. Words were first presented in a sentence and then the children were told which word to spell. (e.g., "I use a comb to style my hair. Write comb"). The target word could appear anywhere in the sentence, meaning that participants could not infer which word they were going to write until it was repeated. Target words and sentences were pre-recorded and presented to participants through headphones. There was no time limit to complete the spelling test, but participants were urged to start spelling the word as soon as possible after the word was presented. To move on to the next word participants pressed enter. For each trial we recorded *accuracy* (whether or not the word was spelled correctly) and fluency. Fluency was measured in terms of, *response-onset latency* (RT, the time from the onset of the target word (e.g., onset of *comb* in *Write comb*) to first keypress), and mean *inter-keypress interval* (MIKI, the mean of all IKIs during production of the word, excluding time prior to first keypress and after last keypress).

Nonverbal ability

Students completed Raven's Standard Progressive Matrices (Raven, 1981) as a measure of general nonverbal cognitive ability. This was group-administered.

Rapid automatized naming (object and letter RAN)

Students were given the letters, and objects subtests from the CTOPP (Wagner, Torgesen, & Rashotte, 1999). Students were presented with two printed pages of each with 36 randomly arranged objects or letters. They were asked to name these as quickly as possible while the researcher scored accuracy and recorded time-to-completion. Students completed this task individually. Score is number of seconds to name all 72 items.

Word-split

A Norwegian version of the word-split task (Jacobson, 2001; Miller-Guron, 1999) was given to the participants as a fluency-focused measure of decoding ability. The word split test consists of 73 word strings each containing four words without inter-word spacing. Participants divide these word chains into single words by drawing a line between words, aiming to complete as many as possible within 5 min. The test is scored according to how many word chains the participants successfully manage to solve. In a shallow orthography this gives a better measure of reading performance in older children than what is provided by single-word reading (Wimmer, 1993), a single word reading task stands the risk of reaching a ceiling effect in an orthography where most words can be read through assembly. The word split task puts emphasis on fluency in addition to accuracy. Because the words are presented with no spacing between them, and because of the time pressure students need to be able to recognize whole words or parts of words that typically make up part of a word, word endings for example in order to get a good score. The word-split task is believed to involve orthographic decoding and to a smaller degree grapheme-phoneme conversions. This task was group-administered.

Short-term memory

Students performed a letter-span task, comprising 3 practice sets followed by 10 experimental sets varying in length from 2 to 6 letters. Letter names were presented through headphones at 500 ms intervals. At the end of each set students repeated aloud all letter names they could recall, in order. If a student recalled all items in a set correctly then they scored the number of items in the set. If they failed to recall any of the items in the set then they scored zero. Scores were then summed across sets, giving a maximum possible overall score of 40.

Key finding

As a measure of keyboard familiarity, and therefore a proxy measure of keyboarding skill, we determined how quickly and accurately students were able to find single keys on a computer keyboard in response to spoken letter-name prompts. Students heard a total of 14 letter names, for letters across a range of frequencies, each occurring twice, with order randomized. On hearing a letter name they were required to press the corresponding key, being as quick and as accurate as possible. Students completed the exercise in small groups, on individual computers with letter names played through headphones. We recorded both *accuracy* (the total number of correctly chosen keys, with a maximum of 28) and *speed*—time from stimulus onset to keypress.

Non-word spelling

To assess phoneme-grapheme encoding, students completed a non-word spelling test comprising 20 pseudo-words varying in length from three letters to ten letters (see "Appendix"). Pseudo-words were created by using phonologically plausible letter-combinations that were easy to pronounce in Norwegian. For the shortest words only one letter separated the non-word from a real word (e.g., *fyt–fyr*). For the longer words the non-words were further away from real words. These stimuli had not been used in other studies. Procedure and scoring were the same as for the real-word spelling task. All phonetically plausible spellings were accepted as correct responses.

Results

Means and inter-measure bivariate correlations for child-level variables are given in Table 1. Mean spelling accuracy, across students, was 70.5% ($M = 22.6$, $SD = 4.1$), placing students, on average, at just below the 40th centile relative to national standards for their age group. Note however, that the test was standardized for students with no urge to start writing words as quickly as they could, and with the possibility to go back and edit previous words.

In describing our findings, we will first explore effects on spelling accuracy and then effects on initial and within-word latencies for words that were spelled correctly. In each case, we first report analyses of effects of child-level predictors. We then explore effects due to the sub lexical features of the target word (specifically location of potential spelling challenge).

Analysis throughout was by incremental sequences of mixed effects regression models, evaluated using the R lme4 package (Bates, Maechler, Bolker, & Walker, 2013). Model fits were evaluated by χ^2 change tests. Statistical significance of parameter estimates was established by z-test for the binomial logistic models reported in the first section of our results and by *t* test, with Satterthwaite approximation for denominator degrees-of-freedom, for models with continuous predictors (all other models). All continuous predictor variables were standardized prior to analysis. All chronometric variables (measures based on response latencies or inter-keypress intervals), and target-word frequency and length were log-transformed to reduce skew. Response latencies and inter-key intervals were trimmed at 2.5 SD.

