LUNDS UNIVERSITET

DEPARTMENT of PSYCHOLOGY

# *I Can't Hear What I'm Reading: An Eye Tracking Study on Reading in Different Noise Environments*

**Nina Pallasch**

Master's Thesis (30 hp)

Spring 2023

Supervisor: Roger Johansson

**Thank you!** To everybody who supported me in the process of this thesis. I want to particularly thank Willy Malmquist for his tireless efforts of helping me recruit participants, Roger Johansson for providing most helpful feedback, Diederick Niehorster and Marcus Nyström for the support regarding the eye tracking methodology, Jonas Brännström for the advice regarding the acoustic stimuli, Sarah Weber, Frida Smids, Carla Marti Valls, Hampus Persson and Martynas Matuzevičius for accompanying me through the whole process and providing not only scientific but also emotional support and last but not least of course all of my participants who made this project possible.

## Abstract

This study investigates how different acoustic environments and spelling manipulations affect the reading process by applying eye tracking methodology. Participants are asked to read sentences while either listening to babble noise or not being exposed to any acoustic stimuli. It was generally possible to understand semantic chunks of the babble noise but not the discourse. The reading material was manipulated by including misspelled words that either do or do not resemble the original word's phonology. A screen-based eye tracking system was used to measure participants first fixation duration, total fixation duration and number of fixations. Using a linear mixed effects model to analyze the effects of the different spelling and acoustic conditions as well as their interactions. The different spelling conditions showed first evidence for the pseudohomophone advantage effect in the Swedish language applying to total fixation duration and number of fixations. Noise distraction did not show significant effects. Regarding working memory, this implies that babble noise does not affect the capacity for the processing of written text which further suggests that processing discourse is more relevant in causing distraction effects than processing semantics. Further theoretical as well as practical implications are discussed.

**Keywords:** Reading Process, Auditory Noise, Pseudohomophone Advantage, Eye Tracking

## Introduction

Reading is a crucial part of everyday life as well as academia and work life. It takes place in a number of different environments, which includes different acoustic environments. Intuition and research agree that readers are distracted by noise in their environment while reading (Vasilev et al., 2018). A noisy environment is particularly distracting when the noise consists of language sounds, also known as the irrelevant speech effect (Colle & Welsh, 1976). The irrelevant speech effect is being investigated mainly on a high-order comprehension level (Boyle & Coltheart, 1996; Cauchard et al., 2012; Hyönä & Ekholm, 2016) and to date there is not sufficient evidence demonstrating that it exists on a word level even though theoretical accounts and first empirical studies suggest it (Yan et al., 2018). This means that noisy environments have a negative impact on readers' comprehension of the discourse of a text but not when they read individual words. Research is inconsistent about how big the distraction effect actually is and what mechanisms induce the effect. As reading is a complex process, there are many potential sub processes that could be affected by different acoustic environments. The present study aims to contribute more understanding into how and where in the reading process acoustic distractions are most prominent.

In order to be able to identify this, the experimental design will make use of the pseudohomophone advantage effect which describes that readers process words faster when they are misspelled but keep the original word's phonology in comparison to when they are misspelled and thereby change phonology. By testing the pseudohomophone advantage effect in different noise conditions the study will be able to provide insights into why noise environments negatively affect reading. In contrast to most studies about effects of different noise environments on reading that look at "symptoms" of noise distraction, this study is able to provide data on what causes these "symptoms".

Furthermore, the pseudohomophone advantage effect can be used as a research tool to investigate what variables, inherent to a text or a group of readers, influence the use of phonology in the reading process. A requirement to be able to use the effect as this kind of tool is that there is evidence for the existence of the effect in the respective language.

The results can be used as a base to develop and improve reading acquisition programs for populations that have problems with reading like the deaf and hard of hearing or children whose reading acquisition takes place in noisy environments (Alasim, 2020; Klatte, 2017). There is evidence for the homophone advantage effect in languages like Chinese and English but this work will serve as first evidence for the existence of the effect in the Swedish language (Yan et al., 2020; Blythe et al., 2018) .

**Basics of Visual Processing, Learning and Acoustic Distraction**

Reading is an advanced form of visual perception and processing. In visual perception light acts as the stimulus and the eye in combination with our brain as the processing unit that interprets this stimulus (Purves, 2013). Light, which can be seen as either waves or as a stream of photons, is only perceived and later processed by humans when it meets the eye. Within the eye, it has to pass through the cornea, proceed to the iris and through the lens be focused on the retina to then be processed by the receptors that are located there. Finally, the information gathered and shaped through different layers of processing in the retina is forwarded to the brain by the optic nerve.

When the signal has reached the brain, the process of interpreting the perceived information starts. Within the brain visual information is early on processed based on what kind of information it is. This means that the visual processing of text, being the information that is processed while reading, cannot necessarily be compared to general visual information like pictures. Text information is processed on different levels in specialized brain areas: first, letters are processed in the “letter form area”, approximately 60 ms later word level information is processed in the “visual word-form area” in the ventral occipito-temporal cortex. Integrative processing then follows and includes the entire network (Thesen, 2012).

Working memory is another key component of the complex reading process. When reading sentences/texts information has to be stored for the entire time period of reading the sentence/text in order to be able to understand the semantics on sentence/text level instead on only word level. It follows that working memory capacity, which is inherently limited, plays an important role when investigating effects that regard distraction, like the current study does. This limitation of working memory capacity is generally ascribed to either limited attentional resources or to interference due to material of similar kind e.g. phonological, visual, etc. (Cowan, 2014). The result of the limited capacity is that stimuli, particularly being of the same kind, compete for this capacity. Of interest for this study is if noise stimuli that only entail a minimal potential for semantic processing still compete with information in working memory that is produced while reading.

The classic working memory model by Baddeley and Hitch (1994) describes a specialized part of working memory, the phonological loop, which enables verbal material to be maintained sub-vocally. While reading, this verbal material is produced through the subvocalization of the read text.

As the current study investigates the conflict between noise and reading, it is important to mention the general effects that noise has on cognitive processing in order to be able to interpret the results in a larger context. Auditory distraction has been shown to impair task performance in auditory as well as non-auditory tasks even when the auditory stimulus is task-irrelevant; these effects are more pronounced in children (Klatte et al., 2013). This is because when we are in noisy environments, the goal-relevant information has to compete with the goal-irrelevant information, which is the background noise. When the background noise demands processing capacity, processing of the goal-relevant information is negatively impacted (Banbury et al, 2001). Particularly negative effects on task performance can be shown for language sounds. Within language sounds, there seem to be differences in effects depending on if a person can understand the language and if a person can understand what is being said. This will be further discussed in “Reading Process and Noise Distraction”.

**Psychology of Reading**

Even though people describe that their eyes go from the left to the right (when this is the direction of the respective language) in a smooth manner when they read, the extensive research by Rayner and colleagues shows that this is not actually the case (see Clifton et al. 2015 as an overview). Instead, our eyes go from mainly left to right in a way that can be more described as jumping, also the eyes occasionally go back in the text, from right to left. The positions where the eyes land are called fixations, because there the eyes rest long enough to process information and the visual information falls on the fovea, the region in the eye that produces a sharp image. This implies that fixations are indicators for information processing which also means that longer fixations can be interpreted as deeper information processing and potentially more general cognitive processing related to the processed information. It can for example be assumed that when fixating a certain word in a text that the reader is processing the information that this word contains during the fixation. This includes the visual composition of the word but also further processing such as associations that the reader has to this particular word.

The eyes' movements between these positions are called saccades. During saccades information processing is on hold because no information is foveally focused. In the reading process this means that readers can never swiftly scan the text with their eyes as they would not process any information. Still, this does not mean that readers fixate every single word. Contrary to the feeling most people have when reading, skilled readers skip words, especially short words. For reading research this means that even when a word does not have fixations this does not mean that it was not attentionally processed. When readers show understanding of the read text it can be assumed that the words that were skipped are easy to process instead of skipped and not processed. But if readers do not process information during saccades and neither fixate each word, how are they able to process words that they skip?

One factor that ensures smooth reading while skipping is experience. Skilled readers have a lot of experience and that means that they have learned to unconsciously predict what word most likely follows after certain words in certain contexts. So they are able to skip words because they know what the next word is going to be before they fixate it. This is of course only possible in contexts where the reader has a lot of experience and even then the process is prone to errors.

Another factor is that while most processing happens where the focus of the fovea lands, information that is outside of this foveal focus is also processed to a certain extent, which for example enables fluent reading. This phenomenon is known as parafoveal processing and is a skill that develops with time as children only have basic parafoveal processing skills (Eilers et al., 2019) but significantly improves between second and third and is comparable to adult skills in sixth grade (Häikiö et al., 2009; Sperlich et al., 2015). Thus, skilled and smooth reading can only be developed after the readers have proficient parafoveal processing. Prior to that, word skipping cannot be done efficiently because the information that is skipped cannot be compensated for. In order to measure how far ahead an individual can effectively perceive information that is not yet foveally focused, their perceptual span, can be tested through the gaze-contingent moving window paradigm, first introduced by McConkie and Rayner (1975). In this paradigm letters outside of a certain window around the current fixation are masked, often by 'X''s. The now well replicated results show that when fixating on a position in a text, readers process on average 15 letter spaces to the right of the fixated letter and three to four to the left, which is one reason why short words often do not need to be fixated (for an overview see Rayner, 2009b). When the window gets smaller than this readers become impaired in their reading speed and eventually in their comprehension.

This span is specific for writing systems that use the latin alphabet which is one example for why results in reading research have to be validated in a number of languages and cannot necessarily be generalized. Chinese readers for example have a much smaller perceptual span because words in Chinese are made up of fewer characters which means that there is simply no need for a perceptual span as large as in latin alphabet writing systems in order to have a smooth reading and reading comprehension (Li & Pollatsek, 2020). Because even when this process is not necessarily conscious, processing more than the word that we fixate at a certain moment is an important part of reading. The region of the text that is not in foveal focus is being processed parafoveally, which results in a lower processing accuracy and depth but enables smooth reading by starting processing of the next word while still fixated on the current word. This way, processing during the fixation is faster because basic information about the next word is already processed. As a result, aspects of the word currently processed influence the processing of the next word through affecting the extent in which the next word can be processed parafoveally prior to being fixated. This is known as the spillover effect (Rayner & Duffy, 1986; Henderson & Ferreira, 1990). In the context of this thesis this means that when comparing different target words or different spellings of a target word the word prior to the target word has to be comparable in frequency and length in order to prevent unwanted covariance.

As named above, eye movements in reading are not restricted to left to right movements even in left to right writing systems. A smaller number of eye movements, around 10 - 15% of saccades while reading go backwards in the text, called regression. This is usually because information was missed or has to be reevaluated which indicates that a word is especially hard to process and the measure is therefore going to be used in this work to identify which changes in phonology or changes in spelling have larger impacts on the reading process.

All these studies are of incredible interest for the understanding of how we read text when talking about what our eyes do and how they are influenced by the text itself. However, they provide little information about semantic processing, how we access the meaning of text while reading, which after all is the reason why we read.

Brysbaert and colleagues (2016) described how without mapping graphemes onto sounds but just recognizing the written word and directly trying to identify its meaning is impossible for learning readers and resembles more a paired-associate learning task. When becoming a more proficient reader on the other hand, Zoccolotti and colleagues (2005) showed that word recognition is so well developed that alphabetic decoding is not a necessary step for some words. This does not mean that phonological decoding does not play a role in the process anymore, it has just turned more covert. Castles and colleagues (2018) refer to this process as orthographic learning. This is especially relevant when comparing reading research in children to that from adults and relates to the reading experience of the individual reader and thereby their prediction capabilities.

## Eye Tracking

Reading has been investigated for decades but methods have changed due to technological advancements and eye tracking technology has become more precise as well as more readily available (Płużyczka, 2018). As early eye tracking methods were introduced, it has become more and more obvious that eye tracking is needed to investigate general cognitive processes but also to complement reading research because behavioral as well as introspective methods are insufficient (Tinker, 1946).

In cognitive science and specifically with eye tracking technology, it is assumed that our minds process what our eyes focus on and our minds control what our eyes focus on. It follows that eye movement measures are ideal correlates of how the human mind processes visual information. Even though numerous studies have shown that the eye-mind hypothesis is roughly valid, there are certain circumstances where researchers have to be very careful in their interpretation of the results of eye tracking data, for example when regarding top down and bottom up processes (Chekaluk & Llewellyn, 1992). This will be further examined in the discussion.

## Eye Tracking in Reading Research

In reading research there are a number of models for eye movements that aim to explain oculomotor control within the reading process. These models are of high importance when using eye tracking methodology because they act as the base to choose what measures are used in eye tracking and how the results are interpreted and linked to the reading process. Due to the limitations of this thesis only one of them is going to be explained, namely the E-Z Reader model developed by (Reichle 1998). This model was chosen over models as the SWIFT model because it has been extensively tested and is less complex than other models which makes it more efficient (Engbert et al., 2002; Rayner, 2009a).

It is based on the model for eye movement control by Morrison (1984) which shares all main principles with the E-Z Reader model. The main assumptions, which distinguishes the model from others, is that words are processed in a serial manner, eye movements are under control of lexical and linguistic processing and more specifically that “word identification” is the central driver of eye movements (Rayner, 1998a). What is meant by “eye movements are under the control of lexical and linguistic processing” is that the linguistic properties of words for example word frequency is the determining factor for where the eyes move while reading. Additionally, the model assumes that programming of a saccade is triggered by a “familiarity check” which involves a vague word identification. The programming of a saccade is inferred to be composed of two successive stages, an early one that can be canceled by a different saccade and a later one that cannot be canceled.

According to the model, saccades are planned to land in the middle of the next word, because this minimizes the average distance to all letters - the further a letter from the fixation, the slower the processing. This explains the empirical findings that longer words take longer to process (Barton et al., 2014). It is important to notice that the model describes that saccades are *planned* to land in the middle of the next word, which does not always result in a successful saccade to that point. Errors in eye movement are thought to either be random and caused for example by imprecision or systematic. The systematic error occurs when words are unusually short or long and the saccade regresses to the average length of approximately eight letters, this explains overshooting or even skipping for short words. Still, it has to be considered only because these words aren’t foveally fixated does not mean that they are not focused by the attention of the reader and due to their simplicity and shortness that means that they can still be successfully identified even without direct foveal focus. Similarly, long words are often not fixated in the middle because readers revert to an average saccade length.

An issue with the model, is that the “word identification” which is the fundamental component of all processes within the model, is never really defined, neither are the subprocesses of “good enough” and complete word identification. In the future, quantitative and qualitative thresholds for when these processes are completed have to be found. Nevertheless, the model explains a vast number of empirical findings while still being quite simplistic, specifically compared to other models (Reichle, 2021).

**Eye Tracking Measures**

In reading research a number of eye tracking measures have been established to compare more and less skilled readers as well as factors within the text stimuli that affect the reading process. These include first fixation duration which measures how long an individual focuses on one word continuously when it is focused on for the first time. As stated in the E-Z reader model, this measure shows the first processing of the target word after parafoveal processing and is influenced by word length and frequency. During this processing stage phonological as well as lexical aspects of the word are being processed but a full identification of the word is not yet completed. Even though the very first processing of a word takes place before the first fixation, the measure of first fixation duration is also influenced by the spillover effect, described earlier in the text. In reading, the average fixation lasts about 200 - 250 ms (Rayner, 1998b).

