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The neurocognitive relationship between sound and meaning

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The Neurocognitive Relationship Between Sound and Meaning

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Yr wyf drwy hyn yn datgan mai canlyniad fy ymchwil fy hun yw'r thesis hwn, ac eithrio lle nodir yn wahanol. Caiff ffynonellau eraill eu cydnabod gan droednodiadau yn rhoi cyfeiriadau eglur. Nid yw sylwedd y gwaith hwn wedi cael ei dderbyn o'r blaen ar gyfer unrhyw radd, ac nid yw'n cael ei gyflwyno ar yr un pryd mewn ymgeisiaeth am unrhyw radd oni bai ei fod, fel y cytunwyd gan y Brifysgol, am gymwysterau deuol cymeradwy.

I hereby declare that this thesis is the results of my own investigations, except where otherwise stated. All other sources are acknowledged by bibliographic references. This work has not previously been accepted in substance for any degree and is not being concurrently submitted in candidature for any degree unless, as agreed by the University, for approved dual awards.

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Summary

In linguistics, the relationship between word form and meaning is largely considered arbitrary. However, in literary works and in the broader discipline of literary theory, it is well acknowledged that word form is stylistically manipulated to link concepts and engage reader attention. Recent work in the field of neurocognitive poetics investigates how stylistic text influences semantic and attentional processes, but currently no research effort has focused on these effects in natural, declarative language. The empirical work presented in this thesis examines how phonological repetition in short phrases impacts upon semantic processing and attentional engagement, addressed in three main research questions: 1) How does phonological repetition between words affect semantic processing and attentional engagement? 2) How does phonological repetition between words affect semantic processing and attentional engagement *in poor readers*? 3) How does the relationship between sound and meaning affect memory? To this end, I constructed adjective-noun phrases, which were orthogonally manipulated for semantic congruency (congruent, incongruent), and alliteration (alliterating, non-alliterating), as in "dazzling-diamond"; "sparkling-diamond"; "dangerous-diamond"; and "creepy-diamond". Over four experiments I establish that: 1) phonological repetition in the form of alliteration creates an illusion of meaning for typical readers, linking words beyond the level of actual semantic relatedness, 2) phonological repetition does not similarly impact readers with dyslexia at the neurocognitive level, though alliteration impacts their overt semantic relatedness judgements, and 3) the presence of alliteration does not improve recognition memory for word-pairs, but it does create a false sense of familiarity. Our findings show that, even in natural language, word form influences both online semantic integration and overt judgement and later memory processes.

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Chapter 1

Literature Review and Thesis Aims

1.0. Chapter Overview

In this chapter, I will outline the primary theoretical concerns of my thesis, the research questions and how I intend to address these questions. The chapter starts with a very brief overview of the current research on the science of reading, before moving on to the latest research findings in neurocognitive poetics; a recent extension of the reading literature, which examines how stylistic properties of language affect neural and behavioural responses in readers of stylistic works. At this point, I outline the key theoretical questions addressed in my thesis, which are reflected in the empirical chapters that follow. Briefly, 1) how sound interacts with meaning in normally developed adult readers, 2) how this interaction may differ in poorer (dyslexic) readers, and 3) whether such stylistic manipulation of sounds experienced online latterly affect recognition of the linguistic content. These research questions will be followed by concise reviews of the literature (and resulting hypotheses) on a) current debate on the interaction between sound and semantics, b) current theorizing in dyslexia – including causal theories, c) current theorizing in recognition memory.

1.1. The Cognitive and Neurocognitive Science of Reading

Reading is a uniquely human skill, that has profound influence on our lives, and goes beyond what is achievable through spoken language. Through the written word, we can become completely immersed and inspired by a story that was written centuries before our births. Indeed, to typically developed readers, this can seem so automatic a process, that they do not think of it as the highly specialised and complicated skill that it is, taking years for children to master (Wolf & Stoodley, 2008). Despite how automatic this process can become once fully developed, there are several cognitive processes involved in extracting the meaning and sounds of a word from written letters. Here, I will give a very brief overview of some of the key theories of reading, from the single word level, through to fluent reading of stylistically complicated texts.

1.1.1 Word Decoding

The fundamental act and purpose of reading words is to derive sound and meaning from a series of arbitrary visual symbols (Coltheart, 2005, 2006). There are two influential models of word reading (Coltheart, 2005, 2006; Rayner & Reichle, 2010); namely the dual-route cascaded (DRC) model (Coltheart et al., 2001), and connectionist extensions of the triangle model (Coltheart, 2006; Seidenberg, 2005). These two models have underscored much reading research and debate within cognitive psychology in recent years, and offer contrasting accounts for how word identification occurs (Coltheart, 2006; Rayner & Reichle, 2010). They will be briefly outlined here.

Dual-Route Cascaded Model (DRC)

The DRC model (see **Figure 1** below) posits that identification of a word's phonology can occur via one of two routes; either via a non-lexical route through applying grapheme-phoneme correspondence rules, or through the more 'direct' lexical route, wherein the whole word is recognized and pronunciation is directly retrieved from the lexicon (Coltheart, 2006; Coltheart et al., 2001; Rayner & Reichle, 2010). Within this model, a word's orthography and phonology are represented as separate processing units in the lexicon, and operate in parallel (Coltheart et al., 2001; Rayner & Reichle, 2010). The direct (lexical) route is used to identify known and irregular words, whereas novel regular words and nonwords are identified via the non-lexical route (Coltheart, 2006; Coltheart et al., 2001). According to this model, the non-lexical route is poorer in individuals with developmental dyslexia, which accounts for their phonological deficits during reading (Coltheart, 2006; Ziegler et al., 2008). The lexical route may also be implicated in some cases, due to the heterogeneous nature of reading deficits in dyslexia (Ziegler et al., 2008).

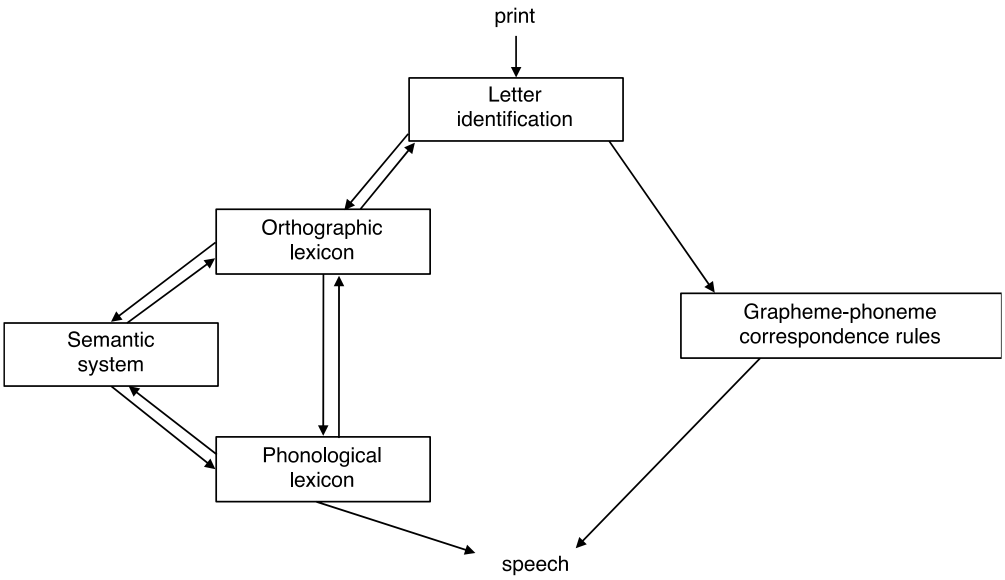

Figure 1: Overview of the basic architecture of the DRC, illustrating the lexical / direct (left side) and non-lexical / indirect (right) routes to word reading, adapted from Coltheart et al., 2001.

Connectionist Reading Models

In contrast to the DRC wherein each word is represented as a single lexical entry in the reading system, connectionist reading models are based on the idea of a distributed representation, whereby each word is represented by several units, and each unit is involved in representing several words (Coltheart, 2006; Harm & Seidenberg, 1999, 2004; Seidenberg, 2005; Seidenberg & McClelland, 1989). These units represent orthographic, phonological, and semantic features of words, with hidden units allowing the network to learn and represent more complex mappings than would be afforded by direct input-to-output mappings (see **Figure 2** below; Seidenberg, 2005). These theories put forward the idea that consistency exists on a continuum as opposed to being a strict dichotomy of regular versus irregular words, and that grapheme-phoneme correspondences are mastered via statistical learning (Seidenberg, 2005). Simulations of dyslexia using these models support the prevalent view that dyslexic readers have degraded phonological representations, but also that other causes are also involved (Harm & Seidenberg, 1999; Seidenberg, 2005).

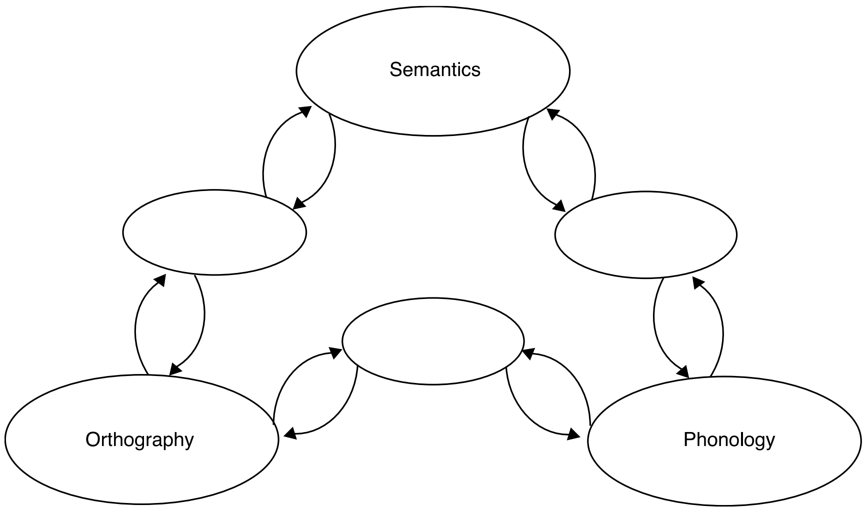

Figure 2: The ‘Triangle Model’ adapted from Seidenberg and McClelland (1989), illustrating the layers of units for semantics, orthography, and phonology, as well as the hidden units (blank ovals).

1.1.2. Reading Fluency

The above models outline the processes involved in word decoding and are complemented by human data involving word recognition paradigms such as lexical decision and word/nonword reading (Grainger et al., 1991; McKague et al., 2001; McNorgan et al., 2015; Pritchard et al., 2012; Schmalz et al., 2013). However, in normal reading conditions (e.g. reading a book), words are not read in isolation. Readers need to be able to read quickly and accurately, and comprehend the text in front of them, which is known as fluent reading (Benjamin & Gaab, 2012; Lyon et al., 2003). Fluent reading relies on the ability to automatically recognize and process words (Wolf & Bowers, 1999). Whilst reading feels effortless for most typically developed readers, many individuals with developmental dyslexia never achieve this level of fluency (Jones et al., 2008). In this way it can be considered that their reading ability does not become fully automatized (Jones et al., 2008). Rapid automatized naming (RAN) tasks are often used as a measure and predictor of reading fluency (Jones et al., 2008, 2009, 2010; Lervåg & Hulme, 2009; Wolf & Bowers, 1999).

The literature summarised above gives a glimpse of the great advances that have been made in understanding the process of how we read, and provides a solid foundation from which we can now begin to extend the field of reading research, moving beyond declarative texts into more stylistic forms. Indeed, a major reason that people read is for enjoyment, whether in the form of poetry or a novel, and it is imperative that we begin to understand what happens in neurocognitive function as we read for pleasure.