Table 1 Means and bivariate correlations (*r*) for child-level predictors

	M (*SD*)	1	2	3	4	5	6	7	8
1. RAN objects	59.9 (13.7)								
2. Nonverbal reasoning (Raven)	42.2 (5.5)	−.15							
3. Non-word spelling accuracy	13.6 (2.8)	−.15	.29						
4. Non-word spelling RT (mean, ms)	2400 (429)	.18	−.07	−.09					
5. Word reading (word split task)	38.5 (11.0)	−.28	.38	.32	−.31				
6. Key-finding accuracy (proportion)	.90 (.07)	−.05	.01	−.07	−.03	.06			
7. Key-finding speed (mean, ms)	1259 (326)	.29	−.18	−.33	.45	−.47	.02		
8. RAN letters	31.5 (7.0)	.65	−.07	−.16	.22	−.23	.03	.29	
9. Short –term memory	23.6 (7.9)	−.12	−.02	.27	−.03	.14	−.05	−.11	−.19

$p < .001$ for $|r| > .19$

Effects on spelling accuracy

Child-level predictors

To determine what cognitive factors predict spelling accuracy, we tested logistic mixed effects regression models with spelling accuracy (child spelled word correctly vs. child did not spell word correctly) as the binomial dependent variable. We started with a zero (intercept-only) model, with random by-subject intercepts. Model 1 added predictors related to non-verbal ability and processing speed (Raven and RAN objects). By adding these variables first, we made sure general cognitive skills were controlled for when including the other predictor variables into the model. Model 2 added orthographic decoding (word-split scores). Model 3 added measures of phonological encoding ability (non-word spelling accuracy and response time). Improved fit as a result of adding these variables therefore indicate contribution of phoneme-grapheme encoding skill over and above that captured by the word-split score. Model 4 added factors relating to single-letter recognition and production (RAN letters, and key-finding speed and accuracy). Finally, Model 5 added short-term memory scores (STM).

Model fits are detailed in Table 2 and parameter estimates from the final model are given in Table 3. Both word-split performance and non-word spelling accuracy predicted spelling accuracy, after controlling for general (non-verbal) ability. Students with greater STM span also tended to spell more accurately. The final model also gave some evidence of greater accuracy for students who were quicker at key finding.

Word-level predictors

We determined the effects of the nature of the spelling challenge imposed by words in the spelling test—word-initial, mid-word, or none—statistically controlling for the effects of word length and frequency, using models similar to those described in

Table 2 Model fits for regression models with just child-level predictors of response accuracy, RT and within-word keypress latencies

	Correct response	Response latency (RT)	Mean within-word key-press latency (MIKI)
Model 1: zero model plus RAN Objects, Nonverbal Reasoning	$\chi^2(2) = 15.3$, $p < .001$	$\chi^2(2) = 6.9$, $p = .03$	$\chi^2(2) = 1.5$, $p = .005$
Model 2: model 1 plus Word Reading (word split task)	$\chi^2(1) = 23.2$, $p < .001$	$\chi^2(1) = 6.4$, $p = .012$	$\chi^2(1) = 33.4$, $p < .001$
Model 3: model 2 plus Non-word spelling accuracy and RT	$\chi^2(2) = 11.0$, $p = .004$	$\chi^2(2) = 3.5$, $p < .001$	$\chi^2(2) = 21.0$, $p < .001$
Model 4: model 3 plus Key-finding accuracy and speed and RAN Letters	$\chi^2(3) = 4.8$, $p = .185$	$\chi^2(3) = 6.5$, $p = .09$	$\chi^2(3) = 17.2$, $p = .001$
Model 5: model 4 plus Short-term memory	$\chi^2(1) = 7.20$ $p = .008$	$\chi^2(1) = 2.2$, $p = .14$	$\chi^2(1) = .64$, $p = .425$

Values are χ^2 change tests for comparison with previous model

Table 3 Child-level predictors: regression coefficients from the final model (Model 5)

	Correct response (probability)	Response latency (RT, ms)	Mean within-word key-press latency (MIKI, ms)
RAN objects	−.01 (−.04, .01)	26 (−25, 83)	1 (−15, 19)
Nonverbal reasoning (Raven)	.00 (−.02, .02)	−15 (−55, 29)	32 (17, 50)***
Word reading (word split task)	.04 (.02, .05)***	−2 (−47, 49)	−31 (−42, −17)***
Non word spelling accuracy	.02 (.00, .03)*	−42 (−80, 1)	−1 (−14, 14)
Non word spelling RT (mean, ms)	.01 (−.01, .02)	102 (56, 153)***	23 (9, 41)**
Key-finding accuracy	.01 (−.01, .02)	4 (−35, 46)	6 (−7, 20)
Key-finding speed (mean, ms)	−.02 (−.05, .00)*	61 (13, 114)**	33 (15, 52)***
RAN letters	−.01 (−.03, .01)	−28 (−75, 23)	8 (−7, 26)
Short-term memory	.02 (.01, .04)**	−31 (−68, 10)	−5 (−17, 8)

Parameters represent estimated change in dependent variable resulting from an increase of 1 SD in the predictor. 95% CI in parenthesis

* $p < .05$, ** $p < .01$, *** $p < .001$ for H_0: parameter = 0

the previous section. We started with an intercept-only model with random by-subject intercepts, and random slopes for word length and for the challenge-type factor. Random slopes for frequency did not improve model fit, and frequency and length were strongly collinear, so frequency slopes were omitted. We then added fixed factors incrementally as follows: We first added length and frequency as control variables, then challenge type (no challenge, word-initial, mid-word). We then added main effects for all child-level factors, and finally incrementally added interactions between the challenge-type factor and the child-level (individual differences) factors that showed main effects in the child-level analysis.

As might be expected, after control for frequency and length [Model 1, $\chi^2(2) = 77$, $p < .001$] adding challenge type substantially improved prediction of accuracy [$\chi^2(2) > 100$, $p < .001$]. Parameter estimates suggested that items with a mid-word challenge were 7.6% less likely to be spelled correctly [95% CI (2.5, 15.1), $z = -3.4$, $p < .001$] and items with a word-initial challenge were 6.4% more likely to be spelled correctly [95% CI (3.1, 7.3), $z = 3.0$ $p = .003$]. We found some evidence of an interaction between challenge-type and performance on the word-split task. Adding this effect improved model fit [$\chi^2(2) = 5.97$, $p = .050$]. These suggest little or no positive benefit for spelling accuracy of word-split ability for items without a spelling challenge, and that benefit were greater for items with mid-word and significantly better for word-initial challenges ($z = 2.4$, $p = .015$ from comparison with the no-challenge slope). There were no other statistically significant interactions between challenge type and child-level factors.