Another measure that is widely used is total fixation duration which measures how long an individual focused on one word independent of if this fixation is interrupted or continuous. The importance of this measure can also be supported by the E-Z reader model as it includes all processes that are needed to read full identification of the word. Both of these measures can be seen as measures for early lexical processing while the measure of refixation (on average about 10 to 15% of all saccades go to refixations) which describes how often an individual goes back to a certain word after already having read that word and moved on to the next one can be seen as a measure of late lexical processing (Rayner, 1998, 2009). Early lexical processing refers to the processing that takes place before a fixation lands on a word, thus during the previous fixation or the saccade parafoveally or immediately when a fixation lands on the word foveally. Phonological codes for example are typically extracted during early processing (Pollatsek, 2000; Miellet & Sparrow, 2004). Late processing describes all processes that happen after the immediate fixation, most importantly complete word identification and matching the read word to the reader’s mental lexicon.

## Reading and Phonology

Phonology forms the base of our reading skills, this can be demonstrated when looking at how children learn how to read. They learn what sound every letter/grapheme makes and then put them together into a whole word which then can be matched to their already existing mental lexicon (Castles et al., 2018). Even skilled readers roughly follow these steps when reading even though their process is a lot more automatic and many words are identified by one look at them and do not have to be decoded letter by letter. Still, skilled readers use phonology in reading, also in silent reading (Pollatsek et al., 2000). While reading the phonological codes of the words are processed and the reader subvocalizes in order to be able to match the decoded written words to their meaning through accessing their phonology.

## Homophones in Reading

In all languages there are words that have different meanings and spellings but the same pronunciation, also called homophones (Trott & Bergen, 2020). Even when words are misspelled, they can be homophones when the misspelling does not change the pronunciation, these words are often called pseudohomophones because the misspelled word is not a real word that exists in readers mental lexicon (Pollatsek, 2000). When misspellings are pseudohomophones, they give the reader a processing advantage compared to phonologically different misspellings, for example in the form of priming (Bélanger et al., 2012; Cripps et al., 2005).

When replacing original spellings with either a misspelling that is phonologically similar or dissimilar, this is thought to evoke a pseudohomophone advantage effect, meaning that the pseudohomophone is processed faster than the phonologically dissimilar spelling (Yan et al., 2021). As named above, this effect has been shown in different alphabetic (Bélanger et al., 2013; Blythe et al., 2018) as well as character-based languages (Yan et al., 2021). Still, evidence for its existence in other languages is needed because of the different phonologies of the languages and because of differences in the similarity between phonology and orthography (Schmalz et al., 2015). Swedish, the language used in the current study, has a very close relationship between phonology and orthography, a shallow orthography, which makes it of interest to investigate and to contrast the results to results from studies that used the English or Chinese language.

**Reading Process and Background Noise**

Auditory distraction has been of interest to many researchers, which has resulted in numerous theoretical approaches. The phonological-interference hypothesis resulting from the phonological loop construct (Baddeley & Hitch, 1994) assumes that one of the three parts of the working memory is the phonological loop which is thought to store and manipulate speech based information. Regarding auditory distraction, the authors theorized that language has inherent phonological properties so that, regardless if the participant understands the language or not, the stimuli gain access to the phonological loop and interfere with other memory processes and more complex cognitive processes such as reading.

The duplex theory by Hughes (2014) claims that interferences can be caused by process and attentional capture. Applied to reading, this implies that interference by semantics occurs because the processing of these stimuli utilize the same process. Interference by noise that cannot be semantically processed occurs when these stimuli draw from attentional resources.

Because the phonology of the stimuli is being manipulated the phonological-interference hypothesis will be investigated from a different angle as in previous studies: during reading of the unrelated spelling condition, the phonological loop should be used to a larger capacity compared to the pseudohomophone spelling condition because the spelling hurdle disturbs the automaticity of the process. It follows that the pseudohomophone advantage would increase in the noise condition according to the phonological-interference hypothesis. When considering the duplex hypothesis, the same results of an enlarged pseudohomophone advantage effect are expected but due to the unrelated spelling condition requiring more attentional resources rather than requiring more capacities of the phonological loop.

Contrary to this, Sörqvist and Marsh (2015) describe that acoustic distraction is easier to ignore when the task is more difficult because the higher difficulty results in more concentration and a steadfast locus of attention which shield against processing of background stimuli. On that account the unrelated spelling condition would make it easier to ignore the acoustic stimuli and processing would be more equal between the spelling conditions, resulting in a smaller homophone advantage effect in the noise condition.

When talking about acoustic environment and noise it is important to differentiate between chronic noise and what is going to be called ambient noise in this thesis. For chronic noise there are many studies that specifically investigate the effect of road or aircraft noise on children's reading (Klatte et al., 2017; Maxwell & Evans, 2000; Spilski et al., 2017). The results are conclusive about a negative effect of chronic noise on several reading outcomes like comprehension, speed and proofreading. For acute noise on the other hand the research is neither as extensive nor conclusive. Vasilev and colleague's (2018) metaanalysis gives an overview over the results of studies that look at effects of different kinds of ambient noise on reading outcomes of speed, comprehension and proofreading. By use of a Bayesian metaanalysis they show that the strongest effect on reading is caused by intelligible speech and lyrical music. The reading variables that were most affected were comprehension which was negatively affected while the effects on reading speed and proofreading were more ambiguous. An overall result that Cauchard and colleagues (2012) eye tracking study also supports is that reading speed is reduced by intelligible background speech. They suggest that more research is needed on reading speed and on the methodology more studies should use eye tracking as it can provide data that is intersubjective, detailed and that shows the online reading process instead of a posteriori behavioral variables. Furthermore, recent studies suggest that word fixation times may be a more sensitive indicator than comprehension regarding distraction (Cauchard et al., 2012; Hyönä & Ekholm, 2016; Vasilev et al., 2019; Yan et al., 2018). In their study, Yan et al. (2018) showed a delayed word frequency effect when background noise was present, meaning that readers did not process high frequency words faster in early processing than low frequency words as they do when reading in silence. This shows that when distracted by background noise, readers cannot access shortcuts in their processing, for example using orthographic learning to merely visually process a word, as often done with high-frequency words, instead of decoding all the letters in order to subvocalize the word.

After having established that background noise does have a negative effect on reading, the question of why background noise affects reading in a negative way needs to be explored. Cauchard and colleagues (2012) looked at syntactic or semantic explanations and excluded the phonological approach from their analysis because of applied methodology. Vasilev and colleagues (2023) stated that there is too little understanding of the type of task that may affect phonological interference. Vasilev (2018) also takes up the fact that the phonological model has mainly been tested in studies with reading comprehension as a dependent variable but that research for reading speed is insufficient. The current study will expand the evidence regarding reading speed as well as approach the phonological-interference anew however from a different angle than before. Instead of altering the phonological features of the noise stimuli, the phonological features of the main task will be manipulated, which has never been done before.

**Aims of the Current Study**

The current study will contribute to the research field by producing evidence not only for the question if certain noise environments disturb the reading process but why they do so, which adds to the depth of knowledge about noise distraction. Regarding real life applications this will help to advance and refine already existing interventions for risk groups when it comes to reading acquisition but also recommendations for the general population as reading in noisy environments is something everybody is exposed to at some point in their lives.

This goal of providing insights to the effect of noise distraction as well as its root cause will be reached by investigating the pseudohomophone advantage effect in different noise environments. The pseudohomophone advantage effect gives insights into if readers use phonological encoding, by manipulating spelling in either phonologically similar or dissimilar way. The comparison between these two misspelled conditions relative to the original word shows if the reader uses phonological encoding because it can be expected that processing is faster for the phonologically similar word when phonological encoding is utilized in the reading process. The addition of noise distraction to this design will consequently produce data on how the phonological encoding is affected by noise distraction.

When transferring the finding of the pseudohomophone advantage effect as presented by Blythe and colleagues (2018) to the current study, it is to be expected that the pseudohomophone advantage effect is dampened in in the noise condition compared to the silence condition when looking at the early measures in the background speech condition. This is because the readers need more cognitive capacity to keep their focus on the goal-relevant information and automatic processing is not applicable to the same extent as in environments free from noise distraction.

In the current study the phonological-interference explanation, which has been rejected in earlier studies, is going to be considered from a different perspective (Hyönä & Ekholm, 2016; Vasilev et al., 2018). Instead of manipulating the background noise in phonology, the phonology of the stimuli is going to be altered by manipulating the orthography of the original word in a way where the word remains similar in phonology and in a way where it does not remain similar in phonology. This type of manipulation has shown a pseudohomophone advantage effect in several studies but the current work is the first study relating it to background noise (Bélanger et al., 2013; Biedermann et al., 2018; Yan et al., 2021). The current study's design also takes into consideration Kyoung's (2020) results that show that lyrical music, which is comparable to irrelevant speech according to Zhang et al. (2018) and Vasilev et al. (2018), was found to lead to a reduction in evoked brain potentials when comparing to silence. This suggests that the orthographic and syntactic processing of the text might be disrupted in the reader.

Yan et al. (2018) presented evidence that the irrelevant speech effect not only exists on sentence but also on word level, previously doubted because of results from studies with less exact measurements. The present work will extend the research about distraction by different noise environments on word level.

This design will be the first one to investigate the pseudohomophone advantage effect in a Swedish language context and combine that with different acoustic environments. Swedish is special in that its orthography is shallow meaning that the grapheme-phoneme mapping is quite regular, compared to other languages like English (Venezky, 1995). This makes it a good language to research the role of phonology in reading in different acoustic environments. It will furthermore on a theoretical level describe the interaction between the visual and linguistic system in an in depth way due to the nature of eye tracking methodology.

H1: Reading times (total fixation duration) will be longer in the noise condition (babble noise) than in the silence condition.

H2: A pseudohomophone advantage effect can be seen in the measures of total fixation duration, first fixation duration, rereading duration and number of fixations

Exploratory H3: The pseudohomophone advantage effect is influenced by the two different noise conditions

## Method

### Participants

Participants were 38 Swedish natives and had a mean age of 27.5, 44.7% were female. Participants with dyslexia were excluded from participation. They were recruited through personal contacts of the author as well as social media. As a reward, participants received coffee and a cinnamon bun.

**Equipment & Materials**

HumLab at Lund university provided the Tobii Pro Spectrum eye tracker, Tobii Pro Lab software (Tobii AB, 2023) as well as additional equipment like over ear headphones, chin and forehead rest that were used for the experiment. The Tobii Pro Spectrum eye tracker was used to record the data at a rate of 600 Hz. Stimuli were presented on a Eizo 24 inch 1920x1080 screen. The screen was placed at a 60 cm distance from the participant's eye.

Acoustic stimuli that was presented to the participants was a babble noise, where several children's voices talked at the same time which made it difficult to follow and semantically understand the utterances. The audio was presented at a volume of 70 db which corresponds to a busy restaurant.

All text was presented in the Courier New font with a font size of 48 (corresponding 13.3089° to 28.0725° of visual angle) in black (#0000) on gray background (#D3D3D3).

**Design & Procedure**

The current study was a 2x2 design with the between dimension of acoustic environment (silence & babble noise) and the within participant dimension of spelling (pseudohomophone spelling & unrelated spelling).

These target words were placed at either the beginning or middle and never at the end of the sentence in order to be able to clearly identify refixations on the target word (leading the gaze back to the target word even though one had continued reading already). Each target word was presented three times, each time in a different spelling condition and embedded in a different sentence in order to avoid rereading effects. This resulted in nine different combinations of condition and sentence. For every three sentences with target words a filler sentence without a target word, which also means without any misspellings, was added in order to lower the participants' expectation of reading misspelled words (complete overview can be found in the appendix). Target words that were chosen were medium to high frequency words, measured by the Zipf value in order to ensure that words would be understood despite the misspellings (van

Heuven et al., 2014; Witte & Köbler, 2019). A visual example for how a sequence of the experiment is displayed in figure 1.

**Figure 1**

*Example of experiment sequence*


A pseudohomophone advantage effect, as named in hypothesis two would be demonstrated when participants take longer to process the target words in the unrelated spelling conditions compared to those in the pseudohomophone spelling condition. This increase in necessary processing is operationalized by longer total fixation duration, longer first fixation duration, more fixations and longer rereading duration. The interaction between the pseudohomophone advantage effect and the noise conditions as described in hypothesis three would be observed if the difference in processing duration would differ between participants that complete the experiment in the babble noise and in the silence condition.

Before the experiment started, participants were asked to read and sign informed consent as well as fill in demographic data. Participants were then asked to adjust the table and the chin and forehead rest to their liking and given the instructions to the experiment orally. These included that participants were to read a number of sentences which included words that were misspelled but that participants should try to read the sentences as normal and to try to understand each word even when they're misspelled. This was done because task instruction is known to alter reading behavior (Cole et al., 2011). All participants were asked to put on headphones. For half of the participants the babble noise was played on the headphones after they were done with reading the instructions as well as completing the example sentence. The half of the participants that were in the silent condition wore the headphones so that outside noise could be canceled out and that silence could be ensured.

After that, the participants did a 5-point calibration for the eye tracker in order to ensure good data quality. For the calibration of the eye tracker, the experimenter checked if the accuracy is within smaller than 1° of visual angle. Instructions that were given orally were now also presented in written form on the screen and after the participant completed an example sentence with understanding check, the rest of the sentences followed and at that point participants that were in the noise condition started listening to the acoustic stimuli. During the whole experiment participants proceeded at their own speed by using the space bar when moving on the next sentence. Depending on each participant's reading speed the experiment took around five to ten minutes to complete. After completion participants were thanked for their contribution and given the reward of coffee and a cinnamon bun. Also, participants were offered to learn more about the purpose of the experiment.

**Materials & Measures**

Stimuli were sentences in the Swedish language that each include one target word. In total participants were presented with 108 sentences, 81 of which included target words. The target words themselves are always three spelling variations of one original word (e.g. kalender) and include a spelling that is similar in phonology (qalender - ka'lɛndər) , a spelling that dissimilar in phonology (lalender - 'la'lɛndər) and the original spelling (kalender - ka'lɛndər). Target words could be nouns, verbs or adjectives and the positioning of the varying letter varied as well. Sentences were presented to the participant one by one and the participant moved forward at their own pace using the space key to indicate that they are ready to proceed with the next sentences.

In pursuance of keeping participant attention up and of testing that participants understand the semantic meaning of the target words even when these were misspelled, an understanding check was added after some sentences. This check consisted of indicating which one of three pictures shown to the participant was related to the target word in the sentence that the participant had just read.

**Data Analysis**

Eye tracking measures included first fixation duration, total fixation durations, rereading duration and number of fixations on the target word. All of the duration measures excluded extremely short fixations (<80ms) because these are most likely a result of blinking or accidental fixations and do not contribute to explaining the variance created by the different conditions. Total fixation duration was used to determine if readers are distracted by the noise condition to the extent that their processing is slowed down (H1), as this measure determines the overall time a reader took to process. In order to make for a simple comparison with the models for the second and the third hypothesis, only reading time of the target words was used even though the effect of noise condition is expected to appear on a sentence level. For the second and third hypothesis, which concern the pseudohomophone advantage effect, the four measures of total fixation duration, first fixation duration, rereading duration and number of fixations were utilized. First fixation duration was used to determine if the effect appears prelexically while total fixation duration, rereading duration as well as number of fixations serve to determine if the effect appears post lexical processing. Because the pseudohomophone advantage effect revolves around if the processing of the two misspelled conditions differ from the original spelling conditions, the measures used in the model will be the differences between the original spelling and the respective misspelled condition for all three eye tracking measures named above.