1.1.3. Neurocognitive Poetics

Neurocognitive poetics is a relatively new research field that brings together classical theorising from linguistics and poetics, with methods and findings from cognitive psychology and neuroscience (Jacobs, 2015a, 2015b). In other words, it applies a cognitive neuroscience approach to the study of literary reading. Key themes involve the influence of certain attentional, emotive and immersive qualities of text on the reading brain.

Much research and theorizing has centred on two primary types of features in text, which readers are known to use when extracting meaning. These are *backgrounding* techniques, which serve to familiarise the reader, and *foregrounding* techniques, which serve to defamiliarize the reader (Jacobs, 2015b). Both will be discussed in relation to relevant research below, with a greater focus on foregrounding, since the experimental chapters will investigate the neurocognitive effects of a common foregrounding technique: alliteration.

Backgrounding

Backgrounding elements in a literary text are used in order to familiarise the reader, and to create an immersive reading experience (Jacobs, 2015a, 2015b). These are considered responsible for the feeling of getting lost in a book, achieved through use of familiar schema, situations, words and phrases, and affective responses (Jacobs, 2015a, 2015b; Jacobs & Willems, 2017), and are thought to elicit quick, fluent reading which is characterised by larger saccades and fewer fixations (Jacobs, 2015b, 2015a). Broadly speaking the plot, character development, and building of suspense over a piece of work are all part of the backgrounding elements according to this model (Jacobs, 2015a, 2015b).

Research into backgrounding has focused on a number of variables, notably participants' experiences of in-text immersion, suspense, empathising with characters, physiological responses to emotional aspects of plot, and how these effects vary as a function of first and second language processing (Hsu, Jacobs, & Conrad, 2015; Hsu, Jacobs, Citron, et al., 2015; Jacobs, 2015a, 2015b; Riese et al., 2014; Wassiliwizky, Koelsch, et al., 2017). Backgrounding is an attractive choice for research since participants are presented with unedited literary works, be they full poems, or long excerpts from novels and therefore have relatively high ecological validity (Willems & Jacobs, 2016). Results from this type of research are particularly valuable in guiding insights in the literary community, yet the trade-off is the lack of experimental control: since there are many different stylistic manipulations within a literary piece, it is difficult to tease apart which variables in the text specifically lead to the measured response. Willems and Jacobs (2016) suggest a more 'traditional' experimental cognitive research approach on this type of phenomenon in order to inform and compliment backgrounding research. In this way, we will establish a full picture of how the effects of literature work, in a piece by piece manner.

Foregrounding

As described above, the purpose of foregrounding in literary works is to *defamiliarize* the reader, and to elicit a dysfluent reading style, characterised by longer fixations (Jacobs, 2015a, 2015b). What is meant by this, is that they capture the readers' attention, and turn reading from an automatic passive event, into a conscious experience (Jacobs, 2015a, 2015b; Miall & Kuiken, 1994). Foregrounding refers to the stylistic effects that occur in literary reading. These may operate at the phonetic level (e.g. assonance, rhyme, or alliteration), the grammatical level (e.g. inversion), or at the semantic level (e.g. irony or metaphor) (Miall & Kuiken, 1994). According to contemporary literary theory these stylistic techniques are thought to be particularly salient, in the way they capture attention, and engage interest, as compared to more neutral, declarative language (Jacobs, 2015b; Miall & Kuiken, 1994). In this way literature is thought to be a special case of language, wherein communicating meaning is of lesser importance than style (Jakobson, 1960; Miall & Kuiken, 1994). Foregrounding may be considered a more natural fit for use in traditional cognitive neuroscience experiments, as it is easier to identify and isolate foregrounding elements for experimental manipulation. I will now give an overview of relevant research relating to such foregrounding techniques, focusing mainly on studies that operate at the phonemic level, given the primary manipulation of stylistic text used in this thesis.

Neuroscientific research on foregrounding techniques

Scheepers et al (2013) conducted a pupillometry study, wherein participants were auditorily presented with Limericks, which are short, humorous poems with a highly constraining rhyme-scheme. Participants were presented with Limericks wherein the last word of the final line conformed to one of the following conditions: 1) no violation, 2) semantic violation, 3) a syntactic violation, 4) rhyme-scheme violation, or 5) metric violation. Each of these violations was in respect to the context that had been set-up throughout the Limerick (Scheepers et al., 2013). Whilst an anomaly rating scale showed that participants were highly accurate at detecting all the violation conditions, only the rhyme-scheme violation led to changes in pupil dilation. The authors interpret this increase in pupil size in response to rhyme-scheme incongruence as reflecting an emotional reaction (Scheepers et al., 2013).[1] They suggest that the reason that only rhyme-scheme incongruency (and specifically, not semantic incongruency) led to a pupillary increase, is due to the relatively greater importance placed on prosody than semantics within poetry (Jakobson, 1960; Scheepers et al., 2013).

In a similar study, participants were presented with verses from classic Chinese poems, that had a highly expected rhyme-scheme (Chen et al., 2016). Event-related potentials (ERPs)[2] were measured from the last character of each verse, which were either congruent or incongruent with the rhyme scheme and were also either semantically congruent or incongruent with the context of the preceding sentence. The ERPs of interest in this study were the P200 which here indexes pre-lexical processes wherein a phonological representation is assigned to a character, and the N400 which here indexes the ease with which a character is semantically integrated into the preceding context (Chen et al., 2016). The P200 results suggest that rhyme-scheme incongruence had a top-down pre-lexical influence on phonological representations. Interestingly, the N400 results were also affected by rhyme-scheme incongruency, in that semantically incongruent items only elicited a larger N400 (typically indexing more difficult semantic processing) when the rhyme scheme was

[1] See the next chapter ‘Methodological Considerations’ for an overview of pupil dilation.
[2] See the next chapter ‘Methodological Considerations’ for an overview of the event related potential technique.

congruent. The authors interpret this result as testimony to the highly biasing context of poetry (Chen et al., 2016).

Both of the above studies suggest that text genre has an impact on how they process information from the text (Chen et al., 2016; Hanauer, 1998; Jakobson, 1960; Obermeier et al., 2013; Scheepers et al., 2013). Indeed, Chen et al (2016) also cite the hypothesis by Jackobson (1960) that sound and meaning are more tightly bound in poetry than in declarative texts. As such, items that do not fit with the expected rhyme scheme may indeed be perceived as less semantically congruent (Chen et al., 2016; Jakobson, 1960). This interpretation is in line with literary theory surrounding foregrounding techniques (Miall & Kuiken, 1994). However, very little research has been conducted into how (and if) these phonological-semantic interactions would operate if participants were shown foregrounding techniques outside of the biasing context of poetry.

Vaughan-Evans et al (2016) conducted an ERP study on ‘Cynghanedd’, which is a form of foregrounding based on phonological and rhythmic principles with complex rules, and is commonly found in traditional Welsh poetry (Vaughan-Evans et al., 2016). The form of Cynghanedd which was used in that study, relies on consonantal repetition, and distinct stress patterns (Vaughan-Evans et al., 2016). Participants were presented with sentences which either conformed to the rules of Cynghanedd or violated the Cynghanedd in one or more ways (e.g. consonant violation, stress violation, or consonant and stress violation). Notably, unlike the other studies which were outlined above, these sentences were presented in isolation (i.e. not in the context of a poem or verse), and participants were unaware that the experiment pertained to poetry (Vaughan-Evans et al., 2016). Whilst the participants in this experiment did not rate the Cynghanedd sentences as sounding better than the other conditions, their ERP responses indicated that they implicitly detected the presence of Cynghanedd, without being consciously aware of it (Vaughan-Evans et al., 2016). This suggests that poetic form still captures readers attention more than neutral writing, even *outside* of the context of poetry or literature.

To summarise, the relatively new science of neurocognitive poetics is already amassing a considerable body of work, and appears to be driven by two principal agendas: first, to provide an empirical basis for historical and current debates in literary theory (Jacobs, 2015a, 2015b). Second, poetry and literature engage not only reading circuits, but also primitive limbic structures involved in emotional responses, and high-level semantic processing of schemata during the reading of narratives. Thus, empirical research on stylistic reading can be used to gain insights into underlying emotional, empathetic, and linguistic processes, that cannot be as effectively measured via typical psycholinguistic paradigms (Jacobs, 2015a, 2015b; D. C. Kidd et al., 2016; D. Kidd & Castano, 2013; Mar, 2011; Wassiliwizky, Jacobsen, et al., 2017). This latter use of neurocognitive poetics, wherein literature is a means through which to study cognitive phenomena, is the primary drive of this thesis. This is not to rule out however, the possibility that findings from this type of work could be of some benefit to researchers in the humanities.

1.2. Thesis Aims

In this thesis, I will investigate some of the potential neurocognitive effects of phonological repetition, outside of the context of poetry. This will allow for these effects to be studied outside of the biasing context of poetry and will allow for greater experimental control. Below I outline the three primary research questions which will be addressed:

RQ1 How does phonological repetition between words affect semantic processing and attentional engagement?

RQ2 How does phonological repetition between words affect semantic processing and attentional engagement in poor readers?

RQ3 How does the relationship between sound and meaning affect memory?

Whilst all three research questions are related to the neurocognitive effects of phonological repetition and broadly fall into the field of neurocognitive poetics, they also have ramifications for neurolinguistic and psycholinguistic theories. As such, the relevant theoretical and research background for each of these three research questions will now be briefly outlined in turn.

1.3. How does phonological repetition between words affect semantic processing and attentional engagement?

RQ1 will investigate whether a stylistic technique which is based on phonological repetition (alliteration) modulates semantic processing and attracts readers attention *outside* of the context of poetry. Additionally, this question as to the relationship between sound and semantics is central to the thesis as a whole, as **RQ2** and **RQ3** follow directly from this question. This section will now give a brief overview of the current debate in psycholinguistics regarding the relationship between phonology and semantics, and of some relevant research regarding how phonological repetition may influence semantic processing.

1.3.1. The Current Debate in Psycholinguistics

The mainstream viewpoint in psycholinguistics has been that the relationship between word form and meaning is largely arbitrary (De Saussure, 2011; Gasser, 2004; Lupyan & Winter, 2018). By this it is meant that the word used to describe a concept usually does not directly map onto its meaning (Gasser, 2004; Lupyan & Winter, 2018). This feature allows more flexibility in learning abstract meanings for example (Lupyan & Winter, 2018). It has also been suggested that if word form and meaning mapped more clearly onto one another, it would make learning the vast amount of words that exist in a language more difficult (Gasser, 2004). However this view of language as arbitrary is idealised, and does not take into consideration the many ways in which the form-meaning relationship is non-arbitrary (Dingemanse et al., 2015).

Iconicity and Sound Symbolism

The occurrence of iconicity in language, is often put forward as a rebuttal to the view that language is arbitrarily related to meaning. Iconic language refers to situations wherein there is a clear relationship between words form and meaning (Gasser, 2004; Lupyan & Winter, 2018; Monaghan et al., 2014; Perniss et al., 2010; Perniss & Vigliocco, 2014). The most salient example of iconicity is in onomatopoeia, wherein the sound of a word maps onto its meaning, e.g. “pop”, “bang”, “beep” (Lupyan & Winter, 2018; Monaghan et al., 2014; Perniss et al., 2010; Perniss & Vigliocco, 2014). Sound symbolism refers specifically to mapping between phonological properties of a word and aspects of its meaning, and may comprise a more subtle example of iconic language, such as specific sound types being often linked to specific meanings (Ković et al., 2010; Monaghan et al., 2014; Perniss et al., 2010; Sučević et al., 2015).