Effects on spelling fluency

In this section, we explore the process of spelling production, testing models similar to those described in the previous section but with response-onset latency (RT) and mean inter-keypress intervals (MIKI) as dependent variables.

Child-level predictors

We tested linear mixed effects models, starting with a baseline model with random by-subject and by-item intercepts. For RT (but not for MIKI) this model also included a fixed factor representing the duration of the audio presentation of the stimulus (i.e. the word to be spelled). Because RT was timed from stimulus onset, stimulus duration necessarily had a substantial effect on RT, and so required statistical control.

Incremental model fits and parameter estimates from the full model can be found in Tables 2 and 3. RT was predicted by the students' non-word spelling RT, and by speed on the key-finding task. There was some evidence of a word-split effect when this measure was added (Model 2), but this effect was subsumed by non-word spelling RT when these were added (Model 3). There were no other effects on RT. By contrast, speed of production once typing has commenced (MIKI) was predicted by word-split performance. MIKI was also predicted by non-word spelling RT and key-finding speed. Unexpectedly, students who got a high score for non-verbal cognitive ability were slower in spelling words, after the initial key. This effect was present in the final model (Table 3).

Word-level predictors

We constructed models following the same design as in the analysis of word-level effects on accuracy, starting with baseline models as described in the previous section, and then adding length and frequency effects as control variables [χ^2 (2) = 14, $p < .001$ and χ^2 (2) = 61, $p < .001$ for RT and MIKI respectively]. Adding challenge-type to the model did not improve fit for RT ($\chi^2 < 1$) but did improve fit for MIKI [χ^2 (2) = 68, $p < .001$]. Items with an initial challenge were produced an estimated 21 ms per character more quickly after the initial keystroke, relative to non-challenge words [95% CI (−32, −7)], and words with a mid-word challenge 31 ms per character more slowly [95% CI (17, 46)]. We found no interaction between challenge type and any of the child-level factors.

We hypothesized that the effect of a mid-word challenge on MIKI resulted from students pausing for longer when they reached the spelling challenge. To test this we looked at individual inter-keypress intervals (IKIs) just for items with mid-word challenges, comparing IKIs immediately prior to a challenge with IKIs at other locations (excluding word-initial latency). We added this factor to a linear mixed effects model with the challenge-type as a random by-subject slope and with random by-item and by-subject intercepts. This gave significantly improved fit [χ^2 (1) = 6.6, $p = .010$]. IKI immediately prior to the challenge was slower by an estimated 110 ms [estimated means with 95% CIs: challenge-initial, 480 (406, 569);

other, 370 (337, 406)]. There was no evidence of an effect on the latency associated with the keypress one key before the challenge-initial key. Note that by comparing keypress latencies within the same word this analysis controls for word-level differences in length and frequency.

Accuracy and process

Finally, we determined whether RT and MIKI were dependent on whether or not the word was spelt correctly. Again, just words that were produced fluently (i.e. with no editing) were included. We started with baseline models that included by-item intercepts, by-subject intercepts and slopes for word-length and for a factor representing whether or not the item was correctly spelled and fixed effects for word length and frequency. Adding a fixed effect of correct spelling gave significantly improved model fit for RT [χ^2 (1) $= 7.7$, $p = .005$] with longer pauses prior to initiation for words that ended up being incorrectly spelt [estimated means: correctly spelled words, 1973 ms (1888, 2061); wrongly spelled words, 2084 ms (1967, 2209)]. We found no evidence of a similar effect on MIKI.

Discussion

The present study differs from previous research exploring single-word spelling (Babayiğit & Stainthorp, 2011; Caravolas et al., 2001; Furnes & Samuelsson, 2011; Moll et al., 2014; Nikolopoulos, Goulandris, Hulme, & Snowling, 2006) in three respects, each of which affect interpretation of findings. First, students were spelling in a shallow orthography. This is likely to make accurate spelling easier, in general, but also it may make spelling by assembly (letter-by-letter mapping of phonemes onto graphemes) a more reliable and therefore more practiced route than is the case in deeper orthographies. Second, in contrast to the majority of studies of spelling development participants were at an age and stage where spelling skills can be expected to have been largely mastered, particularly given the transparent orthography in which they were writing. Third, students were completing an existing, standardized writing task. This has some benefits in that the effects of various factors on spelling accuracy can be indexed against population norms. Using an existing test however had the disadvantage that item-selection was less carefully controlled than we would have wished. With this context in mind, our results point towards the following conclusions.

Looking first at effects on accuracy we found, in line with our predictions, effects of both encoding accuracy (non-word spelling) and orthographic recognition (word-split) performance. These findings are consistent with the argument that both lexical retrieval and assembly play a role in spelling-to-dictation performance (Rapp et al., 2002), at least for a shallow orthography. Non-word spelling relies mainly on direct phoneme-grapheme mapping, word-split performance is underpinned by an ability to rapidly access orthographic lexical knowledge, and therefore is likely to be associated with direct-route processing. This suggests that it will predict spelling performance particularly in the case where the assembly route is likely to be slow or fail. We found some evidence that this was the case: When comparing words with and without a challenge, word-split ability predicted spelling accuracy only for words that contained a spelling challenge.

Accuracy was also predicted by key-finding response time, but not key-finding accuracy, and by short-term memory span. The failure to find key-finding accuracy effects is probably best explained by the inadequacy of single-key finding as an index of accuracy of typing in a word-production context. This measure did not, for example, correlate with non-word spelling accuracy, suggesting that it does not predict tendency to make motor errors ("typos") in normal typing. Key-finding speed, on the other hand, showed some evidence of an effect, even after controlling for several other response-time and vigilance measures, including non-word spelling RT. If rapid key-finding is associated with relatively automatized keyboard skills, then this suggests that keyboarding has the potential to draw attention away from processing spelling, to the detriment of spelling accuracy. It is also probable that keyboarding fluency is associated with more writing practice—students who type quickly write more—which in turn might lead to better learning of spelling: Students who write more are exposed to more spelling decisions and more spelling-related teacher feedback.