To analyze the data linear mixed effect models (LMEM) were applied using the GAMLj module within the jamovi software (The jamovi project, 2022; R Core Team, 2021; Gallucci, 2019). This approach was chosen over an ANOVA which is the method typically used to analyze data with categorical independent variables because the low sample size would violate the assumptions of normal distribution in each condition, homogeneity of variances. Moreover, LMEM was applied because it makes it possible to avoid adding all the data to averages which is especially important for the current study because the stimuli that were directly compared were embedded into different sentences in order to avoid rereading effect which would have affected the dependent variables of fixation times as well as rereading duration (Rayner, 1995, Xue, 2020). Restricted maximum likelihood strategy was chosen in order to avoid bias regarding the estimates that are associated with the maximum likelihood method of estimation.

### Ethics

Within this study ethics were considered at every step of the procedure. Eye tracking is non-invasive and because this study makes use of screen-based eye trackers, the participants do not notice any impact of the aperture. Prior to the experiment, participants were given oral and written information about how they are at any time and without mentioning of reasons able to leave the experiment, what the purpose and aim of the study is, how the experiment worked and how their data was saved. All participants gave informed consent before starting the experiment. Participants were exposed to a number of sentences which they were told to read and understand, some while listening to an audio which by many participants described as “annoying and highly distracting”. The task as well as the conditions that the task was to be performed in are common occurrences to all participants and were therefore not seen as ethically concerning.

Considering the magnitude of reading in today's society and noisy environments being a part of a big number of common study environments like cafés and even classrooms, the minor inconveniences, which all participants also experience in everyday life, are outweighed by the contribution to the field of reading research that the results of this work provide.

## Results

The check up picture task was answered correctly in 96.9% of all tasks. After finishing the experiment, participants were asked about difficulties. Participants that failed to give the correct answer in the check up questions stated that this was due to not recognizing the pictures, mostly of the target word “vanilj" and not because of a lack of understanding of the target words. Due to difficulties regarding the eye tracking software, this target word was excluded from the final analyses regardless.

Prior to the computation of the LMEMs, assumptions of linearity, constant variance of residuals, independence of residuals and normal distribution of residuals were checked for each of the dependent variables. All figures regarding the assumptions of the LMEMs can be found in the appendix. The assumption of linearity was partially met, the author judged them as sufficient in order to apply the LMEMs. For normality of residuals, the Kolmogorov-Smirnov test was significant for all models revealing a non-normal data distribution. When looking at the Q-Q plots, the distribution can be seen as good enough despite the significant test. Although some of the assumptions are only partially met, LMEMs seem to be quite robust against assumption violations (Schielzeth et al., 2020). All figures regarding assumptions for the LMEMs can be found in the appendix.

As the dependent variable for the model to investigate the first hypothesis, raw fixation duration values were used instead of the differences between original and manipulated spelling conditions as used for the models in hypothesis one. This is because in this hypothesis only the general effect of the condition is investigated irrespective of spelling.

The model reached the best model fit of *AIC* = 46546.16 with noise conditions as a fixed factor and participants as random intercepts and reached an effect size of $R^2$= .132. As the significance level for noise condition is $p$ = .215 and the 95% confidence interval crosses 0, the babble noise did not affect total fixation duration of the target words in a significant way. It follows that hypothesis one has to be rejected. Further results of the analysis can be found in table 1 below.

**Table 1**

*Fixed Effects Parameter Estimates for Total Fixation Duration*

| | | | | 95% Confidence Interval | | | | |
|---|---|---|---|---|---|---|---|---|
| Names | Effect | Estimate | *SE* | Lower | Upper | *df* | *t* | *p* |
| (Intercept) | (Intercept) | 486.8 | 29.6 | 428.8 | 545 | 36.0 | 16.45 | < .001 |
| NOISE1 | 1 - 0 | 74.7 | 59.2 | -41.3 | 191 | 36.0 | 1.26 | 0.215 |

*Note.* Noise 1 corresponds to babble noise and Noise 0 corresponds to silence.

In order to analyze the second hypothesis, differences between the original spelling condition and the two misspelling conditions were computed so that the measures depict the differences between the conditions and the original spelling.

For each of the models for the dependent variables of total fixation duration, first fixation duration and number of fixation the best model fit was achieved with fixed effects including noise, spelling conditions and their interaction, random effects included random intercepts for participants and stimuli, random slopes for noise conditions across stimuli, and random slopes for spelling conditions across participants. The model for rereading duration achieved the best fit with spelling and noise condition including their interaction as well as participant and stimuli as random intercepts but no random slopes.

The model with differences in total fixation duration as dependent variable reached a modelfit of *AIC* = 28991.67 with an effect size of $R^2$ = .11. Results show that spelling conditions had a significant effect on total fixation duration ($p$ < .001). The pseudohomophone spelling showed a smaller deviation from the original spelling than the unrelated spelling condition ($b$ = 159.4, 95% *CI* [72.6, 246.2]). Thereby, the data provides evidence in favor of the second hypothesis regarding total fixation duration.

Noise conditions did not show significance on either the scores of differences between misspelled conditions ($p$ = .742) nor in interaction with the spelling conditions ($p$ = .383). Hypothesis three has to be rejected regarding total fixation duration. Further results of the analysis can be found in table 2 below.

**Table 2**

*Fixed Effects Parameter Estimates for Differences in Total Fixation Duration*

| | | | | 95% Confidence Interval | | | | |
|---|---|---|---|---|---|---|---|---|
| Names | Effect | Estimate | *SE* | Lower | Upper | *df* | *t* | *p* |
| (Intercept) | (Intercept) | -179.4 | 29.1 | -236.4 | -122.3 | 53.0 | -6.164 | < .001 |
| SPELLING1 | 1 - 0 | 159.4 | 44.3 | 72.6 | 246.2 | 51.3 | 3.599 | < .001 |
| NOISE1 | 1 - 0 | -16.5 | 49.7 | -114.0 | 81.0 | 38.5 | -0.332 | 0.742 |
| SPELLING1 ✻ NOISE1 | 1 - 0 ✻ 1 - 0 | 56.9 | 64.7 | -69.9 | 183.7 | 59.8 | 0.879 | 0.383 |

*Note.* Noise 1 corresponds to babble noise and Noise 0 corresponds to silence. Spelling 1 corresponds to pseudohomophone spelling and Spelling 0 corresponds to unrelated spelling.

The model with differences in first fixation duration as dependent variable reached a modelfit of *AIC* = 19998.91 and an effect size of $R^2$ = .04. For this model neither spelling (*p* = .247) nor noise conditions (*p* = .814) or interaction between the factors (*p* = .781) were found to have significant effect on the difference in first fixation duration of the target words. It follows that hypotheses two and three are rejected regarding first fixation duration. Further results of the analysis can be found in table 3 below.

**Table 3**

*Fixed Effects Parameter Estimates for Differences in First Fixation Duration*

| Names | Effect | Estimate | *SE* | 95% Confidence Interval Lower | 95% Confidence Interval Upper | *df* | *t* | *p* |
|---|---|---|---|---|---|---|---|---|
| (Intercept) | (Intercept) | -19.36 | 4.93 | -29.01 | -9.70 | 38.5 | -3.929 | < .001 |
| SPELLING1 | 1 - 0 | 10.25 | 8.74 | -6.88 | 27.37 | 43.0 | 1.173 | 0.247 |
| NOISE1 | 1 - 0 | -1.97 | 8.29 | -18.21 | 14.27 | 28.2 | -0.238 | 0.814 |
| SPELLING1 ✻ NOISE1 | 1 - 0 ✻ 1 - 0 | -3.88 | 13.84 | -31.00 | 23.25 | 39.7 | -0.280 | 0.781 |

*Note*. Noise 1 corresponds to babble noise and Noise 0 corresponds to silence. Spelling 1 corresponds to pseudohomophone spelling and Spelling 0 corresponds to unrelated spelling.

The model with differences in number of fixations as dependent variable reached a modelfit of $AIC$ = 8028.57 with an effect size of $R^2$ = .09. For this model results show that spelling was again a significant predictor for difference in number of fixations ($p$ = .001) but not the other factors of noise conditions ($p$ = .557) nor the interaction between the two factors ($p$ = .630). The pseudohomophone spelling showed a smaller deviation from the original spelling than the unrelated spelling condition ($b$ = .53, 95% *CI* [.22, .83]). Thereby, the data provides evidence in favor of the second hypothesis regarding number of fixations. Hypothesis three has to be rejected regarding number of fixations. Further results of the analysis can be found in table 4 below.

**Table 4**

*Fixed Effects Parameter Estimates for Differences in Number of Fixations*

| | | | | 95% Confidence Interval | | | | |
|---|---|---|---|---|---|---|---|---|
| Names | Effect | Estimate | *SE* | Lower | Upper | *df* | *t* | *p* |
| (Intercept) | (Intercept) | -0.6071 | 0.0992 | -0.802 | -0.413 | 53.1 | -6.118 | < .001 |
| SPELLING1 | 1 - 0 | 0.5266 | 0.1559 | 0.221 | 0.832 | 49.4 | 3.377 | 0.001 |
| NOISE1 | 1 - 0 | -0.0958 | 0.1616 | -0.413 | 0.221 | 36.9 | -0.593 | 0.557 |
| SPELLING1 ✻ NOISE1 | 1 - 0 ✻ 1 - 0 | 0.1016 | 0.2102 | -0.311 | 0.514 | 86.5 | 0.483 | 0.630 |

*Note.* Noise 1 corresponds to babble noise and Noise 0 corresponds to silence. Spelling 1 corresponds to pseudohomophone spelling and Spelling 0 corresponds to unrelated spelling.

The model with differences in rereading duration as dependent variable reached a modelfit of *AIC* = 27210.96 with an effect size of $R^2$ = .01. For this model results show that neither spelling (*p* = .348) nor noise conditions (*p* = .967) nor their interaction (*p* = .947) were significant predictors for difference in rereading duration. Thereby, the data provides evidence which leads to a rejection of the second and third hypothesis regarding rereading duration. Further results of the analysis can be found in table 5 below.

**Table 5**

*Fixed Effects Parameter Estimates for Differences in Rereading Duration*

| | | | | 95% Confidence Interval | | | | |
|---|---|---|---|---|---|---|---|---|
| Names | Effect | Estimate | *SE* | Lower | Upper | *df* | *t* | *p* |
| (Intercept) | (Intercept) | -13.416 | 11.9 | -36.8 | 9.92 | 26.3 | -1.1268 | 0.270 |
| SPELLING1 | 1 - 0 | 19.399 | 20.5 | -20.7 | 59.50 | 46.9 | 0.9481 | 0.348 |
| NOISE1 | 1 - 0 | 0.720 | 23.4 | -45.1 | 46.53 | 35.7 | 0.0308 | 0.976 |
| SPELLING1 ✻ NOISE1 | 1 - 0 ✻ 1 - 0 | -2.656 | 39.9 | -80.9 | 75.54 | 1734.5 | -0.0666 | 0.947 |

*Note.* Noise 1 corresponds to babble noise and Noise 0 corresponds to silence. Spelling 1 corresponds to pseudohomophone spelling and Spelling 0 corresponds to unrelated spelling.

Summarizing for hypothesis two, eye tracking measures of total fixation duration as well as number of fixations provide evidence in favor of the second hypothesis while the results from first fixation duration as a measure leads to a rejection of the hypothesis. Regarding the third hypothesis, none of three eye tracking measures analyzed showed significant influence by noise conditions nor interaction with spelling conditions.

# Discussion

## Discussion Hypothesis 1

This work investigated the reading process during acoustic distraction and the role that phonological encoding has in it. The audio stimulus that was chosen as a distraction was described as very distracting by most participants in that condition, still, data for total fixation duration of the target words did not differ between the participants who read the sentences in complete silence and the ones that had noise distraction. As the audio stimulus was a "babble noise" that contained the participants' native language but was modified in a way that the participants could not follow the discourse of what was being said. It follows that the isolated

factor of language interference did not play a significant role in distraction. This is further discussed in regard to the theoretical approaches of acoustic distraction in the discussion for the third hypothesis in order to integrate the all results.
Regarding working memory capacity, the results point to the fact that the babble noise did not take up capacities needed for the reading process indicating that the babble noise was processed on a different level of language processing as the written text. Alternatively, the non-distraction in the results can be explained by the babble noise drawing very little attentional resources. This is however unlikely as many participants commented on how "annoying" and "attention-grabbing" the babble noise was.

Vasilev and colleagues (2018) named in their meta analysis that increased task engagement can decrease the distraction by speech noise. Even though the studies that found these effects looked at a *n*-back task, it should be considered that syntactic complexity of the sentences was not controlled for in the current work (Sörqvist & Marsh, 2015). Therefore, it is possible that the variation in syntactic complexity affected the distraction caused by the noise condition in a way that masked its effect.

**Discussion Hypothesis 2**

Recorded data provided first evidence for the existence of the pseudohomophone advantage effect in the Swedish language. Though, the pseudohomophone spelling condition only showed an advantage in processing when looking at the measure of total fixation duration and number of fixations. The other measures of first fixation duration and rereading duration did not turn out to be significantly affected by the spelling condition. This makes it difficult to make a final judgment regarding the second hypothesis as a whole. With the results from the current study, it remains unclear in which phase of lexical processing the phonological decoding takes place. This non-significant result for the measure of early processing is rather surprising because prior research has established that phonological codes are extracted in the early rather than later processing (Pollatsek et al., 2000). When expanding the research about the pseudohomophone advantage effect, researchers should therefore include more measures that investigate early processing, for example gaze duration which measures the duration of all fixations that were made in one word before the eyes move on to the next word. Looking at the differences in rereading duration, results show however that readers process the misspelled words when they first read them and then move on. It can be inferred that the phonological code might not be processed in the very first fixation but possibly in the first gaze, which includes all fixations within a word before the reader moves on to the next one. It is also possible that misspellings were overlooked because of a highly automated reading process and refixations were simply not necessary.

Additionally, future work should revise the target words and of the composition of the sentences the stimuli were embedded in has to be made. For this revision spillover effects have to be paid extra close attention to.

Furthermore, as many adults have a highly automatized reading process due to orthographic learning and a well-developed prediction ability, even though subvocalization still exists in adult readers it does to a smaller extent compared to less skilled readers, especially those still in their phase of reading acquisition (Castles et al., 2018). That is why the results for the pseudohomophone advantage effect have to be complemented by studies with a different population, for example children or adults with low reading skills. When studying skilled adult readers, the reading task could include reading the sentences out loud instead of silent reading, this could make the effect more prominent.

What could further be of interest regarding the specifics of the pseudohomophone advantage effect is the position of the misspelling within the target word. Participants mentioned that misspellings were more difficult to process when the incorrect letter was in the beginning of the word compared to in the middle. This might be related to and could possibly be explained by the research about the significance of letter position in word comprehension which suggests that if only the first and last letter of a word are correct, the order of the letters in between has little to no effect on readers' processing (Lupker & Perea, 2003). However, this research assumed that all the letters in between are still correct and merely the order of them is changed. Still, this research presents evidence that first and last letters are more important in the reading process which is why it should be included as a factor in further research.