Perhaps the most famous experimental example of sound symbolism is that involving free association of shapes and nonsense words. Participants will overwhelmingly associate a word with unrounded vowels such as ‘kiki’ as referring to the spiky shape and a word with rounded vowels such as ‘bouba’ with the round shape (Fryer et al., 2014; Ković et al., 2010; Sučević et al., 2015; Sweeny et al., 2012; Westbury, 2005). Some of these sound-symbolic relationships occur across many languages and are considered universal (R. W. Brown et al., 1955; Dingemanse et al., 2015; Monaghan et al., 2014). Iconicity is more prevalent in non-indoeuropean languages (Monaghan et al., 2014) and sign-languages (Perniss et al., 2010; Perniss & Vigliocco, 2014), and has been shown to aid language learning in both oral and sign-language (Asano et al., 2015; Imai et al., 2008; Monaghan et al., 2012; Thompson et al., 2012). It has been suggested that sign languages are more iconic as there are more, very clear meaning-form mappings that can be made gesturally as compared to orally (Monaghan et al., 2014; Perniss et al., 2010; Perniss & Vigliocco, 2014; Thompson et al., 2012).

Following from these findings, many researchers are now advocating a more integrated view of language, that acknowledges the roles of both arbitrariness and iconicity in natural language (Ahlner & Zlatev, 2010; Dingemanse et al., 2015). Under a sound symbolism account, phonology has a direct influence on semantic processing (Ković et al., 2010; Monaghan et al., 2014; Perniss et al., 2010), but the role of phonology in inter-lexical processing is less clear (Clifton, 2015). I will now present some relevant evidence that has been conducted to address this gap in the research.

1.3.2. The Interaction Between Phonology and Semantics in Inter-Lexical Language

Empirical work using the tongue twister effect suggests that phonology has a direct effect on semantic processing in reading. Sentences with a high level of phonological overlap between words (e.g. “Barbara burned the brown bread badly”, Clifton, 2015) are visually presented to participants to read (Clifton, 2015; Haber & Haber, 1982; McCutchen & Perfetti, 1982). A recurring finding in these studies, and with variations of this paradigm, is that the phonological overlap between words in the sentence disrupts semantic processing as compared to control sentences with low phonological overlap (Clifton, 2015). Such inter-word phonological effects are found for sentence acceptability judgement accuracy, judgement speed, memory task responses, and participants' overall reading time for the sentence (Haber & Haber, 1982; Keller et al., 2003; Kennison et al., 2003; McCutchen et al., 1991, 1994; McCutchen & Perfetti, 1982; Robinson & Katayama, 1997; Zhang & Perfetti, 1993). Acheson and MacDonald (2011), also showed that when just two words within a sentence had high phonological overlap, participants were slower at reading the sentence from the point at which overlap occurred. Participants were also less accurate and slower at answering comprehension questions about these sentences than for low-overlap sentences which were matched for plausibility (Acheson & MacDonald, 2011). These results suggest that phonological representations has an online effect on sentence processing, which debunks alternative accounts stating that phonological effects on semantics are memory-driven (Acheson & MacDonald, 2011; Waters et al., 1987).

1.3.3. Concluding Remarks on The Relationship Between Phonology and Semantics

Here I have given a brief overview of the debate regarding the interaction between phonology and semantics as it relates to both **RQ1** and the thesis as a whole. I have also given an overview of some of the current research pertaining to this debate, with the aim that it will help to show the theoretical and research background of **RQ1**.

1.4. How does phonological repetition across words affect semantic processing and attentional engagement in poor readers?

Up until this point the field of neurocognitive poetics has focused solely on typical readers, despite the fact that adults with dyslexia do read for pleasure (Fink, 1998; Wennås Brante, 2013). We were interested to observe whether the same effects of phonological repetition would appear for semantic processing and attention in readers with dyslexia, as we see for typically developed readers (cf. **RQ1**). If the same effects are not seen, then this would suggest that a different mechanism may be underlying enjoyment of literary reading for these readers. If the same effects are seen, then this may give valuable insight into how to engage attention for readers with dyslexia, which may be helpful in aiding reading comprehension (Breznitz & Leikin, 2001; Shaywitz & Shaywitz, 2008). The following section will give a brief overview of the major theories of developmental dyslexia. It should be noted that none of the experiments in this thesis are directly testing or comparing these theories. Instead, this overview aims to give context to the population who are tested in Experiment 2, and to help guide the hypotheses and interpretation for that study.

Developmental dyslexia (henceforth referred to as dyslexia) is a specific reading impairment which affects approximately 5-10% of the population, and is characterised by difficulty in learning to decode print, i.e. learning to map phonology onto orthography in reading (Ahissar, 2007; Hulme & Snowling, 2016; Snowling & Hulme, 2012). A diagnosis of dyslexia is given when a reading impairment is present, even when the individual has normal nonverbal IQ, adequate educational opportunity, and no sensory problems that would disrupt normal reading (Lyon et al., 2003; Peterson & Pennington, 2015). In adulthood, reading and spelling can become highly compensated in individuals with dyslexia, such that many progress to third-level education, which typically involves high-literacy demands (J. Hatcher et al., 2002). However, dyslexia remains a lifelong condition, and even highly compensated readers have deficits in phonological tasks (e.g. rapid naming, and nonword reading/repetition), reading speed, and written expression/structure (Bruck, 1992; J. Hatcher et al., 2002; Jones et al., 2010; Ramus & Szenkovits, 2008; Shaywitz et al., 1998). It should be noted that despite these reading deficits, individuals with dyslexia have unimpaired semantic processing skills, and can use their semantic abilities to boost their phonological skills (Snowling, 2000; van Rijthoven et al., 2018).

1.4.1. Theories of Dyslexia

The Phonological Deficit Hypothesis

There are a number of theories regarding the underlying cause of dyslexia (cf. Vellutino, Fletcher, Snowling, & Scanlon, 2004 for an overview), though the most widely accepted is the Phonological Deficit Hypothesis. This posits that dyslexia may be best described as a core phonological deficit, resulting from degraded phonological representations (Snowling, 1998; Snowling, 2000; Stanovich, 1988; Snowling & Nation, 1997). These poor representations of speech sounds lead to difficulty in learning grapheme-phoneme correspondences, and therefore to decoding problems (Ramus et al., 2003; Snowling, 2000; Vellutino & Fletcher, 2008). There are three main dimensions of the phonological deficit in dyslexia, namely problems with phoneme awareness, verbal short-term memory, and lexical retrieval (Mengisidou & Marshall, 2019; Ramus & Szenkovits, 2008; Vellutino et al., 2004; Wagner & Torgesen, 1987). These three skills can be considered the cognitive foundations for successfully learning to read, and appear to be causally related to reading impairments in dyslexia (Hulme & Snowling, 2015).

Phonological awareness is the ability to make judgements about, or manipulate phonemes in words/nonwords (L. Bradley & Bryant, 1983; Hulme & Snowling, 2015; Melby-Lervåg et al., 2012). Both children, and compensated adults with dyslexia perform poorly on measures of phonological awareness such as phoneme deletion tasks (Bruck, 1992; Lyon, Shaywitz, & Shaywitz, 2003; Pennington, van Orden, Smith, Green, & Haith, 1990; Snowling, Nation, Moxham, Gallagher, & Frith, 1997; Wilson & Lesaux, 2001;Vellutino et al., 2004; Felton, Naylor, & Wood, 1990). Phonological awareness is a strong predictor of future reading ability, and interventions focused on improving phonological awareness are beneficial for reading (L. Bradley & Bryant, 1983; Elbro & Petersen, 2004; Foorman et al., 1998; P. Hatcher et al., 1994; Melby-Lervåg et al., 2012; Schneider et al., 2000; Torgesen, 2005; Torgesen, Wagner, Rashotte, et al., 1999; Vellutino et al., 2004; Wise et al., 1999). This appears to support the idea that phonological awareness has a causal role in reading impairments in dyslexia (Vellutino et al., 2004).

Despite the strong evidence in support of the phonological deficit theory, it has been heavily criticised. Firstly, not all individuals with dyslexia display a phonological deficit (Castles & Coltheart, 1993; Pennington et al., 2012; Peterson et al., 2014; Stein, 2019). Secondly, readers with dyslexia perform within normal parameters on tasks that rely on strong phonological representations, which contradicts the predictions of Phonological Deficit Hypothesis (Ramus, 2001a; Ramus & Ahissar, 2012; Ramus & Szenkovits, 2008). Finally, readers with dyslexia also display a range of low-level visual, motor, and attentional deficits, which are not accounted for by this theory (Harries et al., 2015; Klein, 2002; Ramus & Ahissar, 2012; Stein, 2019; Vellutino et al., 2004). Proponents of the phonological hypothesis consider these deficits as potential markers for dyslexia, when they co-occur with phonological deficits, but do not see them as core features of the aetiology (Ramus et al., 2003; Snowling, 2000). Some critics of the phonological hypothesis also hold that the logic underlying the hypothesis is tautologous, and not explanatory (Stein, 2019). They state that as decoding is what underlies successful reading, describing dyslexia as a deficit in this ability is not helpful as it does not explain why the deficit exists (Stein, 2018, 2019).

I will now give a brief overview of some relevant alternative theories that have been proposed in order to address these criticisms.

Deficient Phonological Access Hypothesis

This hypothesis aimed to address one of the main criticisms of the phonological deficit hypothesis. Namely, if phonological representations are degraded or ‘fuzzy’ in individuals with dyslexia, why do they perform normally on tasks relying strongly on these representations (Ramus, 2001a; Ramus & Ahissar, 2012; Ramus & Szenkovits, 2008). The three dimensions of the phonological deficit in dyslexia (phoneme awareness, verbal short-term memory, and lexical retrieval) all involve accessing phonological representations (Ramus & Szenkovits, 2008; Vellutino et al., 2004). Ramus & Szenkovits (2008) state that despite phonological representations being at the centre of these deficits, it does not necessarily follow the representations themselves are degraded. They posit that readers with dyslexia have normal phonological representations, but that phonological access is impaired under certain task demands. Namely tasks that require quick phonological access, have a high working memory load, or require overt manipulation of phonemes (Mengisidou & Marshall, 2019; Ramus & Szenkovits, 2008). Evidence for this interpretation comes from experiments in which participants with dyslexia were only impaired on phonological tasks if working memory was taxed or fast responses were required and not in tasks that directly assess phonological representations (Boets et al., 2013; Dickie et al., 2013; Mengisidou & Marshall, 2019; Ramus et al., 2013; Ramus & Szenkovits, 2008; Soroli et al., 2010; Szenkovits et al., 2016).

The Phonological Recoding Self-Teaching Hypothesis

The phonological recoding self-teaching hypothesis (PRST) posits that during typical reading development readers gain word-specific orthographic representations through ‘self-teaching’ opportunities, wherein they phonologically recode new words (Share, 1995, 1999). Phonological recoding refers to the ability to translate written letters into speech sounds (Share, 1999). For readers with dyslexia this hypothesis posits that they have an impairment in phonological recoding that disrupts their ability to develop an autonomous orthographic lexicon (Jones et al., 2016; Share, 1995). For typical readers, repeated exposures strengthen these orthographic representations, but due to compromised neural links in the formation of visual-orthographic and phonological bindings, dyslexic readers build less well-specified orthographic representations than typical readers do (Ehri, 2005b, 2005a; Ehri & Saltmarsh, 1995; Jones et al., 2016).