Short-term memory span predicted accuracy, even after statistical control for all other predictors. This therefore appears to be a robust effect, which cannot be explained simply in terms of, for example, sustained attention, which was tapped by several other tasks. We do not have a straightforward explanation for this effect, beyond observing that performance on short-term memory span tasks is itself likely to depend, at least in part, on ability to recognize common patterns in the presented stimuli (Jones & Macken, 2015). This may represent a mechanism that memory-span performance and spelling production have in common, particularly given that in the present study the span stimuli were letters.

Two additional points are worth emphasizing here. First, the design of the study —multiple measures and incremental model building—makes it possible to isolate fairly precisely the effects of specific cognitive abilities, even when separate measurement tasks necessarily require a combination of these. Our failure to find RAN effects, for example, (contra Babayiğit & Stainthorp, 2011; Furnes & Samuelsson, 2011) may be because in the present study the various RAN component skills were subsumed by other measures (encoding, decoding, short-term memory). Second, sizes of effect in this study may appear quite small: A standard deviation increase in word-split gave a predicted improvement in accuracy of 3%—around 1 test point. However if should be noted that for 6th grade students, who have relatively high spelling competence, national norms for this spelling test indicate a range of just 4 points between the 50th and 80th centiles.

Effects of child-level factors were not limited to accuracy but extended to the speed with which correctly-spelled words were generated. RT (time to initiate response) was predicted just by response latency on the non-word spelling and speed on the key-finding task. We found no other effects. Particularly, we found no effect for word-split performance, including no interaction with the spelling challenge factor. MIKI (speed after typing onset) by contrast was predicted quite strongly by word-split performance, with an estimated increase of 31 ms (relative to a mean of 370 ms) for a 1 *SD* change in word-split score. This latter finding is consistent with our argument that good word-split performance is associated with increased tendency to spell by retrieval of orthographic lexemes, and are therefore an increased tendency to complete preparation of the word in advance of typing onset. Whether this theory predicts longer (or shorter) word-initial latencies is not clear, and depends on the relative time costs of responding to the auditory word stimulus by initiating grapheme-phoneme conversion and by retrieving the associated orthographic lexeme.

More generally, the fact that students' mean onset latency on the non-word spelling task predicted within word MIKI when spelling real words suggests both that assembly played an important role in students' spelling, and that assembly cascaded beyond typing onset. Direct confirmation of this came from two, related findings. First, words that contained a mid-word spelling challenge were produced reliably more slowly than words with either no challenge or a word-initial challenge. Second, IKIs immediately before a mid-word spelling challenge were reliably longer by an estimated 110 ms (about 30%) relative to elsewhere in the same word. These findings suggest that spelling challenges were addressed, at least some of the time and for some students, when they were met during output and not prior to typing onset.

We did not find any evidence that challenge-type affected word-initial latency. However, it would be wrong to conclude on this basis that initial latency was independent of spelling difficulty. Preparation times for wrongly spelled words were reliably longer, by an estimated 107 ms, after statistical control for length and frequency. At minimum, this suggest that, again for some students some of the time, features of the words' orthography that make it easy or difficult to spell affect word-initial planning. Interestingly accuracy did not appear to be related to post-onset typing speed. One possible explanation is that stored inaccurate spellings compete at point-of-retrieval with correct spellings. In extreme cases (e.g., spelling *necessary* in English for at least one of the present authors) this competition reaches consciousness and is experienced as uncertainty. In the context of a shallow orthography, phoneme-grapheme mappings are likely to be very well learned, and so similar competition does not occur during (assembled) output. Also interestingly, Torrance et al. (2016) found the opposite effect in spontaneous text production, with shorter word-initial latencies for wrongly spelled words, again after control for length and frequency. This might be related to the more explicit focus on accuracy in a spelling test. Note, however, that in both Torrance et al.—which involved a free writing task—and in the present study—because of the use of an existing standardised task developed originally just as a measure of spelling accuracy—length and frequency were no controlled across words that varied in spelling difficulty. Although we held spelling and frequency as covariates in our analyses, stronger conclusions would have been possible had we built this control into the design of the task.

Two final findings: As might be expected, key-finding speed predicted typing speed. Less predictably, students who performed well on Raven's Matrices, as a general measure of non-verbal ability, typed more slowly, to a non-trivial extent. We do not have a straightforward explanation for this effect.

In summary, therefore, our findings suggest two general conclusions: First good pseudo-word encoding skills and ability to recognise orthographic patterns above the letter level are both associated with more accurate and more rapid spelling. This remains true after control for general-ability factors, and measures of keyboarding competence. This finding is consistent with an account of spelling-to-dictation in a shallow orthography, by late-primary aged students, that involves a combination of both phoneme → grapheme assembly, that cascades beyond typing onset, and retrieval of orthographic lexemes (necessarily in advance of typing onset). Second, these factors affect not only spelling accuracy but also spelling fluency even when words were spelled correctly: Students with good encoding and single-word reading skills spell more quickly.

The implication of this second finding for production of extended, spontaneous text—the narratives and short essays that are typical of upper primary education—is not immediately clear. Several authors have argued that there is a causal relationship between the ease with which a child can spell and their ability to generate coherent and ideationally rich text (Sumner, Connelly, & Barnett, 2013; von Koss Torkildsen et al., 2016). However, as we indicated in our introduction, evidence in support of this claim is mixed. If correlation exists between text quality and spelling fluency then third-factor explanations are perhaps most parsimonious: It may simply be that having a well-stocked and easily-accessed orthographic lexicon independently results in good spelling performance and good text-composition performance. At minimum, the present study suggests that spelling fluency, in addition to spelling accuracy, varies across students, is predicted by both orthographic recognition and sound-to-letter processing skill, is worthy of future research, and possibly also should be a focus of teacher attention.