**Discussion Hypothesis 3**

As in the model for the first hypothesis, the models for the third hypothesis do not provide evidence that the noise condition had a significant effect on neither the general reading process nor the phonological decoding. Just as in the model for the first hypothesis, the results could be biased or masked by a number of factors within the stimuli, the design or the participants.

The main question of how noise can affect the reading process cannot be answered in a direct way because there was simply no observed distraction in the data. Nevertheless, some conclusions can in fact be drawn from the non-significant results. When transferring this back to the theoretical approaches of auditory distraction, the phonological-interference hypothesis does not fit the results as it states that all language sounds should negatively affect the reading process. This is in line with a number of other studies investigating the influence of noise distraction (Hyönä & Ekholm, 2016; Vasilev et al., 2018). At the same time, the non-significant results suggest that the semantic-interference hypothesis describes auditory distraction more accurately. Experiments by Martin and colleagues showed that intelligible language is more distracting than non-intelligible language and that acoustic streams of words are more distracting than non-words (Martin et al., 1988). This led them to the semantic-interference hypothesis which describes that it is not language sounds that interfere with the reading process but the semantics of the stimuli. At this point, it is very important to note that it is not sufficient to provide evidence for this hypothesis in the form of explaining why distraction effects do not appear. On the contrary, the hypothesis describes explanations for the existence of distraction. Albeit, because the current study only includes one noise condition besides silence it is not possible to make any final conclusions regarding the semantic-interference hypothesis because of lack of manipulation and therefore comparison of different levels of semantic content.

This also applies to the duplex hypothesis of distraction because there simply were no distraction effects observed, so they cannot be accounted for by taking up neither attention nor process capacities.

## General Discussion

The current work is the first one to provide empirical evidence for the existence of the pseudohomophone effect in the Swedish language, which also suggests that the effect might be inherent to languages with a shallow orthography such as German or Finnish. Still, more research is needed to gather empirical evidence for the respective languages.

As discussed in the introduction, fixation duration is influenced by a number of factors. These include factors such as word frequency and word length of the target word but also of the word prior to the target word. In order to avoid rereading effects in this study, it was not possible to present the exact same sentence to the participant in all three spelling conditions for one target word. The consequence of this was that the word prior to the target word varied slightly in the three conditions. Though the author tried to keep the words prior to the target words as high frequency and short as possible, the influence of the differences in prior words contributes to a higher variance that cannot be explained by the models. With regards to the target word themselves, future research about the pseudohomophone advantage effect has to pay special attention to the orthographic similarities in the misspelled conditions. Often, letters that sound similar look similar, for example “g” and “j” in Swedish. This could have the effect that the pseudohomophones are processed quicker not because of their phonological similarity with the original spelling but because of the orthographic one.

Another factor that specifically affects the phonological processing, more specifically the reliance on the phonological loop, is the syntactic complexity, which also, due to the different sentences for the three spelling conditions, varied despite efforts to make the complexity as similar as possible within the group of sentences for one target word (Cauchard, 2012; Vasilev, 2018).

The current work contributes to the state of research of phonological processing as well as noise distraction and complements already existing research because the target words were embedded in a sentence context which made the reading task close to natural reading scenarios. This has, as discussed, disadvantages regarding the many influences of the sentence on the target word. Still, in order to make the reading task even closer to a natural reading scenario, future studies should include embedment not only in sentences but in a whole text while applying a high control of the lexical properties of the words surrounding the target words and of the syntactic complexity.

When investigating distraction by noisy environments, some studies suggest that not only what environment a person is exposed to but also what personality that person has (Cassidy & MacDonald, 2007; Furnham & Allass, 1999). The theoretical considerations by Eysenk (1967) suggests that extraverted people are less distracted by noisy environments independent of what kind of noise while introverted individuals are more easily distracted by any kind of noisy environment. According to Eysenk’s theory of dimensions of personality this is because introverts and extroverts differ in how much external stimulation is needed to read a point of optimal arousal for cognitive processing, extraverts needing more (Eysenck & Zuckerman, 1978). Newer research however, cannot replicate these effects (Oseland & Hodsman, 2020; Gheewalla et al., 2021). The variables of personality were not part of the current study because of the different focus and in aim of keeping the experiment procedure short due to the difficult nature of recruiting large samples for eye tracking studies. Still, it cannot be ruled out that the results could not partly be explained when adding personality dimensions, possibly in interaction with the effects of syntactic complexity which increases arousal.

As for implications for real life reading contexts, the current results suggest that when readers only can extract a limited amount of semantic content from the distracting noise, that this does not inhibit the reading process regarding processing speed. This means that reading or studying in a café or in a busy area can be done efficiently, as long as the reader is not able to extract discourse from the distracting noise, understanding individual words or phrases do not seem to be negatively affecting the reader.

The current work is the first one to provide empirical evidence for the pseudohomophone advantage effect in the Swedish language. While more extensive research is needed for the effect, it can now be used as a scientific tool to investigate the use of phonological encoding. Further, the data presented showed that noise distraction in the form of babble noise did not have influence on reading speed. This indicates different attentional or procedural working memory capacities for the two tasks of listening to the babble noise and reading sentences even though they both revolve around language processing.

## References

Alasim, K. N., & Alqraini, F. M. (2020). Do d/Deaf and Hard of Hearing Children Need Access to a Spoken Phonology to Learn to Read? A Narrative Meta-Analysis. *American Annals of the Deaf*, *164*(5), 531–545. https://www.jstor.org/stable/26983915

Baddeley, A. D., & Hitch, G. J. (1994). Developments in the concept of working memory. *Neuropsychology, 8*(4), 485–493. https://doi.org/10.1037/0894-4105.8.4.485

Banbury, S. P., Macken, W. J., Tremblay, S., & Jones, D. M. (2001). Auditory Distraction and Short-Term Memory: Phenomena and Practical Implications. *Human Factors*, 43(1), 12–29. https://doi.org/10.1518/001872001775992462

Bélanger, N. N., Mayberry, R. I., & Rayner, K. (2013). Orthographic and Phonological Preview Benefits: Parafoveal Processing in Skilled and Less-Skilled Deaf Readers. *Quarterly Journal of Experimental Psychology*, 66(11), 2237–2252. https://doi.org/10.1080/17470218.2013.780085

Bélanger, N. N., Baum, S. R. & Mayberry, R. I. (2012). Reading Difficulties in Adult Deaf Readers of French: Phonological Codes, Not Guilty!, *Scientific Studies of Reading*, 16:3, 263-285, https://doi.org/10.1080/10888438.2011.568555

Blythe, H. I., Dickins, J. H., Kennedy, C. R., & Liversedge, S. P. (2018). Phonological processing during silent reading in teenagers who are deaf/hard of hearing: An eye movement investigation. *Developmental science*, 21(5), e12643. PMID: 29356239.

Boyle, R., & Coltheart, V. (1996). Effects of Irrelevant Sounds on Phonological Coding in Reading Comprehension and Short term Memory. *The Quarterly Journal of Experimental Psychology Section A*, 49(2), 398–416. https://doi.org/10.1080/713755630

Brysbaert, M., Stevens, M., Mandera, P., & Keuleers, E. (2016). How many words do we know? Practical estimates of vocabulary size dependent on word definition, the degree of language input and the participant's age. *Frontiers in psychology*, *7*, 1116. https://doi.org/10.3389/fpsyg.2016.01116

Cassidy, G., & MacDonald, R. A. R. (2007). The effect of background music and background noise on the task performance of introverts and extraverts. *Psychology of Music*, 35(3), 517–537. https://doi.org/10.1177/0305735607076444

Castles, A., Rastle, K., & Nation, K. (2018). Ending the reading wars: Reading acquisition from novice to expert. *Psychological Science in the Public Interest, 19*, 5–51. https://doi.org/10.1177/1529100618772271

Cauchard, F., Cane, J. E., & Weger, U. W. (2012). Influence of background speech and music in interrupted reading: An eye‐tracking study. *Applied Cognitive Psychology*, *26*(3), 381-390. https://doi.org/10.1002/acp.1837

Clifton Jr, C., Ferreira, F., Henderson, J. M., Inhoff, A. W., Liversedge, S. P., Reichle, E. D., & Schotter, E. R. (2016). Eye movements in reading and information processing: Keith Rayner's 40 year legacy. *Journal of Memory and Language*, *86*, 1-19. https://doi.org/10.1016/j.jml.2015.07.004

Cole, M. J., Gwizdka, J., Liu, C., Bierig, R., Belkin N. J. & Zhang, X. (2011). Task and user effects on reading patterns in information search. *Interacting with Computers*, *23*(4), 346-362. https://doi.org/10.1016/j.intcom.2011.04.007

Colle, H. A., & Welsh, A. (1976). Acoustic masking in primary memory. *Journal of verbal learning and verbal behavior*, *15*(1), 17-31.

Cowan, N. (2014). Working Memory Underpins Cognitive Development, Learning, and Education. *Educational Psychology Review*, 26, 197–223. https://doi.org/10.1007/s10648-013-9246-y

Cripps, J. H., McBride, K. A., & Forster, K. I. (2005). Lexical processing with deaf and hearing: Phonology and orthographic masked priming. *Journal of Second Language Acquisition and Teaching*, *12*, 31-44.

Eilers, S., Tiffin-Richards, S. P., & Schroeder, S. (2019). The repeated name penalty effect in children's natural reading: Evidence from eye tracking. *Quarterly Journal of Experimental Psychology*, 72(3), 403–412. https://doi.org/10.1177/1747021818757712

Engbert, R., Longtin, A., & Kliegl, R. (2002). A dynamical model of saccade generation in reading based on spatially distributed lexical processing. *Vision research*, *42*(5), 621-636. https://doi.org/10.1016/S0042-6989(01)00301-7

Eysenck, H. J. (1967). Personality and extra-sensory perception. *Journal of the Society for Psychical Research, 44*(732), 55–71.

Furnham, A., & Allass, K. (1999). The influence of musical distraction of varying complexity on the cognitive performance of extroverts and introverts. *European Journal of Personality*, *13*(1),27-38. https://doi.org/10.1002/(SICI)1099-0984(199901/02)13:1%3C27::AID-PER318%3E3.0.CO;2-R

Gallucci, M. (2019). *GAMLj: General analyses for linear models*. [jamovi module]. Retrieved from https://gamlj.github.io/.

Gheewalla, F., McClelland, A. & Furnham, A. (2021). Effects of background noise and extraversion on reading comprehension performance, *Ergonomics*, *64*(5), 593-599. https://doi.org/10.1080/00140139.2020.1854352

Henderson, J. M., & Ferreira, F. (1990). Effects of foveal processing difficulty on the perceptual span in reading: Implications for attention and eye movement control. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 16*(3), 417–429. https://doi.org/10.1037/0278-7393.16.3.417

Hughes, R. W. (2014). Auditory distraction: A duplex‐mechanism account. *PsyCh Journal*, *3*(1), 30-41. https://doi.org/10.1002/pchj.44

Hyönä J, Ekholm M (2016) Background Speech Effects on Sentence Processing during Reading: An Eye Movement Study. *PLoS ONE 11*(3): e0152133. https://doi.org/10.1371/journal.pone.0152133

Häikiö, T., Bertram, R., Hyönä, J., & Niemi, P. (2009). Development of the letter identity span in reading: Evidence from the eye movement moving window paradigm. *Journal of experimental child psychology*, *102*(2), 167-181. https://doi.org/10.1016/j.jecp.2008.04.002

Jason J. S. Barton, Hashim M. Hanif, Laura Eklinder Björnström & Charlotte Hills (2014) The word-length effect in reading: A review. *Cognitive Neuropsychology*, *31*(5-6), 378-412, https://doi.org/10.1080/02643294.2014.895314

Klatte, M., Bergström, K., & Lachmann, T. (2013). Does noise affect learning? A short review on noise effects on cognitive performance in children. *Frontiers in psychology*, *4*, 578. https://doi.org/10.3389/fpsyg.2013.00578

Klatte, M., Spilski, J., Mayerl, J., Möhler, U., Lachmann, T., & Bergström, K. (2017). Effects of Aircraft Noise on Reading and Quality of Life in Primary School Children in Germany:

Results From the NORAH Study. *Environment and Behavior*, 49(4), 390–424. https://doi.org/10.1177/0013916516642580

Kyoung, E. (2020). The effect of lyrical and non-lyricalbackground music on different types of language pro-cessing - An ERP study. *Korean Journal of CognitiveScience*, 31(4), 155–178. https://doi.org/10.19066/cogsci.2020.31.4.003

Li, X., & Pollatsek, A. (2020). An integrated model of word processing and eye-movement control during Chinese reading. *Psychological Review*, *127*(6), 1139–1162. https://doi.org/10.1037/rev0000248

Lupker, S., & Perea, M. (2003). Transposed-letter confusability effects in masked form priming. In S. Kinoshita & S. J. Lupker (Eds.), *Masked priming: State of the art* (pp.97-120). Hove, U.K.: Psychology Press.

Martin, R. C., Wogalter, M. S., & Forlano, J. G. (1988). Reading comprehension in the presence of unattended speech and music. *Journal of memory and language*, *27*(4), 382-398. https://doi.org/10.1016/0749-596X(88)90063-0

Maxwell, L. E., & Evans, G. W. (2000). The effects of noise on pre-school children's pre-reading skills. *Journal of environmental Psychology*, *20*(1), 91-97. https://doi.org/10.1006/jevp.1999.0144

McConkie, G.W., Rayner, K. The span of the effective stimulus during a fixation in reading. *Perception & Psychophysics 17*, 578–586 (1975). https://doi.org/10.3758/BF03203972

Miellet, S. & Sparrow, L. (2004). Phonological codes are assembled before word fixation: Evidence from boundary paradigm in sentence reading. *Brain and language*, *90*(1-3), 299-310. https://doi.org/10.1016/S0093-934X(03)00442-5

Morrison, R. E. (1984). Manipulation of stimulus onset delay in reading: Evidence for parallel programming of saccades. *Journal of Experimental Psychology: Human Perception and Performance, 10*(5), 667–682. https://doi.org/10.1037/0096-1523.10.5.667

Oseland, N., Hodsman, P. (2020). The response to noise distraction by different personality types : an extended psychoacoustics study. *Corporate Real Estate Journal, 9*(3), 215–233.

Pollatsek, A., Rayner, K., & Lee, H. W. (2000). Phonological coding in word perception and reading. In *Reading as a perceptual process* (399-425). North-Holland. https://doi.org/10.1016/B978-008043642-5/50019-X

Płużyczka, M. (2018). The first hundred years: A history of eye tracking as a research method. *Applied Linguistics Papers*, *25*(4), 101-116.

Purves, D., Brannon, E. M., Cabeza, R., Huettel, S. A., LaBar, K. S., Platt, M. L., & Woldorff, M. G. (2013). *Principles of cognitive neuroscience*. Sunderland: Sinauer Associates.

R Core Team (2021). *R: A Language and environment for statistical computing*. (Version 4.1) [Computer software]. Retrieved from https://cran.r-project.org. (R packages retrieved from MRAN snapshot 2022-01-01).