Sensory and Attentional Theories

A number of theories have attempted to account for the presence of sensory and attentional deficits in individuals with dyslexia. The major theories in this vein originally focused on dysfunction in rapid auditory (cf. the auditory deficit hypothesis; Tallal, 1980) or visual perception (Livingstone et al., 1991; Lovegrove et al., 1980), or in visuo-spatial attention (Vidyasagar & Pammer, 2010). Visual theories mostly relate visual deficits to dysfunction of the magnocellular system (Livingstone et al., 1991; Milner & Goodale, 2008; Vidyasagar & Pammer, 2010). Recent formulations of the magnocellular theory of dyslexia have conceptualised sensory deficits as being due to impairment in temporal processing of sequences, regardless of modality (Stein, 2019).

Magnocellular theory

Difficulty in sequencing auditory (speech sounds) and visual (letters in words) inputs has been proposed as an underlying sensory cause for reading difficulties in dyslexia (Stein, 2019; Stein & Walsh, 1997; Vidyasagar & Pammer, 2010). The magnocellular theory posits that dyslexia is caused by impaired development of the magnocellular (or transient) system in the brain (Stein, 2019; Vidyasagar, 2013). This is one of two parallel visual processing streams, and the magnocellular neurons within it are sensitive to movement and rapid changes in the visual field (Stein, 2019; Vellutino & Fletcher, 2008). This system is active during saccades in reading, and has been shown to be vital for sequential visual attention (Stein, 2019; Vellutino & Fletcher, 2008; Vidyasagar, 2013). The dorsal visual processing stream has many magnocells, and as such is also known as the magnocellular-dorsal (M-D) attention stream (Stein, 2019). There is an analogous transient system for auditory processing, which functions in much the same way (Stein, 2019).

There is a large body of evidence suggesting that the development of this system is impaired in individuals with dyslexia (Cornelissen et al., 1998; Eden et al., 1996; Livingstone et al., 1991; Lovegrove et al., 1980; Stein, 2018, 2019). This is thought to impact reading in these individuals in the following ways; 1) Slower identification and sequencing of letters, as the M-D system normally facilitates this through focusing ventral stream attention to the letters, and sequencing them (Giraldo-Chica et al., 2015; Howard et al., 2006; Jednoróg et al., 2011; Ozernov-Palchik et al., 2017; Stein, 2019; Stein & Walsh, 1997; Vidyasagar & Pammer, 2010). 2) Less stable fixations, and impaired eye convergence during reading, leading to the illusory appearance of words/letters moving around (visual stress) or seeing double (diplopia) (Bucci et al., 2008; Singleton & Henderson, 2007; Singleton & Trotter, 2005; Stein, 2019). 3) Difficulty in directing visual attention to a specific word in the context of ‘crowded’ sentence, leading to slower and less accurate reading (Gori & Facoetti, 2015;

Martelli et al., 2009; Stein, 2019; Zorzi et al., 2012). 4) Similarly visual/auditory cross-cueing of attention is impaired, which interferes with the learning of grapheme-phoneme correspondences, necessary for decoding in reading (Gabrieli & Norton, 2012; Hahn et al., 2014; Harrar et al., 2014; Ruffino et al., 2014; Stein, 2019).

The main criticisms of this theory related to the lack of consistency with which studies find auditory or visual deficits in individuals with dyslexia, with approximately one third of individuals with dyslexia showing these sensory impairments (Ramus, 2001b; Ramus et al., 2003; Share et al., 2002; Tallal, 1980). Also, studies which use similar methodologies to pinpoint magnocellular deficits find inconsistent results (Ben-Yehudah et al., 2001; Borsting et al., 1996; Spinelli et al., 1997). Additionally, sensory deficits, when shown, extend to stimuli that do not rely on the magnocellular system, which casts doubt on the causal role of magnocellular dysfunction (Amitay et al., 2002, 2003; Farrag et al., 2002; Ramus, 2001b; Ramus et al., 2003; Skottun, 2000). Proponents of this theory acknowledge that magnocellular dysfunction is therefore highly unlikely to be the sole cause of dyslexia (Stein, 2019).

Sluggish attentional shifting hypothesis

Attention also appears to have an important role to play in phonological recoding, reading ability, and fluency, and some researchers suggest that may have a causal role in reading impairment (Hari & Renvall, 2001; Shaywitz & Shaywitz, 2008). The Sluggish Attentional Shifting (SAS) hypothesis attempts to account for the impaired processing of rapid stimulus sequences in readers with dyslexia as an attentional deficit (Hari & Renvall, 2001; Lallier et al., 2010; Stoet et al., 2007). This builds on the suppositions of the magnocellular theory that parietal lobe dysfunction leads to deficits in attention, which therefore interferes with rapid temporal processing (Hari & Renvall, 2001; Lallier et al., 2010; Stein, 2019; Stein & Walsh, 1997). Proponents of this viewpoint acknowledge that deficits may be present due to magnocellular dysfunction, but propose an independent role of attention as the core deficit in dyslexia (Hari & Renvall, 2001). The SAS posits that individuals with dyslexia are significantly delayed at switching their attentional focus (i.e. at disengaging from one stimulus and engaging with a new one), when stimuli are presented in a rapid sequence (Hari & Renvall, 2001). This results in individuals with dyslexia having a longer 'cognitive window' or 'input chunk' (i.e. time taken to process information) than typical readers (Hari & Renvall, 2001). As such, the sequence of events within this cognitive window is easily confused (Hari & Renvall, 2001). This atypical perception of rapid sequences leads to speech segmentation and letter scanning impairments, which may underlie deficient grapheme-phoneme representations and phonological awareness in individuals with dyslexia (Blomert, 2011; Hari & Renvall, 2001; Krause, 2015; Lallier et al., 2010, 2013).

Behavioural studies have shown that participants with dyslexia have slower covert attentional orientating to both visual and auditory stimuli (Facoetti et al., 2005, 2010; Krause, 2015). Facoetti et al. (2010) found that phonological decoding ability correlated with the time-course of spatial attention for readers with dyslexia, in both domains. This supports the notion of sluggish attention underlying reading deficits (Facoetti et al., 2010). Evidence in favour of SAS, also comes from the consistent finding that readers with dyslexia have stimulus stream integration and segregation deficits (Helenius et al., 1999; Krause, 2015; Lallier et al., 2010; Ouimet & Balaban, 2010). Further support for this hypothesis comes from the finding that individuals with dyslexia having a longer attentional blink than typical readers (Hari & Renvall, 2001; Lallier et al., 2010). They also show perceptual-level attentional shifting deficits, but are not impaired on task-switching, which lends support to the notion that magnocellular deficits may be involved in the visual attention deficits found (Doyle et al., 2018; Lallier et al., 2010; Stoet et al., 2007). Recent evidence has shown that inhibition deficits in children with dyslexia are predictive of reading ability, and do not differ between children with/without comorbid ADHD (Doyle et al., 2018; Lonergan et al., 2019). Critics of this theory focus on the fact that individuals may have attentional deficits in the absence of reading deficits, which suggests that attentional deficits are not sufficient to cause dyslexia (Ahissar, 2007).

Anchoring-deficit hypothesis

Another alternative theory as to the core deficit in dyslexia is the anchoring deficit hypothesis; which states that people with dyslexia have perceptual problems that affect the efficiency of working memory, that are due to failing to create a perceptual anchor when repeatedly presented with a stimulus (Ahissar, 2007; Ahissar et al., 2006; Oganian & Ahissar, 2012; Willburger & Landerl, 2010). For typical readers, stimuli which are repeated become perceptual anchors, which helps them to make stronger predictions about upcoming stimuli (Ahissar, 2007; Ahissar et al., 2006). Participants with dyslexia however, are less efficient at detecting regularities in perceptual input, including written word repetitions (Ahissar, 2007; Oganian & Ahissar, 2012). This leads to them to rely less on predictions and instead are more likely to make inferences based on each individual stimulus/set in isolation (Ahissar, 2007; Jones, Kuipers, Nugent, Miley, & Oppenheim, 2018; Oganian & Ahissar, 2012). This hypothesis also posits that, contrary to the predictions of SAS, individuals with dyslexia do not suffer from top-down attentional deficits (Ahissar, 2007). Instead, their bottom-up attentional mechanisms are impeded, as they cannot strategically focus attention based on implicit predictions built from stimulus repetition in the same way that typical readers do (Ahissar, 2007). Poor anchoring may also impede the efficient learning of phonological regularities in a language (Oganian & Ahissar, 2012). This relationship is thought to be reciprocal, in that anchoring may be important for learning regularities and that once the regularities of a language are learned they are easier to then anchor to, which aids in the fluent reading of regular words and non-words (Oganian & Ahissar, 2012).

Similar to the SAS, proponents of this theory highlight readers with dyslexia having a longer attentional blink (Ahissar, 2007; Hari & Renvall, 2001). As attentional blink protocols tend to repeat stimuli, longer processing time for individuals with dyslexia may reflect an impaired perceptual anchor as opposed to top-down attentional deficits, as suggested by proponents of the SAS (Ahissar, 2007; Hari & Renvall, 2001; Lallier et al., 2010). In support of this proposal, participants with dyslexia are relatively poor at discriminating target stimuli, which are presented in the context of a reference that is repeated across trials, as opposed to when a new reference is used for each trial (Ahissar et al., 2006). This effect has been shown using auditory, visual, and linguistic stimuli (Ahissar, 2007; Ahissar et al., 2006; Oganian & Ahissar, 2012). However, more nuanced conclusions were derived from a study in which poor readers were split by attentional ability: only those who had both reading and attentional deficits showed an anchoring deficit (Willburger & Landerl, 2010).

Behavioural and ERP studies have also shown that individuals with dyslexia are impaired in detecting statistical regularities from perceptual input, due to faster decay of their implicit memory for preceding stimuli (Gabay et al., 2015; Jaffe-Dax et al., 2015, 2016, 2017; Jones et al., 2018). Computational models have since been developed to complement the human data, suggesting that dyslexia involves impaired statistical learning based on a fundamental anchoring deficit (Jaffe-Dax et al., 2015).

1.4.2. Concluding Remarks on Dyslexia

This section presented a brief overview of the most prominent causal theories of dyslexia. There is clearly no current consensus as to the cause or core deficit, but all theories agree that impaired phonological processing is a key manifestation of dyslexia (if not its underlying cause). As such, testing this population for **RQ2** will enable us to investigate how phonological repetition impacts semantic processing, and attentional engagement in readers with impaired grapheme-phoneme mappings. Given what we know about dyslexia, it seems likely that phonological repetition will not influence semantic processing in the same way that it does for typical readers. If, however phonological repetition leads to a boost in attentional engagement (**RQ1**), then this may aid semantic processing for readers with dyslexia via a top-down attentional boost.

1.5. How does the relationship between sound and meaning affect memory?

Experiment 4 of this thesis will address **RQ3** which examined the mnemonic effects of alliteration. Literary theorists hold that poetic devices involving phonological repetition (e.g. rhyme, alliteration) have mnemonic properties (Fabb, 2010; Rubin, 1995), but there is as yet scant empirical evidence to support this supposition. In Experiment 4, we will utilize neural correlates of recognition memory in order to investigate whether participants are better able to recognize alliterating than non-alliterating items. We will also investigate how semantic congruency affects this relationship (in line with the preceding three experiments). Indeed, previous research utilizing behavioural methods and ERP Old/New effects has suggested that semantic congruency can enhance recognition (Desaunay et al., 2017; Dougal & Rotello, 2007). The following section provides a brief overview of our current understanding of recognition memory, which will be helpful in guiding the hypotheses and interpretation for Experiment 4. Once again, the work reviewed serves as a framework for Experiment 4, but we are not directly testing or comparing the theories outlined below.