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Appendix

See Tables 4 and 5.

Table 4 Spelling test items

Challenge	Word	English
None	*eplepai*	apple-pie
	kam	comb
	lokomotiv	locomotive
	pløyer	plough
	risper	scratch
	sauer	sheep
	trikset	trick
Word-initial	*gi*	give
	gjelder	apply
	gjerne	happily
	gjort	done
	hjem	home
	hvor	where
	kilometer	kilometre
	kjole	dress
Mid-word	*belagt*	coated
	diesel	diesel
	dusj	shower
	fingrene	fingers
	forkjølet	cold
	godt	good
	grovt	wholemeal
	kanskje	maybe
	kråkeskrik	crow scream
	landet	country
	marsjerer	marches
	pizza	pizza
	rundt	around
	sprinklene	louvers
	tatt	taken
	tillegg	addition
	viktig	important

Table 5 Non word test items

Word
pok
fyt
låp
Aret
dese
glyfe
narot
kjave
keggi
fusse
kjermu
saruli
otelsu
muletla
baska
kaveløy
larkt
pafrsen
drogmulsio
josebjador

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7 Article 3

8 Article 4

9. Overall findings and general discussion

In this thesis - aimed at investigating word-level production - the central questions concerned what causes disfluencies at the word-level, and what the consequences of these are. In this final section, the most important findings are assembled and discussed.

9.1 Overall findings

The first study contributes toward supporting the hypothesis that longer latency times at the word-level are not due to monitoring or reading what the writer has written, but is instead associated with production. This study was designed so as to make it possible to falsify the alternative hypothesis – that monitoring causes longer word-level latencies. Masking the texts, and thus preventing reading, did not affect differences between weak decoders and control students, the weak decoders still had longer word-level latency times. Thus, we found that reduced fluency or long latency times at the word-level, when writing, was associated with production.

In addition, the first study provided information about weak decoders who were diagnosed with dyslexia. Findings demonstrated that weak decoders made more spelling errors when writing, and produced poorer quality text. In addition, we found differences in the writing process between this group and a group of control students. First, we found evidence of a word-level focus for the weak decoders during writing - inter key-press latencies were longer in three word-level locations: word initially, at word-end, and within-word for these writers. In particular, latencies word initially were 36% longer. This location is assumed to be associated with word-level planning. When discussing overall findings here, within word latencies belonging to the pause bin .5s <, and word initial latencies 1s < for the writers in study 1 will be termed disfluencies. Results showed that word initial and mid word disfluencies were more common in weak decoders. This larger proportion of longer pauses or disfluencies further suggests that word-level planning was effortful for weak decoders, and resulted in more interruptions or disfluencies than for the control students.

A final, more tentative finding can be drawn from this study. Findings show that pre-sentence latencies are significantly longer for the weak decoders, that is, the writers with more within word and word initial disfluencies. This finding can be seen as an indication that parallel processing occurred less with the writers that had more disfluencies. For these writers, it is possible that concept retrieval and planning syntax and content could not happen in parallel with transcription, and therefore more time was needed for planning at the sentence level. This finding suggests there is reason to believe that word-level processes can influence other writing processes.

Although this study sorted out the monitoring (reading) issue, what is not clear from the first study, is whether word-level disfluencies are related to spelling. In particular, from a logical point of view, for disfluencies in the middle of a word to be related to spelling, spelling must be a cascaded process. Further, although results from the first study indicate that parallel processing occurred less for writers with more disfluencies, it is not clear whether word-level processes can influence other writing processes, and through these, text quality measures. Thus, the findings from the first study highlighted areas of research that needed to be investigated further – these were dealt with in study 2 and 3.

Results from study 2 support the hypothesis that word-level disfluencies can be explained by spelling. If spelling is fully planned before typing onset, then whether or not a word contained a challenging spelling would only influence spelling onset. However, findings indicated that spellings were not fully planned when typing started. Evidence for this came from two findings. First, mean inter key intervals (IKIs) were longer for words that contained a spelling challenge mid-word; second, the IKIs immediately before these within word challenges were longer than for the other mid-word IKIs in the same word. Taken together with the finding that non-word spelling or encoding, predicted within word IKIs, it indicates that assembly cascades beyond typing onset. This finding bears consequences for understanding mid-word disfluencies in text production. It suggests that spelling can cause mid-word disfluencies as well as word initial disfluencies.

In addition, this study provided evidence that spelling accuracy and spelling response latency and mid word key-press latency are predicted by different child-level cognitive factors.

In the third study, I started out with documenting how transcription skills are associated with word-level latencies and disfluencies when composing text. However, modelling the relationship between transcription skills and word-level disfluencies revealed that the path from spelling loaded more on the dependent variables, word-level disfluencies, than the other transcription measures. Thus, when writing, disfluencies at the word-level are linked to spelling skills, and with struggling with preparation of the word.

Finally, results from this study supported the hypothesis that disfluencies at the word-level influence measures of text quality negatively. It does so indirectly through text length, but for the quality measure theme development it does so directly as well – in the model there is a significant direct path from word initial disfluencies. This can be explained by Christiansen and Chater's (2016) "just-in-time" constraint of language production in that when words are not fluently broken down into chunks low enough for transcription, processes cannot be executed simultaneously. This finding also supports an understanding of written language production as a cascaded process, where higher level processes, like concept planning, can be activated while keyboarding if transcription is fluent. When disfluencies occur, this parallel-cascaded process does not take place, which again has a negative impact on the text.

Overall, transcription measures influence word level latencies in text composition. In particular, it seems that spelling skills or speed of initiating spelling and speed of spelling words predict the proportion of disfluencies when producing text – struggling with, or being slow at spelling increases the amount of disfluencies. Finally, it appears that the writing process is linked to and influences text quality; word-level disfluencies have a negative impact on text quality measures. Even for older students.