Raney, G. E., & Rayner, K. (1995). Word frequency effects and eye movements during two readings of a text. *Canadian Journal of Experimental Psychology / Revue canadienne de psychologie expérimentale, 49*(2), 151–173. https://doi.org/10.1037/1196-1961.49.2.151

Rayner, K. (1998b). Eye movements in reading and information processing: 20 years of research. *Psychological Bulletin, 124*(3), 372–422. https://doi.org/10.1037/0033-2909.124.3.372

Rayner K. (2009a). Eye Movements in Reading: Models and Data. *Journal of eye movement research*, *2*(5), 1-10. PMCID: PMC2906818

Rayner, K. (2009b). The 35th Sir Frederick Bartlett Lecture: Eye movements and attention in reading, scene perception, and visual search. *Quarterly Journal of Experimental Psychology*, 62(8), 1457–1506. https://doi.org/10.1080/17470210902816461

Rayner, K., Duffy, S.A. (1986). Lexical complexity and fixation times in reading: Effects of word frequency, verb complexity, and lexical ambiguity. *Memory & Cognition* 14, 191–201. https://doi.org/10.3758/BF03197692

Rayner, K., Reichle, E. D. & Pollatsek, A. (1998a). Eye movement control in reading: an overview and model. In G. Underwood, Eye guidance in reading and scene perception (243–268). Oxford, UK: Elsevier

Reichle, E. D., Pollatsek, A., Fisher, D. L., & Rayner, K. (1998). Toward a model of eye movement control in reading. *Psychological Review, 105*(1), 125–157. https://doi.org/10.1037/0033-295X.105.1.125

Reichle, E. D. (2021). *Computational models of reading: A handbook*. Oxford University Press.

Schielzeth, H., Dingemanse, N. J., Nakagawa, S., Westneat, D. F., Allegue, H., Teplitsky, C., Réale, D., Dochtermann, N. A., Garamszegi, L. Z. & Araya‐Ajoy, Y. G. (2020).

Robustness of linear mixed‐effects models to violations of distributional assumptions. *Methods in ecology and evolution*, *11*(9), 1141-1152. https://doi.org/10.1111/2041-210X.13434

Schmalz, X., Marinus, E., Coltheart, M., & Castles, A. (2015). Getting to the bottom of orthographic depth. *Psychonomic bulletin & review*, *22*, 1614-1629. https://doi.org/10.3758/s13423-015-0835-2

Sperlich, A., Schad, D. J. & Laubrock, J. (2015) When preview information starts to matter: Development of the perceptual span in German beginning readers. *Journal of Cognitive Psychology*, *27*(5), 511-530. https://doi.org/10.1080/20445911.2014.993990

Spilski, J., Bergstrom, K., Mayerl, J., Mohler, U., Lachmann, T., & Klatte, M. (2017). The relationship between aircraft noise and reading: Mediator and moderator effects. In *Proceedings of the 12th ICBEN Congress on Noise as a Public Health Problem, Zurich, Switzerland* (18-22).

Sörqvist, P., & Marsh, J. E. (2015). How Concentration Shields Against Distraction. *Current Directions in Psychological Science*, *24*(4), 267–272. https://doi.org/10.1177/0963721415577356

The jamovi project (2022). *jamovi*. (Version 2.3) [Computer Software]. Retrieved from https://www.jamovi.org.

Thesen, T., McDonald, C., Carlson, C., Doyle, W., Cash, S., Felsovalyi, O., Girard, H., Barr, W., Devinsky, O., Kuzniecky, R., Halgren, E. (2012). Sequential then interactive processing of letters and words in the left fusiform gyrus. *Nat Commun* 3, 1284. https://doi.org/10.1038/ncomms2220

Tinker, M. A. (1946). The study of eye movements in reading. *Psychological Bulletin, 43*(2), 93–120. https://doi.org/10.1037/h0063378

Tobii AB (2023). Tobii Pro Lab (Version 1.217.49450) [Computer software]. Danderyd, Sweden: Tobii AB.

Trott, S., & Bergen, B. (2020). Why do human languages have homophones?. *Cognition*, *205*, 104449. https://doi.org/10.1016/j.cognition.2020.104449

Underwood, G., & Everatt, J. (1992). The role of eye movements in reading: some limitations of the eye-mind assumption. *Advances in psychology, 88*, 111-169. https://doi.org/10.1016/S0166-4115(08)61744-6 van Heuven, W. J. B., Mandera, P., Keuleers, E., & Brysbaert, M. (2014). Subtlex-UK: A New and Improved Word Frequency Database for British English. *Quarterly Journal of Experimental Psychology*, *67*(6), 1176–1190. https://doi.org/10.1080/17470218.2013.850521

Vasilev, M. R., Hitching, L. & Tyrrell, S. (2023). What makes background music distracting? Investigating the role of song lyrics using self-paced reading. *Journal of Cognitive Psychology*, *102*(2), 167–181. https://doi.org/10.1080/20445911.2023.2209346

Vasilev, M. R., Kirkby, J. A., & Angele, B. (2018). Auditory Distraction During Reading: A Bayesian Meta-Analysis of a Continuing Controversy. *Perspectives on Psychological Science*, *13*(5), 567–597. https://doi.org/10.1177/1745691617747398

Vasilev, M. R., Liversedge, S. P., Rowan, D., Kirkby, J. A., & Angele, B. (2019). Reading is disrupted by intelligible background speech: Evidence from eye-tracking. *Journal of Experimental Psychology: Human Perception and Performance, 45*(11), 1484–1512. https://doi.org/10.1037/xhp0000680

Venezky, R.L. (1995). How English is Read: Grapheme-Phoneme Regularity and Orthographic Structure in Word Recognition. In: Taylor, I., Olson, D.R. (Eds) *Scripts and Literacy. Neuropsychology and Cognition*, vol 7. Springer, Dordrecht. https://doi.org/10.1007/978-94-011-1162-1_8

Witte, E., & Köbler, S. (2019). Linguistic materials and metrics for the creation of well-controlled Swedish speech perception tests. *Journal of Speech, Language, and Hearing Research*, *62*(7), 2280-2294. https://doi.org/10.1044/2019_JSLHR-S-18-0454

Xue, S., Jacobs, A. M., & Lüdtke, J. (2020). What is the difference? Rereading Shakespeare's sonnets—An eye tracking study. *Frontiers in psychology*, *11*, 421. https://doi.org/10.3389/fpsyg.2020.00421

Yan, G., Lan, Y., Meng, Z., Wang, Y. & Benson, V. (2021) Phonological Coding during Sentence Reading in Chinese Deaf Readers: An Eye-Tracking Study. *Scientific Studies of Reading*, *25*(4), 287-303. https://doi.org/10.1080/10888438.2020.1778000

Yan, G., Meng, Z., Liu, N., He, L., & Paterson, K. B. (2018). Effects of irrelevant background speech on eye movements during reading. *Quarterly Journal of Experimental Psychology*, *71*(6), 1270–1275. https://doi.org/10.1080/17470218.2017.1339718

Zhang, H., Miller, K., Cleveland, R., & Cortina, K. (2018). How listening to music affects reading: Evidence from eye tracking. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *44*(11), 1778–1791. https://doi.org/10.1037/xlm0000544

Zoccolotti, P., De Luca, M., Di Pace, E., Gasperini, F., Judica, A., & Spinelli, D. (2005). Word length effect in early reading and in developmental dyslexia. *Brain and language*, *93*(3), 369-373. https://doi.org/10.1016/j.bandl.2004.10.010

## Appendix

**Table 6**

*Target Words*

| Letter Pairing | Orthographic similarity | Word type | Positioning of manipulated letter | Original Word (Zipf value: measure of word frequency 1 = low; 7 = high)[1] | Unrelated | Homophone | Sentence CO | Sentence HP | Sentence UN |
|---|---|---|---|---|---|---|---|---|---|
| j - g | Phonology | Noun | End | adjektiv | adpektiv | adgektiv | Adjektiv är en ordklass. (1)<br><br>Ett adjektiv kan böjas.<br><br>Ett adjektiv beskriver ett substantiv. | Adgektiv är en ordklass.<br><br>Ett adgektiv kan böjas. (9)<br><br>Ett adgektiv beskriver ett substantiv. | Adpektiv är en ordklass.<br><br>Ett adpektiv kan böjas.<br><br>Ett adpektiv beskriver ett substantiv. |
| | | Noun | End | Vanilj (3.95) | Vanild | Vanilg | Mamma köpte vanilj till kakan.<br><br>Med vanilj smakar det bättre.<br><br>Utan vanilj var det inte gott. | Mamma köpte vanilg till kakan.<br><br>Med vanilg smakar det bättre.<br><br>Utan vanilg var det inte gott. | Mamma köpte vanild till kakan.<br><br>Med vanild smakar det bättre.<br><br>Utan vanild |

[1] (van Heuven et al., 2014; Witte & Köbler, 2019)

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | | | | | | var det inte gott. |
| Noun | Middle | Biljett (4.02) | Bildett | Bilgett | Vi köper biljetter till bion. (4)<br><br>De har biljetter till teatern.<br><br>Dessa biljetter var inte billiga. | Vi köper bilgetter till bion.<br><br>De har bilgetter till teatern.<br><br>Dessa bilgetter var inte billiga. | Vi köper bildetter till bion.<br><br>De har bildetter till teatern.<br><br>Dessa bildetter var inte billiga. |
| Noun | Ending | Fåtölj | Fåtölp | Fåtölg | I farfars fåtölj får ingen annan sitta. (8)<br><br>Deras fåtölj har röda armstöd.<br><br>Denna fåtölj passar bra till er soffa. | I farfars fåtölg får ingen annan sitta.<br><br>Deras fåtölg har röda armstöd.<br><br>Denna fåtölg passar bra till er soffa. | I farfars fåtölp får ingen annan sitta.<br><br>Deras fåtölp har röda armstöd.<br><br>Denna fåtölp passar bra till er soffa. |
| Noun | Middle | Subjekt | Subpekt | Subgekt | Alla subjekt har en artikel. | Alla subgekt har en artikel. | Alla subpekt har en artikel. (8) |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | Det behövs ett subjekt i alla meningar.<br><br>Subjekt kan vara bestämda eller obestämda. | Det behövs ett subgekt i alla meningar.<br><br>Subgekt kan vara bestämda eller obestämda. | Det behövs ett subpekt i alla meningar.<br><br>Subpekt kan vara bestämda eller obestämda. |
| | Adjective | Middle | Objektiv | Obwektiv | Obgektiv | En objektiv domare är en bra domare.<br><br>Någon objektiv och kunnig kritik var det aldrig.<br><br>En objektiv forskare var han inte. | En obgektiv domare är en bra domare. (8)<br><br>Någon obgektiv och kunnig kritik var det aldrig.<br><br>En obgektiv forskare var han inte. | En obwektiv domare är en bra domare.<br><br>Någon obwektiv och kunnig kritik var det aldrig.<br><br>En obwektiv forskare var han inte. |
| g - j | Noun | Middle | Borg (4.18) | Borm | Borj | Denna borg har stora torn.<br><br>På en borg bor en prins.<br><br>De byggde en | Denna borj har stora torn.<br><br>På en borj bor en prins.<br><br>De byggde en | Denna borm har stora torn. (2)<br><br>På en borm bor en prins. |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | | | | borg på kullen. | borj på kullen. | De byggde en borm på kullen. |
| Noun | Beginning | Geting | Peting | Jeting | En geting flög in genom fönstret.<br><br>En geting surrade ute i trädgården.<br><br>En geting kan stinga andra djur. | En jeting flög in genom fönstret.<br><br>En jeting surrade ute i trädgården.<br><br>En jeting kan stinga andra djur. | En peting flög in genom fönstret. (5)<br><br>En peting surrade ute i trädgården.<br><br>En peting kan stinga andra djur. |
| Noun | Ending | Korg | Korl | Korj | Hon bär en flätad korg över axeln. (9)<br><br>Man tog bara en korg och plockade ner saker i den.<br><br>På köksbordet fanns en korg med äpplen. | Hon bär en flätad korj över axeln.<br><br>Man tog bara en korj och plockade ner saker i den.<br><br>På köksbordet fanns en korj med äpplen. | Hon bär en flätad korl över axeln.<br><br>Man tog bara en korl och plockade ner saker i den.<br><br>På köksbordet fanns en korl med äpplen. |
| Adjektiv | Ending | Arg | Arb | Arj | Barnet var arg på sin syster.<br><br>Att vara arg | Barnet var arj på sin syster.<br><br>Att vara arj eller | Barnet var arb på sin syster. (9) |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | eller ledsen är okej ibland.<br><br>Han var arg när jag slog honom. | ledsen är okej ibland.<br><br>Han var arj när jag slog honom. | Att vara arb eller ledsen är okej ibland.<br><br>Han var arb när jag slog honom. |
| | | ? | Middle | Adjö | Adrö | adgö | Han sa adjö till alla.<br><br>Hon säger adjö till sina syskon.<br><br>De sa adjö för alltid. | Han sa adgö till alla.<br><br>Hon säger adgö till sina syskon.<br><br>De sa adgö för alltid. | Han sa adrö till alla. (1)<br><br>Hon säger adrö till sina syskon.<br><br>De sa adrö för alltid. |
| k - l - q | None | Adjective | Middle | Försiktig (4.03) | Försiltig | Försiqtig | Var försiktig med elden.<br><br>Han var försiktig med ugnen.<br><br>Man ska vara försiktig med kemikalier. | Var försiqtig med elden. (2)<br><br>Han var försiqtig med ugnen.<br><br>Man ska vara försiqtig med kemikalier. | Var försiltig med elden.<br><br>Han var försiltig med ugnen.<br><br>Man ska vara försiltig med kemikalier. |
| | | Noun | Beginning | Kalender (3.94) | Lalender | Qalender | I kalendern kommer januari först. | I qalendern kommer januari först. (1) | I lalendern kommer januari först. |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | | | | Min kalender är full.<br><br>Hon hängde kalendern på väggen. | Min qalender är full.<br><br>Hon hängde qalendern på väggen. | Min lalender är full.<br><br>Hon hängde lalendern på väggen. |
| Verb | Middle | Raka (4.50) | Rala | Raqa | Pappa rakar sitt skägg. (2)<br><br>Min faster rakar sina ben varje dag.<br><br>Han rakar sitt skägg bara varannan dag. | Pappa raqar sitt skägg.<br><br>Min faster raqar sina ben varje dag.<br><br>Han raqar sitt skägg bara varannan dag. | Pappa ralar sitt skägg.<br><br>Min faster ralar sina ben varje dag.<br><br>Han ralar sitt skägg bara varannan dag. |
| Verb | Beginning | Krama | lrama | qrama | Barnet kramar nallen.<br><br>Flickan kramar sin bror.<br><br>Pojken kramar dockan. | Barnet qramar nallen. (6)<br><br>Flickan qramar sin bror.<br><br>Pojken qramar dockan. | Barnet lramar nallen.<br><br>Flickan lramar sin bror.<br><br>Pojken lramar dockan. |
| Noun | End | Bok | Bol | Boq | De läste en bok i skolan. (7) | De läste en boq i skolan. | De läste en bol i skolan. |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | | | | Han skrev en bok under lovet.<br><br>Vi läste en bok med barnen. | Han skrev en boq under lovet.<br><br>Vi läste en boq med barnen. | Han skrev en bol under lovet.<br><br>Vi läste en bol med barnen. |
| Verb | Middle | Baka | Bala | Baqa | Vi bakar en kaka till fika.<br><br>De bakar kakor för henne.<br><br>Han bakar bröd på söndagar. | Vi baqar en kaka till fika.<br><br>De baqar kakor för henne.<br><br>Han baqar bröd på söndagar. | Vi balar en kaka till fika. (7)<br><br>De balar kakor för henne.<br><br>Han balar bröd på söndagar, |
| Noun | Middle | Skor | Slor | Sqor | Han har fina skor på fötterna.<br><br>Hon har skor med klack.<br><br>Deras skor var en storlek för stora. | Han har fina sqor på fötterna. (7)<br><br>Hon har sqor med klack.<br><br>Deras sqor var en storlek för stora. | Han har fina slor på fötterna.<br><br>Hon har slor med klack.<br><br>Deras slor var en storlek för stora. |
| | Middle | Bråka | bråfa | bråqa | Syskonen håller på att bråka om | Syskonen håller på att bråqa om gosedjuret. | Syskonen håller på att bråfa om |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | gosedjuret. (5)<br><br>Att bråka om saken är meningslöst.<br><br>De kan bråka om saken så länge de vill. | Att bråqa om saken är meningslöst.<br><br>De kan bråqa om saken så länge de vill. | gosedjuret.<br><br>Att bråfa om saken är meningslöst.<br><br>De kan bråfa om saken så länge de vill. |
| s - p - c | Verb | Middle | arkiv | arpiv | arqiv | I ett arkiv lagrar de många böcker.<br><br>Ett arkiv är en analog databas.<br><br>I detta arkiv jobbar många historiker. | I ett arqiv lagrar de många böcker. (3)<br><br>Ett arqiv är en analog databas.<br><br>I detta arqiv jobbar många historiker. | I ett arpiv lagrar de många böcker.<br><br>Ett arpiv är en analog databas.<br><br>I detta arpiv jobbar många historiker. |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Adjective | Middle | Bästa (5.68) | Bäpta | Bäcta | Du är min bästa vän. (3)<br><br>Mitt bästa räckte inte till.<br><br>Hennes bästa kompis var ledsen. | Du är min bäcta vän.<br><br>Mitt bäcta räckte inte till.<br><br>Hennes bäcta kompis var ledsen. | Du är min bäpta vän.<br><br>Mitt bäpta räckte inte till.<br><br>Hennes bäpta kompis var ledsen. |
| Noun | Middle | Försök (4.77) | Förnök | Förcök | Hans försök gick bra.<br><br>Ett försök var det värt.<br><br>Det enda försök han fick. | Hans förcök gick bra.<br><br>Ett förcök var det värt.<br><br>Det enda förcök han fick. | Hans förnök gick bra. (3)<br><br>Ett förnök var det värt.<br><br>Det enda förnök han fick. |
| Noun | End | Is | Il | Ic | På isen är det halt.<br><br>På isen kan man halka.<br><br>Den isen har nästan smält. | På icen är det halt. (4)<br><br>På icen kan man halka.<br><br>Den icen har nästan smält. | På ilen är det halt.<br><br>På ilen kan man halka.<br><br>Den ilen har nästan smält. |
| Noun | Beginning | soppa | roppa | coppa | Hon har med sig en tallrik | Hon har med sig en tallrik av | Hon har med sig en tallrik |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | | | | av soppan och lite bröd.<br><br>I soppan hade hon hittat ett hår.<br><br>Koka ner soppan och sila den sedan. | coppan och lite bröd.<br><br>I coppan hade hon hittat ett hår.<br><br>Koka ner coppan och sila den sedan. | av roppan och lite bröd. (4)<br><br>I roppan hade hon hittat ett hår.<br><br>Koka ner roppan och sila den sedan. |
| Noun | End | kaos | kaov | kaoc | Det var kaos i hennes rum.<br><br>Vilket kaos det var.<br><br>Detta kaos gillar mamma inte. | Det var kaoc i hennes rum. (5)<br><br>Vilket kaoc det var.<br><br>Detta kaoc gillar mamma inte. | Det var kaov i hennes rum.<br><br>Vilket kaov det var.<br><br>Detta kaov gillar mamma inte. |
| Verb | Middle | måste | måfte | mácte | De måste vara trevliga mot varandra. (6)<br><br>Han måste göra alla läxor.<br><br>Hon måste klara av provet. | De mácte vara trevliga mot varandra.<br><br>Han mácte göra alla läxor.<br><br>Hon mácte klara av provet. | De måfte vara trevliga mot varandra.<br><br>Han måfte göra alla läxor.<br><br>Hon måfte klara av |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | | provet. |
| | Noun | End | glas | glak | glac | Han kastade glaset mot väggen.<br><br>Hon tappade glaset på golvet.<br><br>De ställde glaset in i skåpet. | Han kastade glacet mot väggen.<br><br>Hon tappade glacet på golvet.<br><br>De ställde glacet in i skåpet | Han kastade glaket mot väggen. (6)<br><br>Hon tappade glaket på golvet.<br><br>De ställde glaket in i skåpet. |