1.5.1. Theories of Recognition Memory

Single-process models of recognition memory

Recognition refers to the judgement that a stimulus has been previously encountered (Rugg & Curran, 2007). Single-process models of recognition memory assume that such recognition judgements are based on one type of mnemonic information, usually (but not always) item familiarity (Heathcote et al., 2006; Rugg & Curran, 2007; Wixted, 2007). Familiarity is defined as the item's similarity to the contents of the individual's memory (Heathcote et al., 2006; Rotello & Heit, 1999). An item that is the same as a previously encountered stimulus will be highly familiar and recognizable (Heathcote et al., 2006; Rotello & Heit, 1999). Familiarity in recognition memory is defined as the memory strength of an item, and it gives continuous quantitative – but no qualitative – information about an item (Heathcote et al., 2006; Wixted, 2007). This means that the decision as to whether an item has been previously encountered or not is solely based on the strength of the items memory signal (Heathcote et al., 2006; Wixted, 2007).

Single-process models are often linked to signal detection theory, discussed further below (Wixted, 2007). However, single-process accounts of recognition memory are unable to account for participants' ability to actively recall a previous encounter with an item (Diana et al., 2006). Recent formulations of single-process theories have attempted to address this weakness, stating that recollection may occur in some instances, but underscoring its independence from recognition judgements (Diana et al., 2006). Whilst there is still some debate in the literature regarding how exactly recognition judgements are made, the majority of recent experimental studies are based on the assumption of a dual-process account, in which recognition is thought to be based on both familiarity and recollection (Diana et al., 2006; Rugg & Curran, 2007; Yonelinas, 2002; Yonelinas et al., 2010). As mentioned previously, single process theories of recognition memory are often linked to signal detection theory (SDT). In such formulations' familiarity is thought of as the signal which is being detected during recognition tasks. SDT will now be outlined in some detail below, along with the ways in which it relates to recognition memory.

Signal Detection Theory (SDT)

SDT is a quantitative theoretical framework in which to consider individuals' discrimination of two stimulus types. In the context of recognition memory, these stimulus types would comprise previously seen and new items (Stanislaw & Todorov, 1999). SDT posits that recognition memory decisions are based on memory signal strength, in relation to a decision criterion, which is only known to the participant (Stanislaw & Todorov, 1999; Wixted, 2007). Under this theory, recognition judgements consist of 'signal' (old) trials and 'noise' (new/lure) trials, and the decision criterion is based on a certain level of memory strength / familiarity. According to SDT, participant responses are influenced by a combination of sensitivity to detect signal (*d'*) and their decision criterion (*c*). If a participants' decision criterion is appropriate, and they are sensitive to the presence of the signal, then they will be able to detect signal from noise reliably (Stanislaw & Todorov, 1999). This will however be affected by the difference in familiarity of the different items (both old and new). Additionally, the decision criterion may be influenced by factors such as changes in participants' attention (Stanislaw & Todorov, 1999).

The SDT view of participants' decision making in recognition tasks is outlined in **Figure 3** below. Participants' decision criterion is on the x axis, with the probability of an 'Old' response on the y axis. In the example shown in **Figure 3**, participants make an 'Old' response when a criterion of 0.5 is reached. If the participant had a more liberal response bias, then their decision criterion would be further to the left in this example. This would increase both their proportion of hits, and their proportion of false alarms. Conversely, a more conservative response bias would lead to fewer false alarms, but also fewer hits.

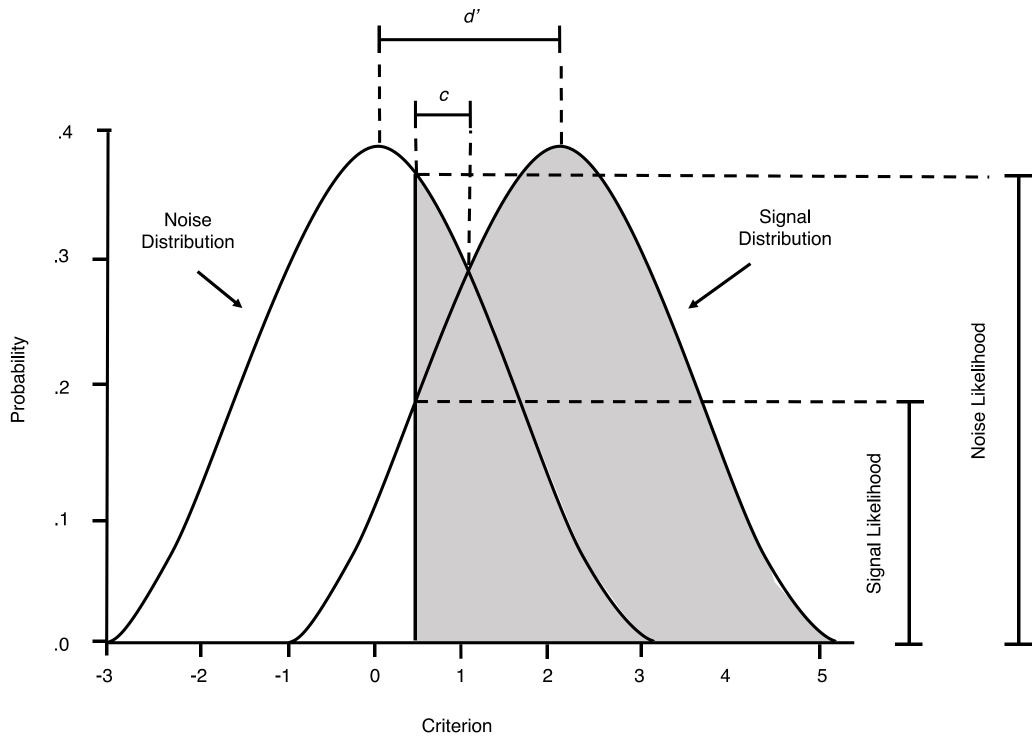

Figure 3: Example distribution adapted from Stanislaw & Todorov (1999), illustrating the decision variable across signal and noise trials, with *d'* and *c*. The hit rate is shown as the proportion of the signal distribution that exceeds the criterion, and the false alarm rate as the proportion of the noise distribution which does. Shaded area represents situations when participants would respond that they had previously seen an item.

SDT was originally considered compatible only with single-process accounts of recognition memory, given its assumption that quantitative memory signal strength (or familiarity) drives recognition judgements (Stanislaw & Todorov, 1999; Wixted, 2007). However, researchers have recently attempted to reconcile the signal detection view with dual-processing theories (Wixted, 2007; Yonelinas et al., 2010).

Dual-process theories of recognition memory

Dual-process theories of recognition memory are based on the assertion that recognition of a previously encountered stimulus is in fact based on two dissociable processes; familiarity and recollection (Jacoby, 1991; Mandler, 1980; Yonelinas, 2002; Yonelinas et al., 2010). A commonly used example which illustrates how these processes function is the *butcher-on-the-bus* example (cf. Mandler, 1980; Yovel & Paller, 2004). In this example you are asked to imagine that you see a person on the bus and realise that you know them from somewhere but are unsure as to who they are. This experience indicates face recognition driven by a strong sense of familiarity as the source of the memory remains unknown (Mandler, 1980; Yovel & Paller, 2004). You then try to recollect who they are and how you know them. Are they famous? Or an old friend? This reflects a retrieval process whereby individuals attempt to use context in order to remember the source of recognition. Finally, you realise that the man is in fact your butcher, whom you did not initially recognize outside of his usual context.

Recognition of the mans' true identity reflects recollection, wherein an individual actively remember who the person is, and the context through which they know them (Mandler, 1980; Yovel & Paller, 2004). Recollection is based on an active memory retrieval process whereby the present instance of a stimulus (in this case the butcher) is matched with previous memories (Mandler, 1980; Yonelinas, 2002; Yonelinas et al., 2010; Yovel & Paller, 2004). This type of recollection is also thought to underpin recall (Yonelinas et al., 2010). As illustrated in the above example, both familiarity and recollection have unique contributions to recognition (Mandler, 1980; Paller et al., 2007; Yonelinas, 2002). Familiarity is thought to be the *faster* of the two processes, but with the trade-off being that there is less information available (Rugg & Curran, 2007; Yonelinas et al., 2010). Dual-process models posit that whilst these two processes are dissociable and may occur independently of each other, they often co-occur and have an additive effect in aiding recognition (Mandler, 1980; Yonelinas, 2002).

The Dual Process Signal Detection Model (DPSD)

The dual-process signal detection model (DPSD) is a recent quantitative formulation of a dual-process theory, which attempts to account for a wide breadth of recognition study findings, both behavioural and ERP, and to reconcile dual-process theories and SDT (Wixted, 2007; Yonelinas et al., 2010). As the most recent and prominent of these theories, the DPSD has been applied as the theoretical framework for a number of electrophysiological studies, and will be the basis for the memory research in this thesis also (Dougal & Rotello, 2007; Rugg & Curran, 2007; Wixted, 2007; Yonelinas et al., 2010). The DPSD builds on previous formulations of dual-process theories by incorporating signal detection theory (SDT).

According to DPSD, familiarity may be conceptualised via signal detection, with every item giving off a memory signal (Wixted, 2007; Yonelinas et al., 2010). The strength of this memory signal informs how familiar we find an item, and recognition occurs when a very strong familiarity signal is present, i.e. when it reaches the criterion (Wixted, 2007; Yonelinas et al., 2010). This is also the proposed mechanism through which false alarms (where a new item is falsely identified as being recognized) are thought to occur (Wixted, 2007; Yonelinas et al., 2010). Under DPSD familiarity is thought to lead to accurate associative and source recognition judgements, also under certain circumstances (Yonelinas et al., 2010).

Recollection on the other hand is conceptualised as a threshold retrieval process (Wixted, 2007; Yonelinas et al., 2010). In contrast with familiarity, which exists on a continuum, items are either recollected or they are not. This is the key difference between

SDT and DPSD, since single-process theories do not account for such a threshold-dependent process (Diana et al., 2006; Stanislaw & Todorov, 1999; Yonelinas et al., 2010). An old item that reaches the recollection threshold is a hit, whereas an old item that does not is a miss. Recollection does not account for false alarms, since contextual information can only be recalled for previously seen items (Yonelinas et al., 2010). This is often described as the qualitative aspect of recognition memory (Wilding, 2000; Wilding et al., 1995; Wixted, 2007; Yonelinas, 2002; Yonelinas et al., 2010). Familiarity and recollection are each indexed by distinct ERP components, which will be outlined in some detail in the next chapter (Curran, 2000; Luck, 2014; Rugg & Curran, 2007; Wilding & Ranganath, 2012; Yonelinas, 2001).

Brain regions supporting familiarity and recollection

Under the DPSD account, recollection – the process of creating and retrieving associations in memory – is subserved by the hippocampus (M. W. Brown & Aggleton, 2001; Yonelinas, 2002; Yonelinas et al., 2002, 2010). Familiarity, however, is thought to be dependent on middle temporal lobe (MTL) regions surrounding the hippocampus, and to reflect repeated neural processing (M. W. Brown & Aggleton, 2001; Yonelinas, 2002; Yonelinas et al., 2002, 2010). Supporting evidence comes from lesion studies showing that recollection (but not familiarity) is impaired with hippocampal damage (Fortin et al., 2004; Yonelinas et al., 2002), and from fMRI studies showing under-activation of the hippocampus with impaired recollection (Heckers et al., 1998). Additionally, many fMRI studies have shown that the hippocampus is predominantly active during recollection, but not familiarity (Eichenbaum et al., 2007; Skinner & Fernandes, 2007; Yonelinas et al., 2010).