9.2 Theoretical implications

Findings from the first study provide new information about reading or reviewing during writing. Reading is included in many theories of writing (Hayes & Flower, 1980; Kellogg, 1996). Reading what is already written can serve different functions; error detection, maintaining cohesion, or help generating new ideas (Wengelin et al., 2009). Hayes (1996) emphasizes reading as important in evaluation of a text. In our study, preventing reading by masking the text resulted in more spelling errors, proving that reading what is written is important for error detection. Masking the text also meant students spent less time on task, suggesting that normally some time is spent reading the text. However, masking the text did not have any negative consequences for text quality. This can be seen as an indication that for writing of spontaneous short texts, organization, vocabulary, and idea generation does not rely on reading.

We found evidence that different writing processes can work in parallel, thus we found support for a cascading model of writing. First, for word production we found evidence that spelling is a cascaded process. Further, we found support for higher level processes, like planning or concept retrieval, working in parallel with transcription. For typically developing writers, sentence initial latencies were shorter than for a dyslexic or weak decoder. It seems planning sentences can start in parallel with typing when word production is smooth. When word production is effortful, like for the group of weak decoders, more sentence planning is delayed until the sentence boundary.

Finally, our findings suggest that it is disfluencies, rather that median mid word latencies that has an impact on text length. This supports our view that disfluencies are disruptive.

9.3 Practical implications

In the introduction, I emphasized the importance of being able to take part in literate society, and the importance of educators and developers of supportive writing tools to focus on the writer and the writing process. In this section, I will discuss possible practical implications of my findings.

Feng, Lindner, Xuejun, & Joshi (2017) recommend a focus on fluency in combination with legibility when instructing handwriting legibility to enhance students' writing skills. I think their focus on fluency is important, but it is essential that fluency is understood as more than motor execution. Results from this thesis indicate that the fluency part of spelling is essential for the writing process and thus for writing as a whole. I want to stress the importance of explicit focus on spelling, and several experiences with written text to support orthographic learning (Share, 1999). Further, our findings suggest that when interpreting results from classroom spelling tests, teachers might get more information about the influence results might have when composing longer text, if process measures were included.

When writing longer texts, teachers should possibly encourage students, and in particular students who struggle with spelling, not to worry about spelling, or to pay attention to spelling at a later stage. Some practitioners already do this. However, this does not mean teachers should place less emphasis on the teaching of spelling, but the opposite. Explicit training in spelling, both phonology and morphology, in combination with opportunities to engage in meaningful text writing and reading. Possibly a focus on what is correct and good, and explanations as to why this is good, rather than a focus on errors, may quell some of the anxiety associated with making spelling errors (Mossige, Rønneberg, Johansson, Uppstad, & Torrance, n.d.).

It seems even the best of ideas can be disturbed by transcription. Brilliant stories may remain untold, due to struggling with the low-level processes involved in writing. Individual process oriented feedback might be part of the solution to help writers. This involves students getting feedback based not only on the written product, but also on the writing process. It involves integrating key-logging to the educational practice. By getting information about the time-course of text production, and discussing this with students, it is possible to get information about the cognitive processes that demand a lot of time and resources. If, for example, a student has a tendency to write short texts, with an argument that is not well developed, but with few spelling mistakes, there may be several reasons for this, and information about the writing process might provide some answers. If this student's writing process is fluent; shows latency times that are typical of her age group, and there are few disfluencies, then the student can be directed towards writing more and possibly use strategies for planning in advance. On the other hand, if the process data reveal several word-level disfluencies, and long latency times, then this would seem to indicate a problem with transcription. The teacher could prescribe keyboard practice if that seems to be part of the problem, or the student can also be assigned spelling practises based on mistakes the student has made or on words she that contained a disfluency. Another suggestion is to urge the student to sometimes pay less attention to spelling – just get his/her idea down on paper and then deal with spelling at a later point.

Our results also bear consequences for how spellcheckers or tools for writing support should be developed. Results from study I suggest that it is possible to leave revision for a later stage. Further, results suggest that disfluencies at the word-level are disruptive for text writing. Together with our claim from paper 4 that writers need less information, rather than more, and that fluency should be the most important principle when supporting writers, we suggest that a writing tool should be nonintrusive, and possibly wait with feedback until a later stage, separating text production from editing. Some developers of spellcheckers have also suggested that this might be beneficial for writers. This thesis gives empirical support and a theoretical rationale for doing so.

9.4 Final conclusion

The research presented in this thesis illustrates that word-level disfluencies have an impact on writing, by reducing parallel processing in the writing process, and thereby entailing negative consequences for the higher-level text features. Moreover, the process of spelling words can cause these disfluencies when writing. It seems "thinking one's way through a text" (Tønnessen & Uppstad, 2015) can be obstructed by retrieving a word's orthographic representation.

Questions still remain for future research to explore. A first next step would be to parse the text, and to study disfluencies in relation to syntactic measures. This would further expand our knowledge of when and why disfluencies occur. Moreover, when studying writing processes and when evaluating text quality, we should ideally have had the possibility to look at more texts written by the same student. Future research might aim to collect more texts written by the same students, written in different genres. Another interesting thought is to use keylogging in future intervention studies with students with dyslexia. The research presented here indicate that students diagnosed with dyslexia have more word-level disfluencies than typically developing students. Moreover, word-level disfluencies have negative consequences for text composing. An intervention aiming at not only improving written text quality- writing more text, with fewer spelling mistakes, and better organized text, but also aiming at improving writing fluency is another suggestion for future research.