**Filler sentences**

1. Mamma borstar håret.
2. Pizza är min favoriträtt.
3. Gillar han chokladglass?
4. Kvinnan rider på en häst.
5. Var snäll mot henne!
6. De läser många böcker.
7. Prinsen bor på ett slott.
8. Bilen kör för snabbt.
9. Mobilen funkar inte.
10. Det snöar mycket i Norden.
11. Solen skiner klart.
12. Flickan älskar äpplen.
13. Fotboll gillade hon mest.
14. De gjorde inget på söndag.
15. Katten myser med pojken.
16. Det slutade regnar.
17. Han är bjuden på kalaset
18. Lådan är tom.
19. Hunden skakade sig.
20. Alla var förvirrade
21. Det är en spännande film.
22. Han spelar gitarr.
23. Vi tycker om kanelbullar.
24. Han äter frukost nu.
25. De är duktiga på matte.
26. Man kan måla om här.
27. Det blev natt.

**Assumptions for LMEMs**

Total Fixation Duration

**Figure 2**

*Effect Plot Noise on Total Fixation Duration*

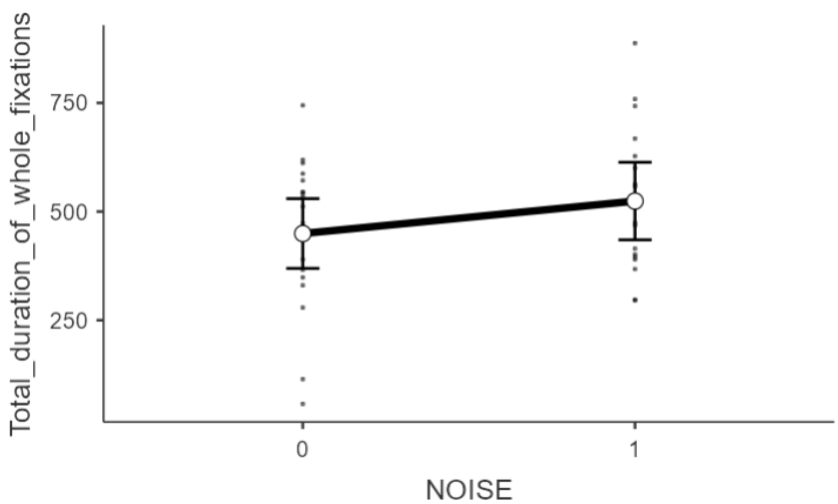



**Figure 3**

*Q-Q Plot Total Fixation Duration*

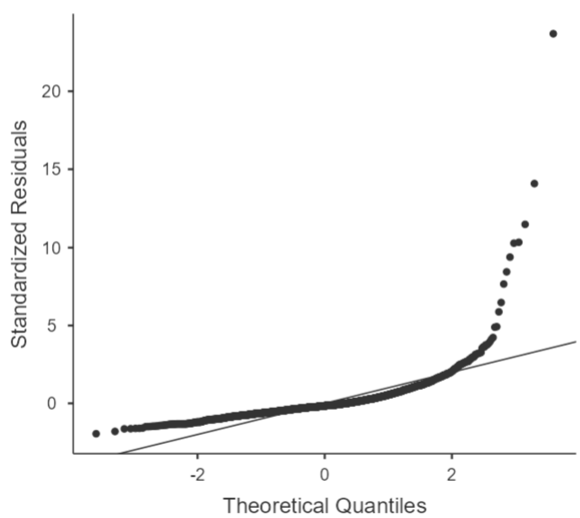


**Figure 4**

*Residual Histogram Total Fixation Duration*

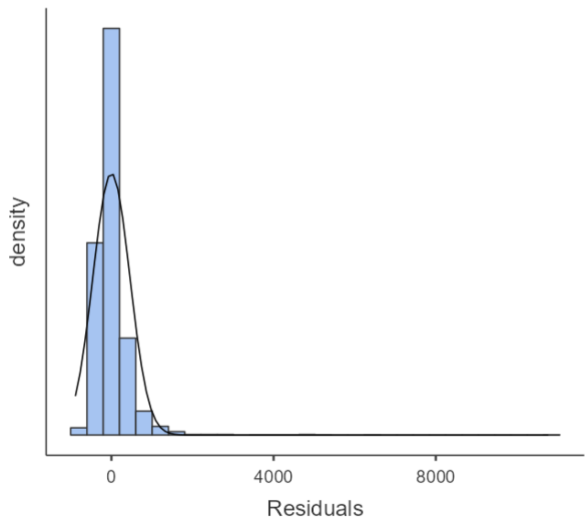



**Figure 5**

*Residual-Predicted Scatterplot Total Fixation Duration*

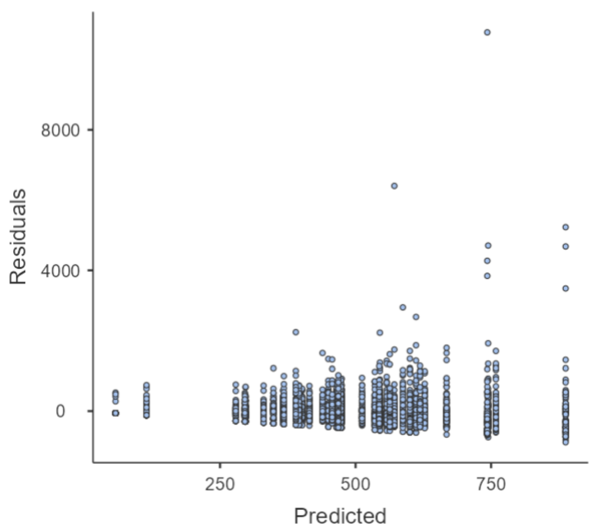
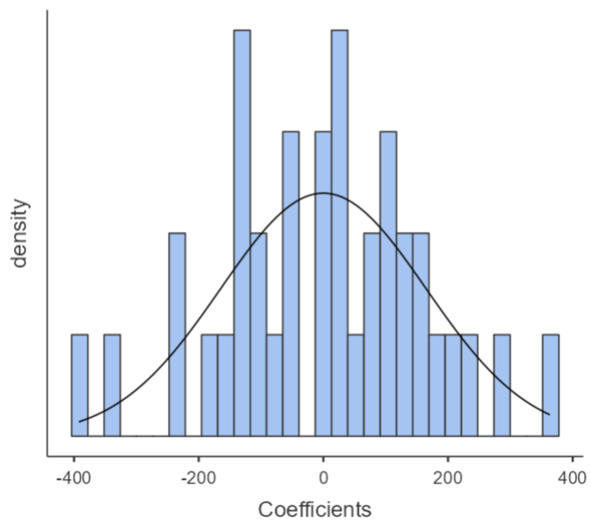


**Figure 6**

*Random Coefficients Histogram: Coefficient (Intercept) random across Participant Total Fixation Duration*




Difference in Total Fixation Duration

**Figure 7**

*Effect Plot Difference in Total Fixation Duration*

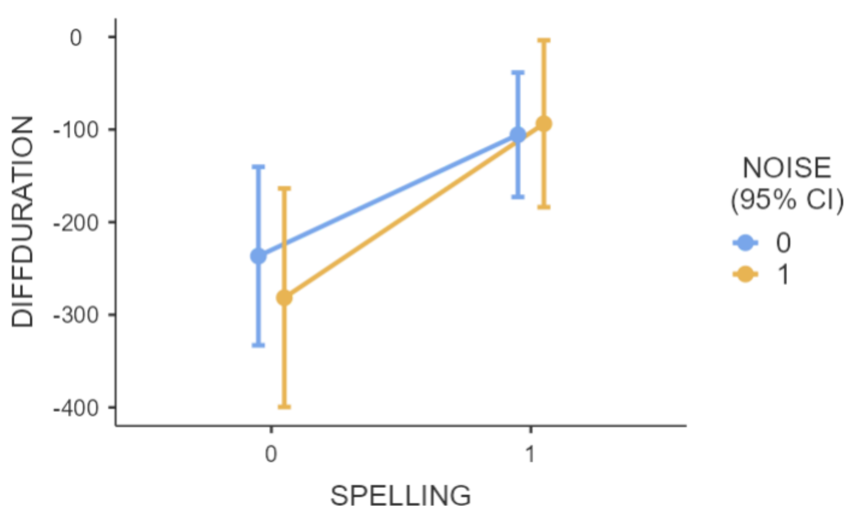


**Figure 8**

*Q-Q Plot Difference in Total Fixation Duration*

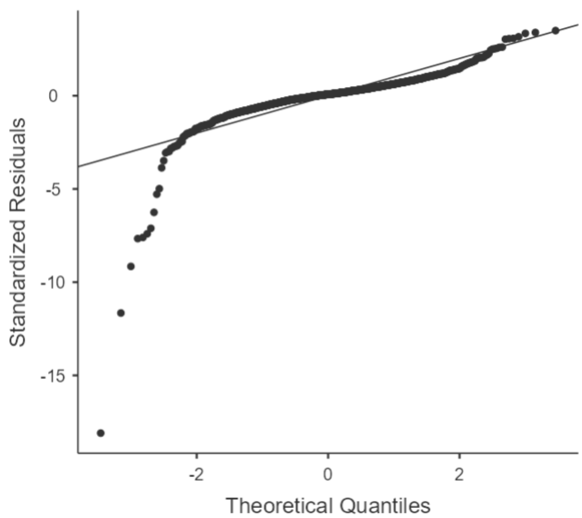



**Figure 9**

*Residual Histogram Difference in Total Fixation Duration*

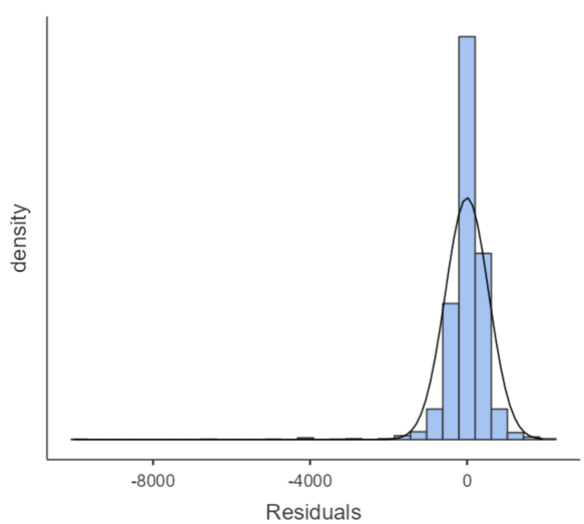


**Figure 10**

*Residual-Predicted Scatterplot Difference in Total Fixation Duration*

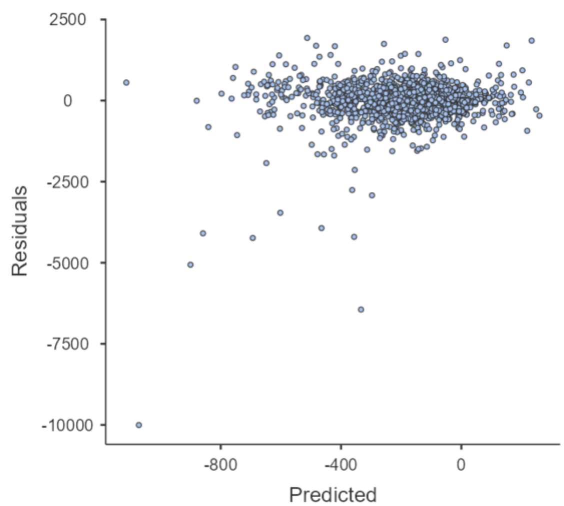



**Figure 11**

*Random Coefficients Histogram: Coefficient (Intercept) Random across Stimuli Difference in Total Fixation Duration*