Similarly, other studies have shown that when patients have MTL lesions (specifically in the perirhinal cortex), but their hippocampus is spared, they are impaired for familiarity, but have spared recollection abilities (Bowles et al., 2007; Yonelinas et al., 2002). Event-related fMRI has also indicated that encoding-related activity in the rhinal cortex can predict familiarity based recollection, whereas hippocampal and posterior parahippocampal encoding related activity predicts recollection-based recognition (Ranganath et al., 2004). These studies suggest a functional dissociation whereby the hippocampus is mainly responsible for recollection, and the rhinal and perirhinal cortex is implicated in familiarity (Bowles et al., 2007; M. W. Brown & Aggleton, 2001; Fortin et al., 2004; Haskins et al., 2008; Heckers et al., 1998; Ranganath et al., 2004; Yonelinas et al., 2002, 2010).

However, an alternative account suggests that these studies conflate recollection with memory strength, suggesting that stronger memories recruit more hippocampal activity than weaker memories (C. N. Smith et al., 2011; Wais et al., 2006, 2009). Recollection tends to be accompanied by higher confidence memory judgements and greater accuracy (Yonelinas et al., 2010), and as such they suggest that what has been called recognition-specific activation in the literature, may in fact be a by-product of these memories being stronger (C. N. Smith et al., 2011; Wais et al., 2006, 2009). Support for this interpretation comes from fMRI studies, which show familiarity-related hippocampal activation during old-new memory judgements, when confidence ratings were high for familiarity-based judgements (C. N. Smith et al., 2011; Wais et al., 2009). This view is also supported by lesion studies, which suggest that both recollection and familiarity are impaired when the hippocampus is damaged (Manns et al., 2003; Wixted & Squire, 2004).

Additionally, there is evidence that the prefrontal cortex (PFC) is important for recognition memory, both during encoding and retrieval (Yonelinas, 2002; Yonelinas et al., 2010). Some have argued that the PFC is involved mainly in recollection (Janowsky et al., 1989; Wheeler et al., 1997; Wheeler & Stuss, 2003). This view has been supported by lesion studies, which show that recall is more impaired with PFC damage than recognition (Farovik et al., 2008; Wheeler et al., 1995, 1997), and that source memory deficits are worse than item recognition tests for these patients (Janowsky et al., 1989; Shimamura et al., 1990). Although another study suggests that the recall impairment may be driven by participants whose pathologies extend to the MTL (Kopelman et al., 2007). Conversely, other lesions studies have shown that either familiarity is impaired, and recollection is intact (Aly et al., 2011), or that both familiarity and recollection are impaired (Duarte et al., 2005; Kishiyama et al., 2009; MacPherson et al., 2008) when the PFC is damaged. TMS studies have indicated that disrupting the PFC led to impairment for both recollection and familiarity, but only during encoding, as stimulation during retrieval had no effect (Turriziani et al., 2008, 2010; Yonelinas et al., 2010). This is contrary to the neuroimaging literature, which typically suggests that the PFC is active during both retrieval and encoding, and again that is important for both recollection- and familiarity-based recognition (Blumenfeld & Ranganath, 2007; Dobbins et al., 2004; Henson et al., 2000; Yonelinas et al., 2005, 2010). Though there are also fMRI studies which suggest that the PFC is only active during recollection (Kahn et al., 2004). Overall while there is no clear consensus on the precise role of the PFC in recognition memory, it seems apparent that it is does indeed play a role, and it does not seem likely that it is specific to either recollection or familiarity (Yonelinas et al., 2010).

1.5.2. Concluding Remarks on Recognition Memory

Here I have given a brief overview of some of the most prominent theories regarding recognition memory. This overview is not exhaustive, as the literature on this area is vast, and outside of the remit of this thesis. Indeed, there are many variants of both single-process and dual-process theories, which have not been discussed. However, electrophysiological research on this topic is commonly aligned to some form of dual-process theory (Addante et al., 2012; Curran, 2000; Curran & Friedman, 2004; Desaunay et al., 2017; Rugg & Curran, 2007; Wilding & Ranganath, 2012). As such, the DPSD will be the theoretical framework for Experiment 4, with classic SDT methods being used to investigate the effects of alliteration on recognition memory and response bias. The use of ERP Old/New effects will allow us to investigate to what extent mnemonic properties of alliteration effect either familiarity or recollection, addressing **RQ3**.

1.6. Chapter Summary

In this chapter, I outlined the primary theoretical concerns of my thesis, and the ensuing research questions. Neurocognitive poetics is a relatively new field, which has of yet been primarily focused on the effects of stylistic techniques *within* the context of poetry. This thesis aims to go beyond this approach and investigate the neurocognitive effects of alliteration *outside* of the biasing context of poetry. As such, I refer throughout not only to the extant research in this field, but also to relevant theorising and research in other domains, notably cognitive neuroscience, and psycholinguistics. The primary aims of this thesis are to establish 1) how sound interacts with meaning in normally developed adult readers, 2) how this interaction may differ in poorer (dyslexic) readers, and 3) whether such stylistic manipulation of sounds experienced online latterly affect recognition of the linguistic content. In the next chapter, I outline the experimental design, and methodologies used in the experimental chapters.

Chapter 2

Methodological Considerations

2.0. Chapter Overview

This chapter describes and justifies the two principal methodologies used in the thesis. I will therefore outline how event related potentials (ERPs; Experiments 1, 2, and 4) and pupil dilation (PD; Experiments 1, 2, and 3) provide precise temporal indices of early cognitive and attentional processes, useful for addressing the research questions outlined at the end of the previous chapter. First, I briefly describe the rationale for the design of the stimuli. Following this, I describe the principles and main components of interest in ERP and PD measures, paying particular attention to the less-well established measure of PD. Detail of these implicit cognitive measures is then followed by a separate description of explicit behavioural measures (accuracy and reaction times). Finally, I will outline and briefly discuss the literacy and cognitive tests, which were administered in each of the experiments.

2.1. Stimulus Design

As outlined in the previous chapter, the central research questions in this thesis focus on the relationship between word form and meaning during silent reading. We therefore constructed word-pairs, corresponding to short adjective-noun phrases that were orthogonally manipulated across the dimensions of semantic congruency and alliteration.

e.g.

a. Dazzling – Diamond (Congruent – Alliterating)
b. Sparkling – Diamond (Congruent – Non-Alliterating)
c. Dangerous – Diamond (Incongruent – Alliterating)
d. Creepy – Diamond (Incongruent – Non-Alliterating)

Semantic congruency was manipulated by presenting plausible and implausible adjective-noun contingencies, in which the adjective (presented first, in isolation) altered the expectancy level – i.e., the congruency or incongruency – of the subsequent noun (presented second, also in isolation).

Short phrases were chosen (rather than sentences, for example), in order to exert high levels of experimental control. Specifically, we were able to ***fully counterbalance all adjective and noun stimuli across the experimental session***. The fact that all stimuli had equal probability of appearing in any given condition meant that lexical factors were fully controlled across conditions; a very important consideration, given that both ERPs and pupil dilations are highly susceptible to the perceptual and linguistic properties of lexical stimuli. This design also enabled us to examine the neurocognitive effects of alliteration on meaning comprehension *without* the biasing context of literary genre (Chen et al., 2016; Scheepers et al., 2013).

The same set of stimuli were used for Experiments 1, 2, and 3 (see **Appendix A**). New stimuli were constructed for Experiment 4 (see **Appendix B**), though there is some overlap with the original stimulus set. Please note that for the stimuli used in Experiments 1, 2, and 3 were 99.9% rotated, with 6 of the pairs not appearing in all conditions, due to the constraints of semantic congruency.

2.2. Event Related Potentials (ERPs)

Electroencephalography (EEG) reflects a continuous signal of electrical activity that is generated by postsynaptic potentials in the brain (Luck, 2014; Luck & Kappenman, 2012). For experimental purposes this signal is measured by electrodes, which are placed in pools of electroconductive gel on a participant's scalp (Luck, 2014). ERPs consist of variations of the voltage of this EEG waveform, time-locked to a stimulus of interest; in our experiments the noun in an adjective-noun phrase (Luck, 2014; Luck & Kappenman, 2012). Whilst some large ERPs can be seen from single trials, it is typical to average across many trials to improve the signal-to-noise ratio (Luck, 2014). From this averaged data, ERP components can be identified, with between-condition differences being ascertained via differences in voltage amplitude (Luck, 2014).

ERPs are an online, non-invasive measure of a participant's implicit response to a stimulus (Luck, 2014). They also have very high temporal resolution, which allows for millisecond-level precision at identifying neural responses to a stimulus, and they often unveil responses which are not apparent at the behavioural level (Luck & Kappenman, 2012; Rugg, 1995). Several ERP components are known to index specific cognitive processes (e.g. the N170 component is specifically responsive to viewing faces), and as such are useful in investigating how different experimental manipulations affect these processes (Luck, 2014; Luck & Kappenman, 2012).

Our experiments were specifically designed to elicit predictable modulations in mean amplitudes of the N400 component, and ERP old/new effects, which are discussed below.

The N400

The N400 component is a negative-going ERP, which occurs between 200 - 600ms post-stimulus onset, is maximal over centro-parietal electrodes, and is larger in response to semantic expectancy violations (Kutas & Federmeier, 2011; Luck, 2014; Swaab et al., 2012). This is the most researched language-related ERP component, and it is thought to be a reliable index of semantic integration, and words that are easier to integrate with the preceding context elicit a reduced-amplitude N400 (Luck, 2014; Swaab et al., 2012). A typical experimental paradigm to elicit an N400 would involve highly semantically constraining sentences with an incongruent final word, e.g.

"I take my coffee with cream and **dog**" (Kutas & Hillyard, 1980).

The final word in this sentence should elicit a large N400 component as it is semantically incongruent with the preceding context (Luck, 2014), and the N400 is especially responsive to words in this final position (Kutas & Federmeier, 2011). N400 effects have reliably been shown in a variety of populations in both the visual and auditory domains, and are also elicited by non-linguistic stimuli such as pictures (Friedrich & Friederici, 2004; Kutas & Federmeier, 2011; Nigam et al., 1992; O'Rourke & Holcomb, 2002; Schulz et al., 2008; Swaab et al., 2012; West & Holcomb, 2002)

Importantly for the research reported in this thesis, the N400 is also reliably elicited by semantically unrelated word-pairs, in which the second word does not make sense in the context of the first (Hinojosa et al., 2001; Holcomb & Neville, 1990; Kiefer et al., 1998; Silva-Pereyra et al., 1999). As you will note from section 2.1 above, the experimental manipulations (particularly the incongruency manipulation) reported in this thesis follow the logic and paradigms commonly used to elicit an N400 effect. We would therefore expect a larger N400 for our semantically incongruent word-pairs. In the context of linguistic stimuli, the N400 can be taken as an index of ease of semantic integration, with a greater N400 indicating greater difficulty in comprehension (Kutas & Federmeier, 2011).

The ERP Old/New effect

Having examined whether the inter-lexical manipulation of sound (alliteration) affects access to meaning (semantic integration) in Experiments 1, 2, and 3, Experiment 4 focused on whether alliteration also facilitates the consolidation and/or retention of phrasal information in long-term memory. We therefore examined how our manipulations of semantic congruency and alliteration affect recognition, measured via the ERP Old/New effect (Curran, 2000). Dual-process theories of recognition memory posit that there are two separate processes that contribute to recognition memory: familiarity and recollection (Curran, 2000; Rugg & Curran, 2007; Yonelinas, 2001). As such, the Old/New effect is actually comprised of two distinct and functionally, temporally, and topographically dissociable ERP components: a) the midfrontal old-new effect (or FN400), and b) the left-parietal old-new effect (or late positive component; LPC), both of which are named after their topography (Luck, 2014; Wilding & Ranganath, 2012).