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Appendices

Appendix 1: Letter of consent from the Norwegian Social Science Data Services, study 1:

Norsk samfunnsvitenskapelig datatjeneste AS
NORWEGIAN SOCIAL SCIENCE DATA SERVICES

Harald Hårfagres gate 29
N-5007 Bergen
Norway
Tel: +47-55 58 21 17
Fax: +47-55 58 96 50
nsd@nsd.uib.no
www.nsd.uib.no
Org.nr. 985 321 884

Per Henning Uppstad
Nasjonalt senter for leseopplæring og leseforsking Universitetet i Stavanger

4036 STAVANGER

Vår dato: 02.12.2015 Vår ref: 45500 / 3 / MHM Deres dato: Deres ref:

TILBAKEMELDING PÅ MELDING OM BEHANDLING AV PERSONOPPLYSNINGER

Vi viser til melding om behandling av personopplysninger, mottatt 03.11.2015. All nødvendig informasjon om prosjektet forelå i sin helhet 27.11.2015. Meldingen gjelder prosjektet:

45500	*Skriveflyt (supplering av tidligere meldt prosjekt Skriveflyt 30960)*
Behandlingsansvarlig	*Universitetet i Stavanger, ved institusjonens øverste leder*
Daglig ansvarlig	*Per Henning Uppstad*

Personvernombudet har vurdert prosjektet, og finner at behandlingen av personopplysninger vil være regulert av § 7-27 i personopplysningsforskriften. Personvernombudet tilrår at prosjektet gjennomføres.

Personvernombudets tilråding forutsetter at prosjektet gjennomføres i tråd med opplysningene gitt i meldeskjemaet, korrespondanse med ombudet, ombudets kommentarer samt personopplysningsloven og helseregisterloven med forskrifter. Behandlingen av personopplysninger kan settes i gang.

Det gjøres oppmerksom på at det skal gis ny melding dersom behandlingen endres i forhold til de opplysninger som ligger til grunn for personvernombudets vurdering. Endringsmeldinger gis via et eget skjema, http://www.nsd.uib.no/personvern/meldeplikt/skjema.html. Det skal også gis melding etter tre år dersom prosjektet fortsatt pågår. Meldinger skal skje skriftlig til ombudet.

Personvernombudet har lagt ut opplysninger om prosjektet i en offentlig database, http://pvo.nsd.no/prosjekt.

Personvernombudet vil ved prosjektets avslutning, 29.02.2016, rette en henvendelse angående status for behandlingen av personopplysninger.

Vennlig hilsen

Katrine Utaaker Segadal

Marianne Høgetveit Myhren

Kontaktperson: Marianne Høgetveit Myhren tlf: 55 58 25 29
Vedlegg: Prosjektvurdering

Dokumentet er elektronisk produsert og godkjent ved NSDs rutiner for elektronisk godkjenning.

Avdelingskontorer / District Offices
OSLO: NSD. Universitetet i Oslo, Postboks 1055 Blindern, 0316 Oslo. Tel: +47-22 85 52 11. nsd@uio.no
TRONDHEIM: NSD. Norges teknisk-naturvitenskapelige universitet, 7491 Trondheim. Tel: +47-73 59 19 07. kyrre.svarva@svt.ntnu.no
TROMSØ: NSD. SVF, Universitetet i Tromsø, 9037 Tromsø. Tel: +47-77 64 43 36. nsdmaa@sv.uit.no

Appendix 2: Letter of consent from the Norwegian Social Science Data Services, study 2:

Norsk samfunnsvitenskapelig datatjeneste AS
NORWEGIAN SOCIAL SCIENCE DATA SERVICES

Harald Hårfagres gate 29
N-5007 Bergen
Norway
Tel. +47-55 58 21 17
Fax: +47-55 58 96 50
nsd@nsd.uib.no
www.nsd.uib.no
Org.nr. 985 321 884

Vibeke Rønneberg
Institutt for lingvistiske, litterære og estetiske studier Universitetet i Bergen
Sydnesplassen 7
5007 BERGEN

Vår dato: 19.09.2014 Vår ref: 39536 / 3 / KH Deres dato: Deres ref:

TILBAKEMELDING PÅ MELDING OM BEHANDLING AV PERSONOPPLYSNINGER

Vi viser til melding om behandling av personopplysninger, mottatt 22.08.2014. Meldingen gjelder prosjektet:

39536	*Writing fluency/Skriveflyt*
Behandlingsansvarlig	*Universitetet i Bergen, ved institusjonens øverste leder*
Daglig ansvarlig	*Vibeke Rønneberg*

Personvernombudet har vurdert prosjektet, og finner at behandlingen av personopplysninger vil være regulert av § 7-27 i personopplysningsforskriften. Personvernombudet tilrår at prosjektet gjennomføres.

Personvernombudets tilråding forutsetter at prosjektet gjennomføres i tråd med opplysningene gitt i meldeskjemaet, korrespondanse med ombudet, ombudets kommentarer samt personopplysningsloven og helseregisterloven med forskrifter. Behandlingen av personopplysninger kan settes i gang.

Det gjøres oppmerksom på at det skal gis ny melding dersom behandlingen endres i forhold til de opplysninger som ligger til grunn for personvernombudets vurdering. Endringsmeldinger gis via et eget skjema, http://www.nsd.uib.no/personvern/meldeplikt/skjema.html. Det skal også gis melding etter tre år dersom prosjektet fortsatt pågår. Meldinger skal skje skriftlig til ombudet.

Personvernombudet har lagt ut opplysninger om prosjektet i en offentlig database, http://pvo.nsd.no/prosjekt.

Personvernombudet vil ved prosjektets avslutning, 01.07.2015, rette en henvendelse angående status for behandlingen av personopplysninger.

Vennlig hilsen

Katrine Utaaker Segadal

Kjersti Haugstvedt

Kontaktperson: Kjersti Haugstvedt tlf: 55 58 29 53
Vedlegg: Prosjektvurdering

Dokumentet er elektronisk produsert og godkjent ved NSDs rutiner for elektronisk godkjenning.

Avdelingskontorer / District Offices
OSLO: NSD. Universitetet i Oslo, Postboks 1055 Blindern, 0316 Oslo. Tel: +47-22 85 52 11. nsd@uio.no
TRONDHEIM: NSD. Norges teknisk-naturvitenskapelige universitet, 7491 Trondheim. Tel: +47-73 59 19 07. kyrre.svarva@svt.ntnu.no
TROMSØ: NSD. SVF, Universitetet i Tromsø, 9037 Tromsø. Tel: +47-77 64 43 36. nsdmaa@sv.uit.no

Appendix 3: Letter of consent study 1

Forespørsel om deltakelse i forskningsprosjektet

"Skriveflyt"

Til elev og foresatte.