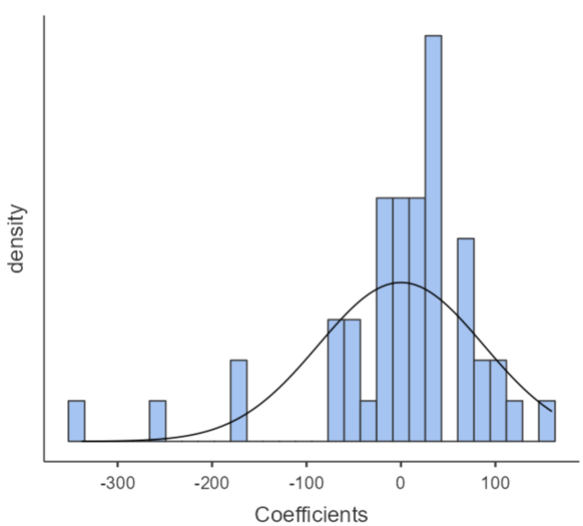


**Figure 12**

*Random Coefficients Histogram Coefficient NOISE1 Random across Stimuli Difference in Total Fixation Duration*

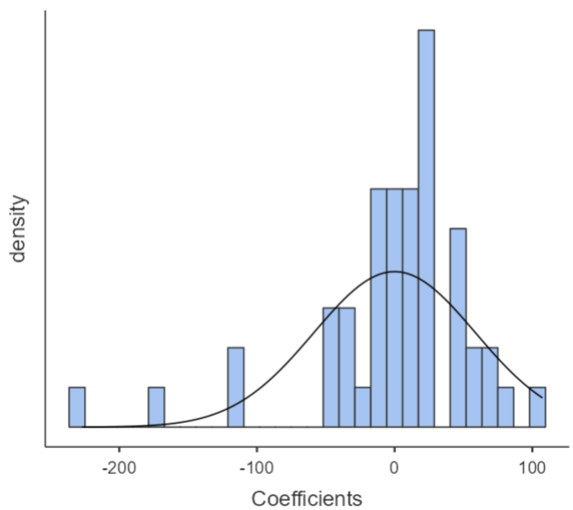



**Figure 13**

*Random Coefficients Histogram Coefficient (Intercept) Random across Participant Difference in Total Fixation Duration*

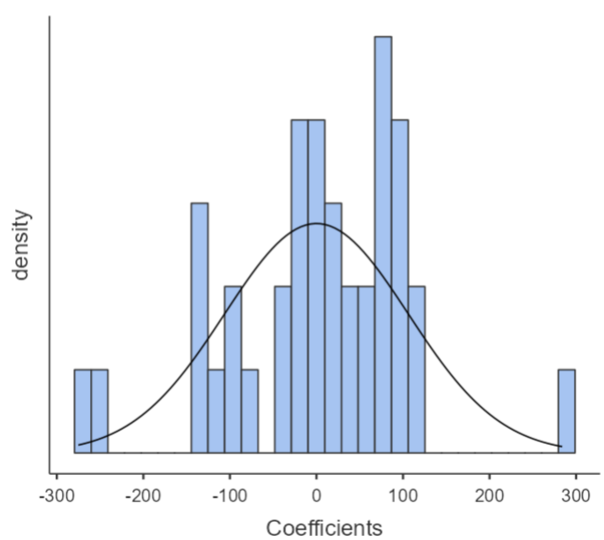
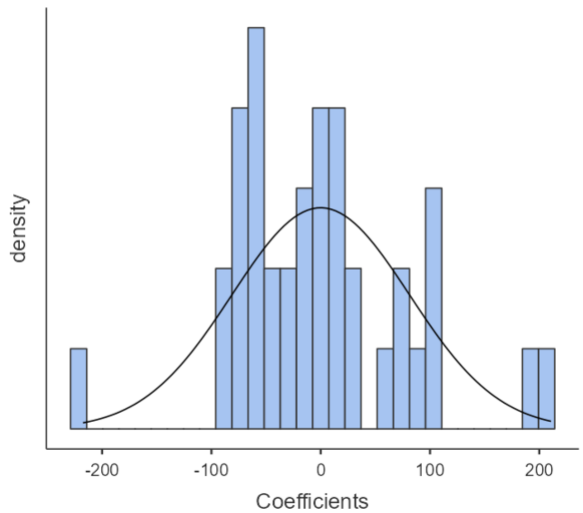


**Figure 14**

*Random Coefficients Histogram Coefficient SPELLING1 Random across Participant Difference in Total Fixation Duration*




Difference in First Fixation Duration

**Figure 15**

*Effect Plot Difference in First Fixation Duration*

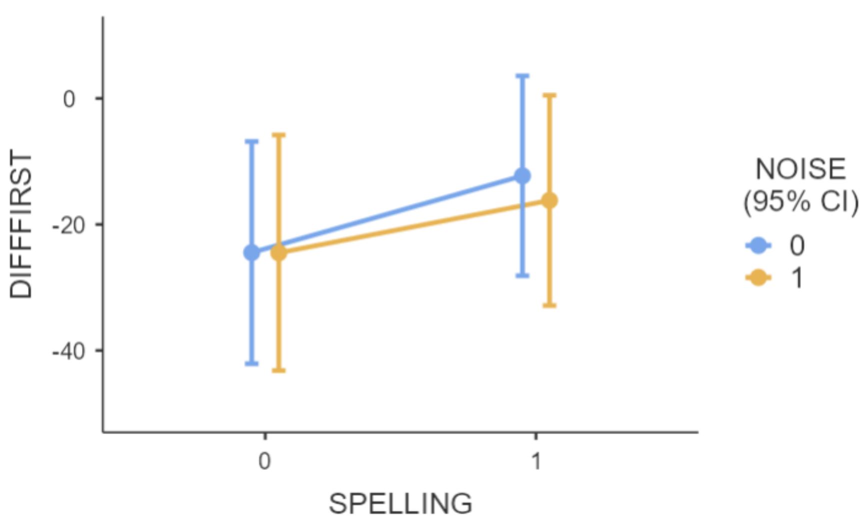


**Figure 16**

*Q-Q Plot Difference in First Fixation Duration*

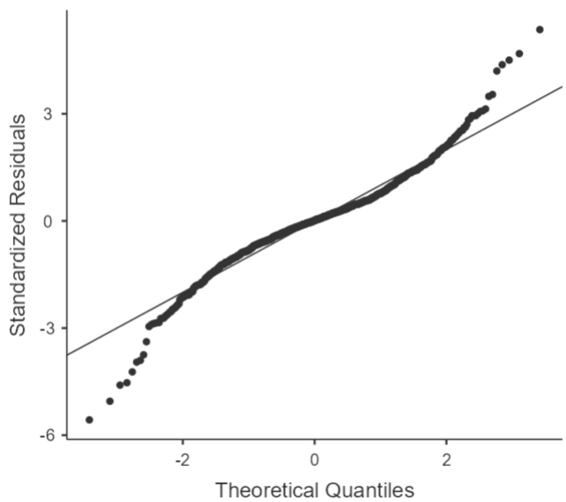



**Figure 17**

*Residual Histogram Difference in First Fixation Duration*

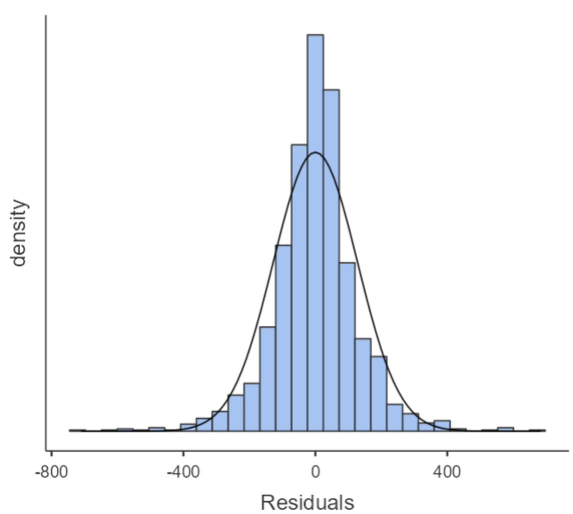


**Figure 18**

*Residual-Predicted Scatterplot Difference in First Fixation Duration*

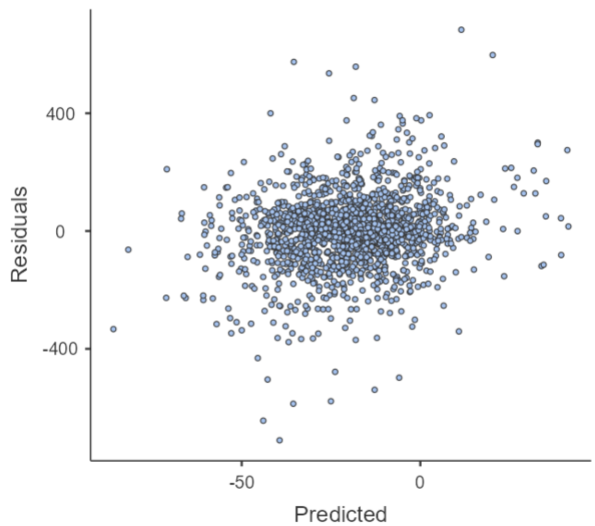



**Figure 19**

*Random Coefficients Histogram Coefficient (Intercept) Random across Stimuli Difference in First Fixation Duration*

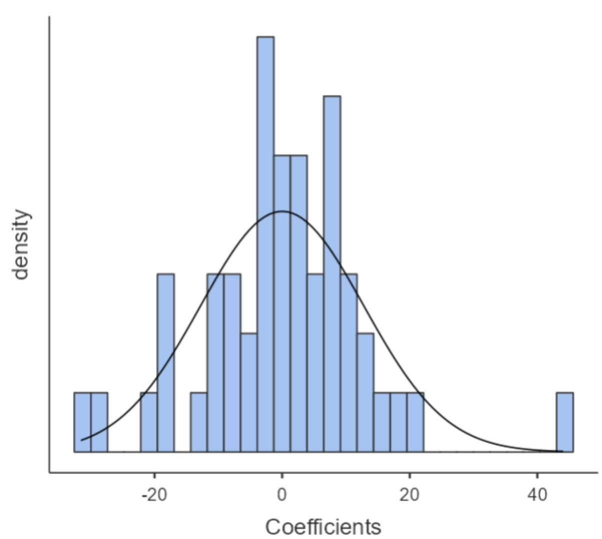


**Figure 20**

*Random Coefficients Histogram Coefficient NOISE1 Random across Stimuli Difference in First Fixation Duration*

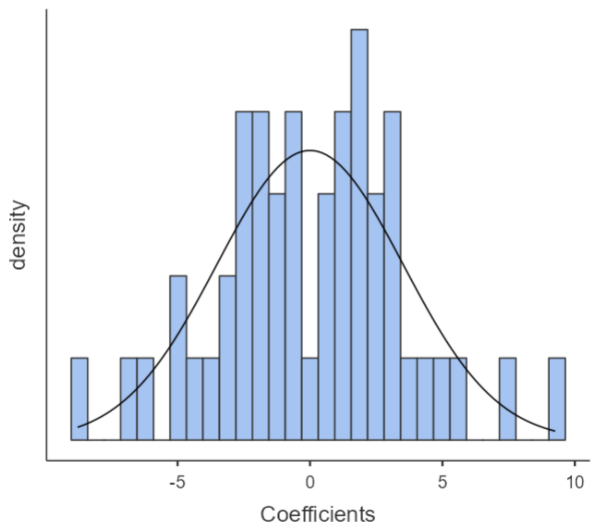



**Figure 21**

*Random Coefficients Histogram Coefficient (Intercept) Random across Participant Difference in First Fixation Duration*

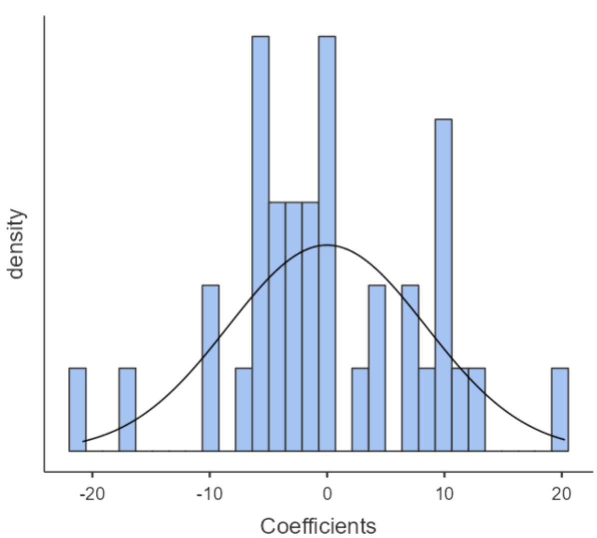
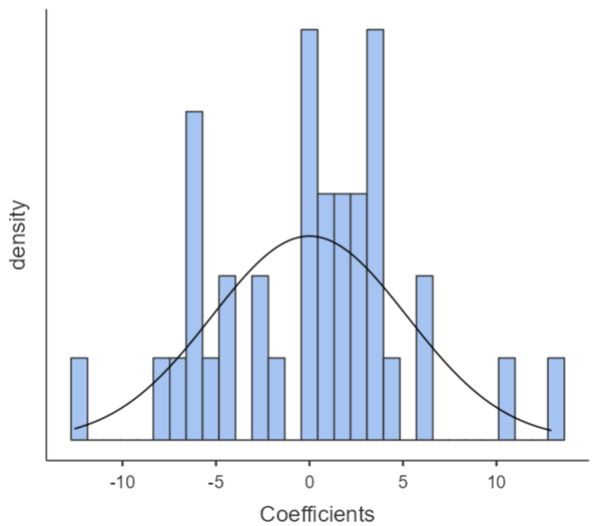


**Figure 22**

*Random Coefficients Histogram Coefficient SPELLING1 Random across Participant Difference in First Fixation Duration*