The midfrontal old-new effect peaks between 300 - 500 ms post-stimulus onset and new (previously unseen) items typically elicit larger negativity compared with old items. This effect is thought to index familiarity (Addante et al., 2012; Curran, 2000), which is conceptually defined as “information that supports recognition in the absence of recollection” and operationally defined as strength of memory signal in the absence of context (Rugg & Curran, 2007; Wilding & Ranganath, 2012; Yonelinas et al., 2010).

The left-parietal old-new effect peaks between 400 - 800 ms post-stimulus onset and consists of a larger positive-going amplitude for old items compared to new ones. This effect is thought to index recollection, which indicates a conscious memory of having encountered the specific item previously, and of the context in which it was encountered (Addante et al., 2012; Curran, 2000; Wilding & Ranganath, 2012). As such larger amplitudes are only seen for items which participants actively remember having seen (Addante et al., 2012; Curran, 2000; Rugg & Curran, 2007).

2.3. Pupil Dilation

Pupil dilation refers to expansion of the pupil in response to a stimulus, through contraction of the iris dilator muscle and relaxation of the iris sphincter muscle, which are controlled by the parasympathetic and sympathetic nervous systems respectively (Larsen & Waters, 2018; Mathôt, 2018). Pupillometry (the measurement of this dilation) has been used for over 50 years as an implicit measure of the "intensity" of cognitive activity, specifically attentional allocation and perceptual consolidation (Laeng et al., 2012). Research using this method has mostly focused on pupil dilation increase as a function of either: 1) emotionally arousing stimuli and / or increased attention (M. M. Bradley et al., 2008; Hess et al., 1965; Hess & Polt, 1960; Partala & Surakka, 2003; Siegle et al., 2003; Wang et al., 2018), or 2) mental effort or executive load (e.g. Beatty, 1982; Beatty & Kahneman, 1966; Hess & Polt, 1964; Just & Carpenter, 1993; Kahneman & Beatty, 1966; Kang, Huffer, & Wheatley, 2014; Laeng, Ørbo, Holmlund, & Miozzo, 2011; Piquado, Isaacowitz, & Wingfield, 2010; Van Gerven, Paas, Van Merriënboer, & Schmidt, 2004; Zekveld, Heslenfeld, Johnsrude, Versfeld, & Kramer, 2014).

Neuroscience has intensified its focus on the biology and function of pupil dilation in recent years, particularly on the relationship between the locus coeruleus-noradrenergic (LC-NA) system and pupil dilation (see Laeng et al., 2012; Larsen & Waters, 2018; Mathôt, 2018 for reviews of the recent literature). The locus coeruleus (LC) is part of the pupil dilation pathway, and increased dilation has been shown to correlate with increased noradrenergic activity in this region (Joshi et al., 2016; Larsen & Waters, 2018; Mathôt, 2018; Reimer et al., 2016). Broadly speaking the LC-NA system is involved in autonomic arousal, which directly affects wakefulness/sleep, focused attention, and sensory and memory processes[3] (Aston-

[3] We direct the interested reader to Adaptive gain theory (Aston-Jones & Cohen, 2005) for an extensive theory as to the role of LC-NA in behaviour.

Jones & Cohen, 2005; Berridge & Waterhouse, 2003). Pupil dilation also correlates with other measures of autonomic arousal such as heart rate, and the galvanic skin response (M. M. Bradley et al., 2008; Wang et al., 2018). It has also been linked to increased BOLD activity in the LC (Murphy et al., 2014).

There are three stimulus categories which cause the human pupil to dilate: luminance (the pupillary light response; PLR), fixations to objects or areas of the visual field that are closer to the eye (the pupillary near response: PNR), and cognitive factors (the psychosensory pupil response: PPR). I will briefly outline all measures below, before focusing on the PPR as our measure of interest in Experiments 1, 2, and 3.

The Pupillarly Light Response (PLR)

The PLR is perhaps the best-known pupil response, wherein the pupil constricts in response to bright light, and contracts in darkness (Mathôt, 2018). Proposed to be an evolutionarily adaptive tool, it increases visual acuity in difficult viewing conditions by increasing retinal illumination, and helps with visual sensitivity (Larsen & Waters, 2018; Mathôt, 2018; Mathôt & Van der Stigchel, 2015). The PLR was not a measure of interest in our experiments, yet it was crucial that we considered its impact on pupil size, since it had the potential to mask/distort the cognitively-driven changes in pupil size arising from the experimental manipulations. To control luminance, we took two precautionary measures: 1) Luminance in the testing room was kept constant across participants, and 2) all words presented were manipulated so that the size varied as a function of word length, i.e. longer words would be physically smaller (see **Appendix C** for an example). This systematic procedure ensured that each visual stimulus in the experiment (including the fixation /

response cues) contained the same number of pixels. Onscreen luminance therefore remained constant throughout the experiment.

The Pupillary Near Response (PNR)

In the PNR the pupil constricts in response to fixating a close stimulus, and it dilates when looking at a distant stimulus (Mathôt, 2018). The evolutionary purpose of this is thought to be to increase depth of field when viewing nearby objects (Mathôt, 2018). The pupillary near response was not manipulated in this thesis, and its influence as a potential confound was controlled by seating participants at a constant distance of 100 cm from the screen.

The Psychosensory Pupil Response (PPR)

The PPR refers to pupil dilation elicited by top-down, cognitive processes, which can be driven by both psychological and/or sensory stimuli (Laeng et al., 2012; Mathôt, 2018). The PPR is biphasic, and manifests in two distinct peaks of pupil dilation, which index separate cognitive processes (Kuipers & Thierry, 2011; Mathôt, 2018; Wetzel et al., 2016) and are outlined below.

The orienting response (peaks between 0.5 - 1 second post visual stimulus onset)

The pupillary orientating response is an involuntary, brief, and rapid reaction to a stimulus which has gained the participant's attention (Mathôt, 2018; Wang & Munoz, 2015; Wetzel et al., 2016). The pupillary orienting response is controlled by the superior colliculus (Mathôt, 2018; Wang & Munoz, 2015). This response, at least in the context of most experiments, is quite small compared to the other responses discussed here, and is particularly sensitive to unexpected, novel, and particularly salient stimuli (Friedman et al., 1973; Mathôt, 2018; Wang & Munoz, 2015). The involuntary nature of this response is key, as distracting stimuli that are task-irrelevant (e.g. a sudden loud noise) capture attention and elicit this pupillary response (Wetzel et al., 2016).

Dilation in response to higher level cognition (peaks between 1-2 seconds post stimulus onset)

This dilation typically follows the orienting response and is both later and slower to manifest. As outlined above, dilation in this time window is sensitive to the intensity of mental effort, and emotional or attentional engagement (M. M. Bradley et al., 2008; Kang et al., 2014; Laeng et al., 2012; Mathôt, 2018; Riese et al., 2014). Recent research has shown that dilation in this time window is also sensitive to more subtle cognitive effects (Laeng et al., 2012). For example, a number of studies have shown that semantic information can modulate this pupillary response (Laeng et al., 2011; Mathôt et al., 2017). In the field of neurocognitive poetics, dilation in this time-window has been used as a measure of attentional engagement during literary reading (Riese et al., 2014).

2.4. Simultaneous Measurement and Correlation of Pupil Dilation and the N400

Concurrent recordings of ERPs and pupil dilation have now been obtained and presented in several studies (Briesemeister et al., 2009; Kuipers & Thierry, 2011, 2013; Ledoux et al., 2016). Advantages of this approach are that both measures are recorded from the same participants in response to the same stimuli, and as such the responses to the two stimuli – as indices of semantic and attention processes – can be compared. Previous research has shown that reduced N400 amplitudes correlate with larger pupil dilation in the time-window for the attentional orientating response (Kuipers & Thierry, 2011; 2013). They specifically found that for monolingual adults, when N400 mean amplitude was larger (indexing greater difficulty with semantic integration), pupil dilation in the same time-window was smaller (Kuipers & Thierry, 2011). The authors interpret their results broadly as indicating that cortical arousal is lower when semantic integration is more effortful.

These results are interesting as they show that correlating the two measures lends insight into the relationship between semantic integration and attentional processes. However, for this thesis we were more interested in later pupillary effects than the pupillary orientating response, since we predicted that the effect of alliteration on pupil dilation would manifest at a time point reflecting attentional engagement and interest. To enable us to examine this relationship we ran a nonsynchronous correlation, wherein the mean activity from the N400 time-window for each participant is correlated with each time-bin for pupil dilation. This ensured that potential correlations between semantic integration (the N400) and attentional engagement (the later PPR) could be investigated. By using this approach, any relationship between modulations of attentional allocation and semantic processing can be directly assessed.

2.5. Behavioural Responses

Whilst ERP and pupillary response measurement to stimuli is possible in the absence of an explicit task (Mathôt, 2018; Swaab et al., 2012), we decided to collect data on participants' explicit judgement on whether word pairs were semantically related or not (specifically, whether the phrase 'makes sense'). This task allowed us to examine and compare responses at the implicit and explicit levels, but it also ensured that participants conducted semantic-level processing of the items, and their continued engagement and focus over the course of the experiment. This in turn reduced alpha-contamination in the EEG signal (Luck, 2014). In general, we expected that participants would be less accurate in correctly verifying congruent items than in rejecting incongruent items (Boutonnet et al., 2014; Wu et al., 2011). Note that reaction times for the behavioural response were not analyzed in Experiments 1, 2, or 3, since participants were asked to make a delayed response.

In Experiment 4, in which we examined the effect of alliteration on recognition, the judgement task described above was used in the encoding session. In the second session, we asked participants to make a binary judgement as to whether or not they had seen the word pair during the previous session. Given that explicit behavioural and implicit neural responses do not always converge, this strategy allowed us to examine at which point the effect of alliteration appeared, if at all. Specifically, whether recognition occurred in a way that was fully accessible to the participant – and therefore evidence in their behaviour – or only evidence in the neural signature.

2.6. Background Literacy and Cognitive Measures

A battery of literacy and cognitive measures were administered to all participants who took part in the experiments reported in this thesis. These tests were used to control and assess for differences in participant reading/cognitive profiles which may have affected lexical processing speed and responsivity/appreciation of sound-based features such as alliteration. As such, they provided potentially useful measures of covariance in our data, which is exemplified well in the case of failure to replicate certain effects between Experiments 1 and 2. In the case of Experiment 2, these tasks ensured that the two reading groups – typically developed and developmentally dyslexic readers –were appropriately validated (similar IQ, discrepant reading scores). Each test is outlined below, along with a short justification for its use.

2.6.1. Print exposure and subjective reading measures

Exposure to print and reading habits is a key determiner of reading ability (Stanovich, 2009). Beyond testing readers of varying levels of skill (i.e. typically developed and dyslexic readers), we collected data on the habitual enjoyment of literature on the assumption that it may affect readers' responses to poetic techniques (i.e. alliteration).

Author Recognition Test (ART)

The ART is an implicit measure of print exposure, wherein participants choose which authors they know out of a mixed list of authors from a variety of genres, and foils (Acheson et al., 2008; Stanovich & West, 1989). It was developed in order to avoid subjective biases related to socially desirable answers in self-report questionnaires relating to reading habits (Stanovich & West, 1989). The version used in this thesis was created by Acheson et al (2008), to include more contemporary authors and a larger number of items than in the original (see **Appendix D** for the task as it was given to participants). The ART is in no way an ideal measure of print exposure, however it seems to be the one that is most reliable and most frequently used for experiments relating to literary reading for adults (Arnold et al., 2018; D. Kidd & Castano, 2013).