Vi vil invitere ditt barn til å delta i et prosjekt om skriving hvor vi undersøker situasjoner som kan påvirke selve skrivingen. Vi prøver å finne ut når det er naturlig for skivere å ta pause og hva som ser ut til å være utfordrende når de skriver. Dette gjør vi for at vi i neste omgang kan lage bedre verktøy for skrivestøtte. Prosjektet inngår en del av en doktorgradsstudie ved UiB/UiS. Barnet ditt er invitert med i studien på bakgrunn av skolen sine opplysninger om elevens lese- og skrivevansker. Elevens identitet er ikke kjent for oss før dere krysser av og signerer på at dere vil delta.

Hva innebærer deltakelse i studien?
I selve studien vil vi at elevene skal skrive to korte tekster på pc i to forskjellige situasjoner, de skal og gjennomføre en orddelings oppgave, en staveoppgave og et kort intervju. Intervjuet dreier seg om tekstene elevene skriver. I pausen får elevene litt å drikke og frukt. Deltakelsen vil vare maksimalt 2 timer.

Hva skjer med informasjonen om eleven?
Alle personopplysninger vil bli behandlet konfidensielt. Når vi skal studere selve skrivingen, vil også en forsker ved Universitetet i Bergen delta. Forskerne som er med i prosjektet har taushetsplikt når det gjelder opplysninger fra studien. Undersøkelsen er avklart med og i tråd med retningslinjene fra personvernombudet for forskning, Norsk samfunnsvitenskapelig datatjeneste (NSD).

Prosjektet skal etter planen avsluttes 01.07.2015. Datamaterialet anonymiseres ved prosjektslutt.

Frivillig deltakelse
Vi understreker at det er frivillig å delta i studien, og en kan når som helst trekke samtykke uten å oppgi noen grunn. Dersom en trekker seg, vil alle opplysninger bli anonymisert. Det vil ikke få noen konsekvenser i forhold til skolen om man velger å ikke delta.

Dersom har spørsmål til studien, ta kontakt med Vibeke Rønneberg vibeke.ronneberg@uis.no eller på telefon 90042611

Studien er meldt til Personvernombudet for forskning, Norsk samfunnsvitenskapelig datatjeneste AS,

Samtykke til deltakelse i studien

☐ Jeg har mottatt informasjon om studien fra skolen, og samtykker i at mitt barn kan kontaktes av forskere fra Lesesenteret og delta i studien.
Barnets navn:____________________

Foresattes signatur: ____________________

Appendix 3: Letter of consent study 2

Forespørsel om deltakelse i forskningsprosjektet "Skriveuke"

Til elev og foresatte.

Vi vil invitere deg/ditt barn til å delta i et prosjekt om skriving hvor vi undersøker situasjoner som kan påvirke selve skrivingen. Vi prøver å finne ut når det er naturlig for skrivere å ta pause og hva som ser ut til å være utfordrende når de skriver. I tillegg ønsker vi å identifisere faktorer som kan fremme god flyt i tekstproduksjon. Dette gjør vi for at vi i neste omgang kan lage bedre verktøy for skrivestøtte. Prosjektet inngår en del av en doktorgradsstudie ved UiB/UiS.

Hele klassen til barnet ditt er invitert til å være med, på en «Skriveuke». De elevene som takker nei til å være med vil jobbe med de samme tingene som resten av klassen, men tekstene deres vil ikke bli gitt til oss. Elevenes identitet er ikke kjent for oss før dere krysser av og signerer på at dere vil delta. I tillegg ber vi om tillatelse til at skolen oppgir elevens resultat på nasjonale prøver fra 5.trinn.

Hva innebærer deltakelse i studien?
I selve studien vil vi at elevene skal skrive fire korte tekster i forskjellige situasjoner, de skal og gjennomføre en orddelingsoppgave, en staveoppgave, en undersøkelse av håndskrifts og keyboard ferdighet, en oppgave som handler om å gjenkjenne mønster og en navngivningsoppgave. Skriveoppgavene, staveoppgaven og mønsteroppgaven gjøres sammen med resten av klassen. Resten skjer individuelt. Vi legger hele tiden vekt på at elevene skal oppleve mestring og ha positive opplevelser knyttet til skriving.

Hva skjer med informasjonen om eleven?
Alle personopplysninger vil bli behandlet konfidensielt. Når vi skal studere selve skrivingen, vil også en forsker ved Universitetet i Bergen delta. Forskerne som er med i prosjektet har taushetsplikt når det gjelder opplysninger fra studien. Undersøkelsen er avklart med og i tråd med retningslinjene fra personvernombudet for forskning, Norsk samfunnsvitenskapelig datatjeneste (NSD).

Prosjektet skal etter planen avsluttes 01.07.2015. Datamaterialet anonymiseres ved prosjektslutt.

Frivillig deltakelse
Vi understreker at det er frivillig å delta i studien, og en kan når som helst trekke samtykke, uten å oppgi noen grunn. Dersom en trekker seg, vil alle opplysninger bli slettet. Det vil ikke få noen konsekvenser i forhold til skolen om man ikke velger å delta.

Dersom har spørsmål til studien, ta kontakt med Vibeke Rønneberg vibeke.ronneberg@uis.no eller på telefon 90042611.

Studien er meldt til Personvernombudet for forskning, Norsk samfunnsvitenskapelig datatjeneste AS.

Samtykke til deltakelse i studien

☐ Jeg har mottatt informasjon om studien fra skolen, og samtykker i at mitt barn kan delta i studien.
Barnets navn:____________________

Foresattes signatur: ______________________