Difference in Number of Fixations

**Figure 23**

*Effect Plot Difference in Number of Fixations*

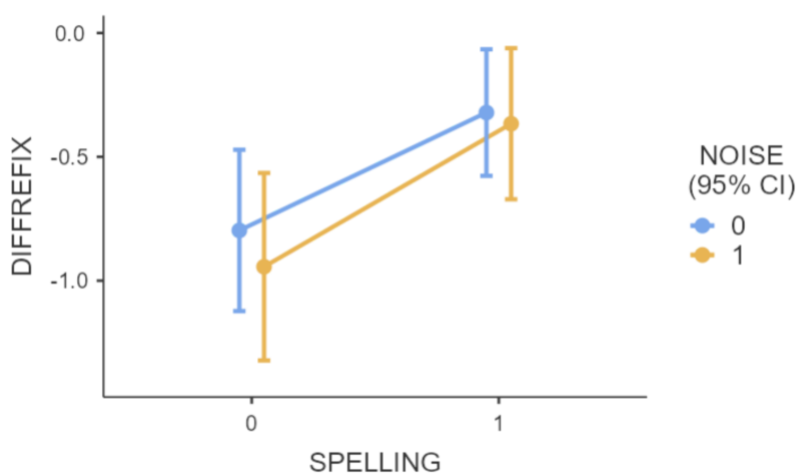


**Figure 24**

*Q-Q Plot Difference in Number of Fixations*

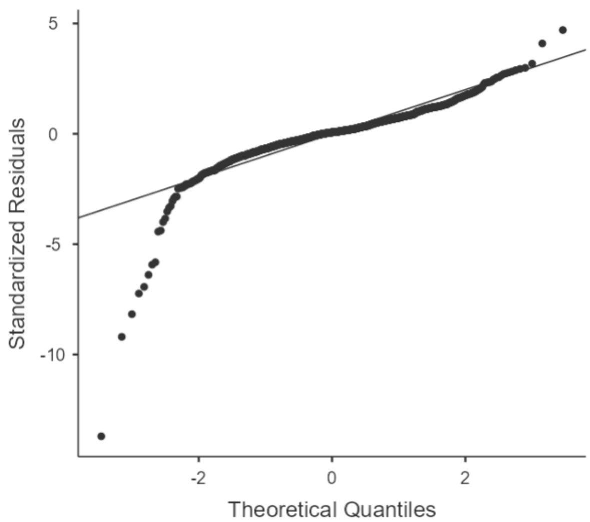



**Figure 25**

*Residual Histogram Difference in Number of Fixations*

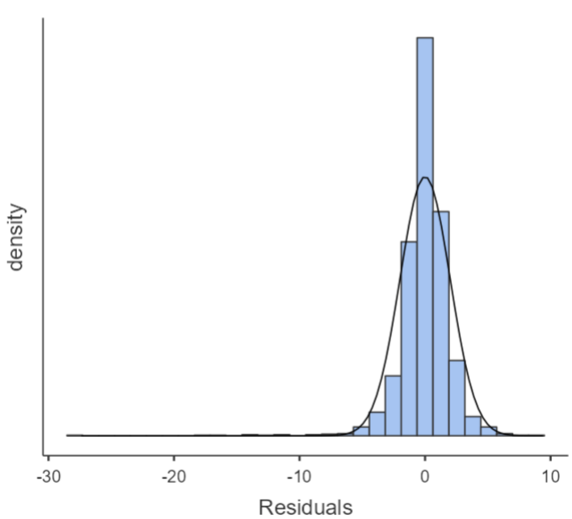


**Figure 26**

*Residual-Predicted Scatterplot Difference in Number of Fixations*

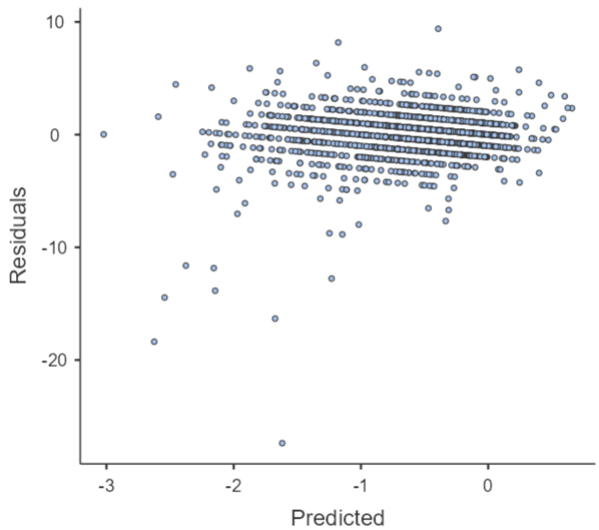



**Figure 27**

*Random Coefficients Histogram Coefficient (Intercept) Random across Stimuli Difference in Number of Fixations*

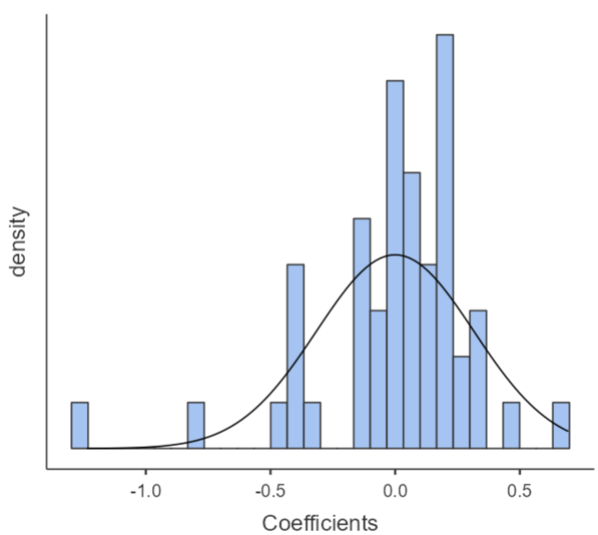


**Figure 28**

*Random Coefficients Histogram Coefficient NOISE1 Random across Stimuli Difference in Number of Fixations*

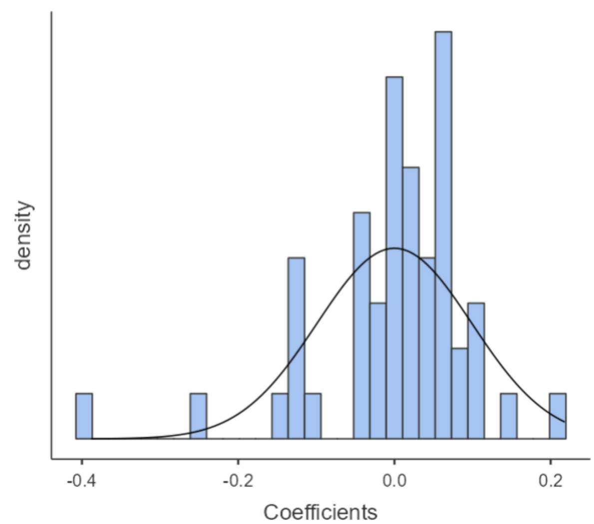



**Figure 29**

*Random Coefficients Histogram Coefficient (Intercept) Random across Participant Difference in Number of Fixations*

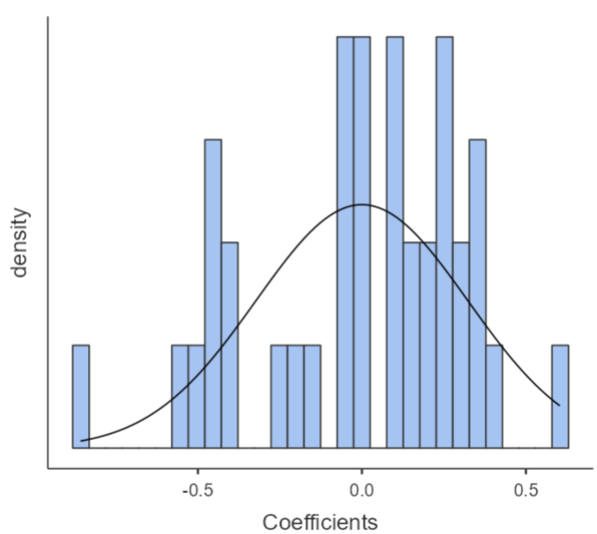
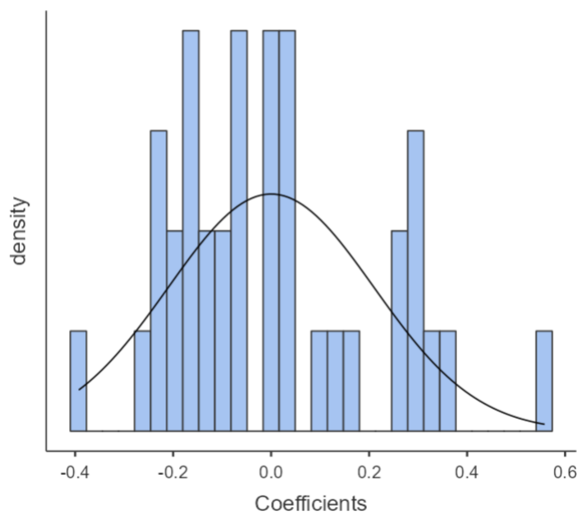


**Figure 30**

*Random Coefficients Histogram Coefficient SPELLING1 Random across Participant Difference in Number of Fixations*




Difference in Rereading Duration

**Figure 31**

*Effect Plot Difference in Rereading Duration*

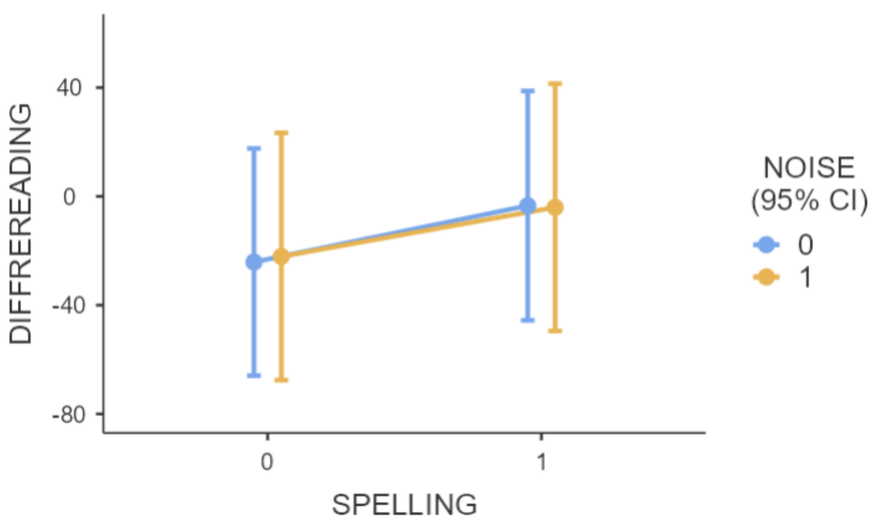


**Figure 32**

*Q-Q Plot Difference in Rereading Duration*

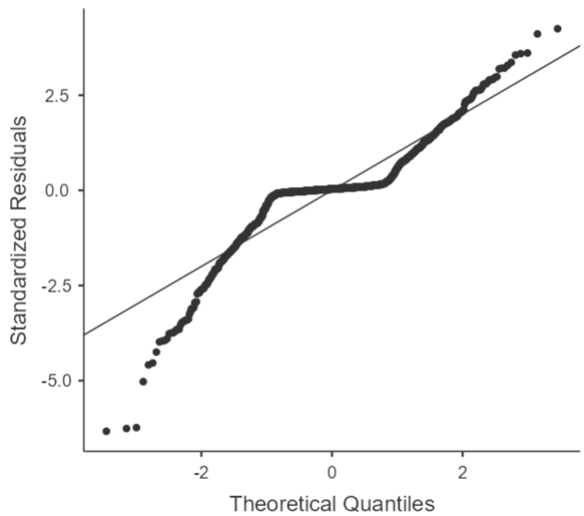



**Figure 33**

*Residual Histogram Difference in Rereading Duration*

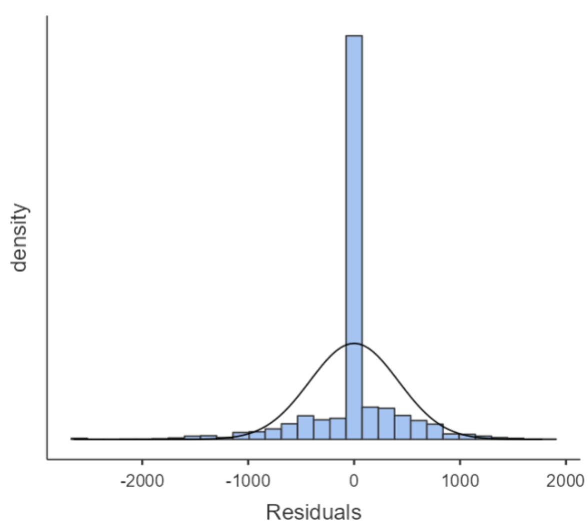


**Figure 34**

*Residual Predicted Scatterplot Difference in Rereading Duration*

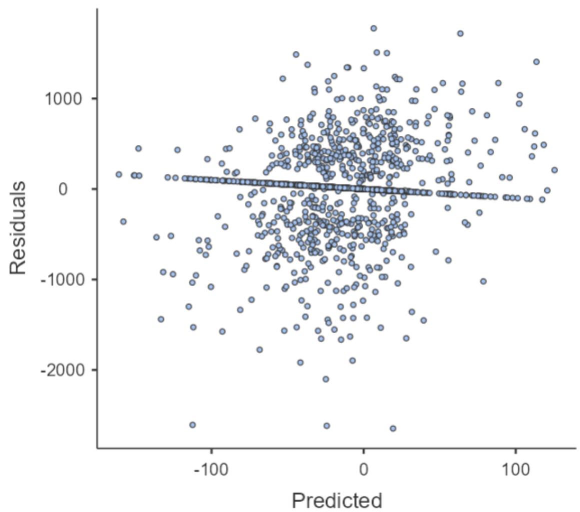



**Figure 35**

*Random Coefficients Histogram Coefficient (Intercept) Random across Stimuli Difference in Rereading Duration*

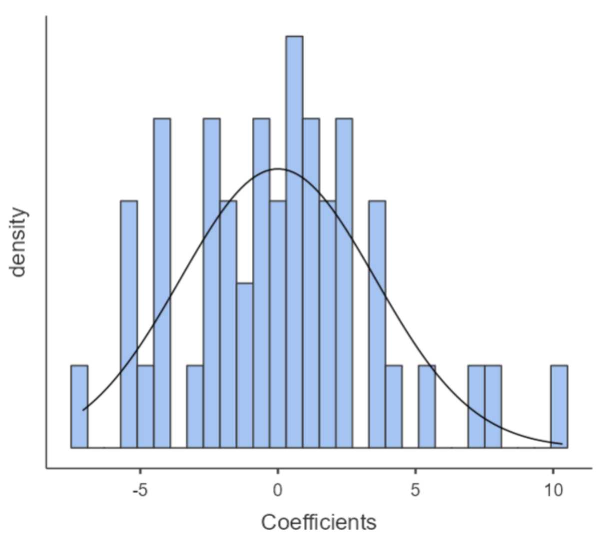


**Figure 36**

*Random Coefficients Histogram Coefficient (Intercept) Random across Participants Difference in Rereading Duration*