Self-Report Reading Measure

The self-report reading measure used here were adapted from Acheson et al (2008). The questionnaire includes three sections: time spent reading, time spent writing, and comparative reading habits (including measures of reading enjoyment, and difficulty of reading materials). Participants were explicitly asked to base their answers to each of these sections on a typical week. Some phrasing was altered to make it more appropriate for university students in the UK rather than the USA (where the test was devised) and to avoid confusion (e.g. college was changed to university; see **Appendix E** for the task as it was given to participants).

2.6.2. Objective measures of reading ability

As Experiment 2 directly compared participants with dyslexia to typical readers it was important to have reading ability measures in order to objectively dissociate them from control participants.

Rapid Automatized Naming (RAN)

The rapid digit naming, and rapid letter naming subtests from the Comprehensive Test of Phonological Processing (CTOPP; Wagner et al., 1999) were used in this thesis. These measure participants' naming speed for numbers and letters respectively. Here, the experimenter records reaction time as participants name a display of numbers/letters, as quickly and accurately as possible. This gives an index of the participants' rapid naming speed. Rapid naming refers to the ability to quickly retrieve a phonological code from memory, and is predictive of reading fluency (Lervåg & Hulme, 2009; Mitchell, 2001; Wolf

& Bowers, 1999). Participants with developmental dyslexia have longer naming times on this measure, though there is debate about the underlying mechanisms of this impairment (Denckla & Cutting, 1999; Jones et al., 2008, 2010; Mitchell, 2001).

Test of Word Reading efficiency (TOWRE)

The TOWRE (Torgesen, Wagner, & Rashotte, 1999) is a measure of sight reading efficiency (word reading task), and also of phonemic decoding efficiency (nonword reading task). In both tasks, participants are asked to read a list of words or non-words aloud as quickly and accurately as possible, and both accuracy and reaction times are recorded. Both adults and children with developmental dyslexia typically have impaired performance on these measures (Berninger et al., 2006).

2.6.3. Objective measures of IQ

Relevant subtests of the WASI were used as proxy measurements for participants' verbal and non-verbal IQ. This data allowed us to ensure that all participants were within normal range on these measures. This is important, as 1) although reading ability has been shown to be dissociable from IQ (Cutting & Scarborough, 2006; Landi, 2010), we could not guarantee that it would not have a confounding effect on our results if there were differences between our experimental groups on this measure. 2) Individuals with dyslexia have normal IQ (Lyon et al., 2003), as such these measures were necessary to establish that our sample of dyslexic participants impairments' were indeed reading specific. 3) to ensure that our results are generalizable to the population we aimed to study, i.e. typically developed young adults with no cognitive impairments.

Matrix reasoning

The matrix reasoning subtest of the Wechsler Abbreviated Scale of Intelligence (WASI, Wechsler, 2011), is an index of nonverbal intelligence. For this task participants are presented with a series of incomplete patterns, and they had to choose which picture completed the pattern.

Vocabulary

The vocabulary subtest of the WASI (Wechsler, 2011) is an estimate of verbal IQ. The experimenter read words aloud from a list, and the participant was asked to provide a definition for each word. Accuracy, which is defined as a precise definition of the word comprises the measure of interest, yielding a score of 2 (specific definition), 1 (vague definition), or 0 (inaccurate definition).

2.7. Chapter Summary

In this chapter, I outlined and justified the methods used to address the research questions posed in the previous chapter. The following four chapters are empirical chapters, in which each of the four experiments are presented in turn.

Chapter 3

How Alliteration Enhances Conceptual-Attentional Interactions in Reading

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Abstract

In linguistics, the relationship between phonological word form and meaning is mostly considered arbitrary. Why, then, do literary authors traditionally craft sound relationships between words? We set out to characterise how dynamic interactions between word form and meaning may account for this literary practice. Here, we show that alliteration influences both meaning integration and attentional engagement during reading. We presented participants with adjective-noun phrases, having manipulated semantic relatedness (congruent, incongruent) and form repetition (alliterating, non-alliterating) orthogonally, as in "dazzling-diamond"; "sparkling-diamond"; "dangerous-diamond"; and "creepy-diamond". Using simultaneous recording of event-related brain potentials and pupil dilation (PD), we establish that, whilst semantic incongruency increased N400 amplitude as expected, it reduced PD, an index of attentional engagement. Second, alliteration affected semantic evaluation of word pairs, since it reduced N400 amplitude even in the case of unrelated items (e.g., "dangerous-diamond"). Third, alliteration specifically boosted attentional engagement for related words (e.g., "dazzling-diamond"), as shown by a sustained negative correlation between N400 amplitudes and PD change after the window of lexical integration. Thus, alliteration strategically arouses attention during reading and when comprehension is challenged, phonological information helps readers link concepts beyond the level of literal semantics. Overall, our findings provide a tentative mechanism for the empowering effect of sound repetition in literary constructs.

The question as to whether the phonological form of a word has any bearing on its meaning has intrigued scholars for millennia (cf. Plato's *Cratylus,* Sedley, 2003). Mainstream opinion in the language sciences advocates no such relationship, claiming instead that phonological forms are arbitrarily associated with semantic concepts (De Saussure, 2011; Gasser, 2004; Lupyan & Winter, 2018). Nevertheless, proponents of sound symbolism (i.e., iconicity in natural language) have advocated that a word's phonology can and does reflect some of its semantic features, particularly in non-indoeuropean languages (cf. Asano et al., 2015; Kovic, Plunkett, & Westermann, 2010; Monaghan, Shillcock, Christiansen, & Kirby, 2014; Perniss, Thompson, & Vigliocco, 2010; see also Culler, 1975; Jakobson, 1960), as is the case for onomatopoeic words (e.g., bang, pop, splash; Perniss & Vigliocco, 2014).

A natural extension to this question, then, is whether interactions between phonology and semantics extend beyond the level of intra-lexical iconicity, i.e., affect relationships between words at the phrasal level. In spoken language, comprehenders use prosodic patterns to structure the input and parse the speech stream which has an immediate impact on semantic processing (e.g., Breen, Dilley, McAuley, & Sanders, 2014; Brown, Salverda, Dilley, & Tanenhaus, 2015). But it is unclear whether and how phonological information derived during (silent) reading affects comprehension. Recent work in neurocognitive poetics suggests that stylistic prosodic features in phrases, such as phonological repetition, attract more attentional resources and that their neural representations are more strongly activated than those of neutral, declarative forms, as shown in behavioural (e.g. Carminati, Stabler, Roberts, & Fischer, 2006; Hanauer, 1998; Tillmann & Dowling, 2007; Yaron, 2002) and in event-related potential (ERP; (Chen et al., 2016; Obermeier et al., 2013; Vaughan-Evans et al., 2016) studies.

The Current Study (Experiment 1)

Here, we measured event-related brain potentials (ERPs) and pupil dilation (PD) changes in native English speakers reading adjective-noun phrases manipulated orthogonally for semantic relatedness and alliteration. We chose to study form-meaning relationships at the most elementary level of word combination in reading, i.e., two-word phrases, in order to (a) have full experimental control via counterbalancing of stimuli across conditions, and (b) remove an inherently ‘poetic’ attribute from the potentially biasing context of verse, thus providing an evaluation of form-meaning relationship as it occurs in natural language. Our choice of methods also allowed us to examine semantic processing in the context of attentional engagement: In ERP research, increased negativity in mean amplitudes of the N400 wave is associated with increased difficulty in accessing the meaning of a stimulus (Chwilla et al., 1995; Kutas & Federmeier, 2011). On the other hand, increased PD indexes the recruitment of attentional resources and task-related uncertainty (Geng et al., 2015; Kang et al., 2014; Mathôt, 2018). Early dilation (<1000 ms) is associated with attentional orienting, relating to stimulus saliency or novelty, whereas later dilation (>1000 ms) is thought to reflect autonomic arousal, linked with mental effort or interest (Mathôt, 2018; Wang & Munoz, 2015; Wetzel et al., 2016).

We anticipated that semantic processing would be more difficult (and thus elicit greater N400 amplitudes) for incongruent adjective-noun pairs, and that alliteration would interact with semantic processing. We also expected that attention allocation would be boosted (and thus increase PD) in response to more effortful semantic processing, analogous to the N400 (Kuipers & Thierry, 2011; Wetzel et al., 2016), and that alliteration would also attenuate this response. We further expected these effects to occur during the later phase of pupil dilation (Mathôt et al., 2017; Wetzel et al., 2016). Moreover, potential correlations between ERP amplitude and PD index offered an opportunity to empirically describe dynamic links between semantic integration and attentional engagement (cf. Kuipers & Thierry, 2011, 2013). In order to investigate whether semantic integration (occurring ~400 ms) further relates to early or later phases of attentional engagement, we examined the relationship between mean ERP amplitude in the classical N400 time window (300-500 ms) and pupil dilation over the entire sequence of a trial.

Materials and Methods

Participants

The data of 20 native English speakers (16 females, mean age = 22, SD = 2.97) were included in the analysis (a further 5 were excluded owing to technical failures and/or excessive alpha contamination). This sample size was determined on the basis of recent similar studies (e.g., Chen et al., 2016; Vaughan-Evans et al., 2016). All participants had normal or corrected-to-normal vision and reported no past or present diagnosis of a learning difficulty. Ethical approval was granted by the School of Psychology, Bangor University and all participants provided written informed consent before taking part.

Stimuli and Procedure

In a two-by-two experimental design manipulating semantic congruency and alliteration orthogonally, a total of 416 adjective-noun word pairs were constructed, resulting in 104 pairs per condition. All stimuli, i.e., adjectives and nouns considered independently, were quasi-rotated across conditions (99.9%) and presented alongside 208 randomly interspersed filler trials. Stimuli were normed for semantic congruency in a separate study, in which 60 native English speakers rated each adjective-noun phrase on a 5-point Likert scale, answering the question “how likely would it be for the second word to follow the first in a normal sentence (ranging from 1: very unlikely to 5: very likely)”. Congruent alliterating (M = 4.05, SD = 0.74) and non-alliterating (M = 3.96, SD = 0.78) phrases were both rated significantly more related than pairs from either the incongruent alliterating (M = 1.80, SD = 0.53) or incongruent non-alliterating (M = 1.66, SD = 0.53) conditions (p < .05). There was no significant difference between the ratings of the two congruent conditions (p = .743), or between the two incongruent conditions (p = .364). All stimuli were then resized using a mathematical algorithm in Matlab so that each word presented in white on a black background as a picture object contained the same number of lit pixels on the screen (i.e., words varied in size and length but luminance was kept constant from one stimulus to the next).

Participants sat at a distance of 100 cm from the monitor. Following setup of the EEG system and calibration of the eye-tracker, each trial began with a drift correction (single-point recalibration) also serving as fixation in the centre of the screen. Then, the adjective was presented for a random duration in the range of 330–550 ms in 20 ms increments. On 50% of the experimental trials the noun was then presented without an inter-stimulus interval for 500–600 ms in random 20 ms increments, whilst on the remaining 50% the noun was presented for 2000 ms, allowing for collection of PD data. Then, a response cue (#####) prompted the participant to indicate, using a counterbalanced, binary-decision button press, whether or not the two words were related in meaning (see **Figure 4**). Importantly, visually-presented fixation and response cues also had the exact same number of lit pixels as word stimuli, such that luminance was constant throughout experimental blocks. For data analysis, ERPs were analysed across all experimental trials, whereas PD data were analysed only on the longer presentation trials owing to the slow time-course of the pupil response (Mathôt et al., 2017).

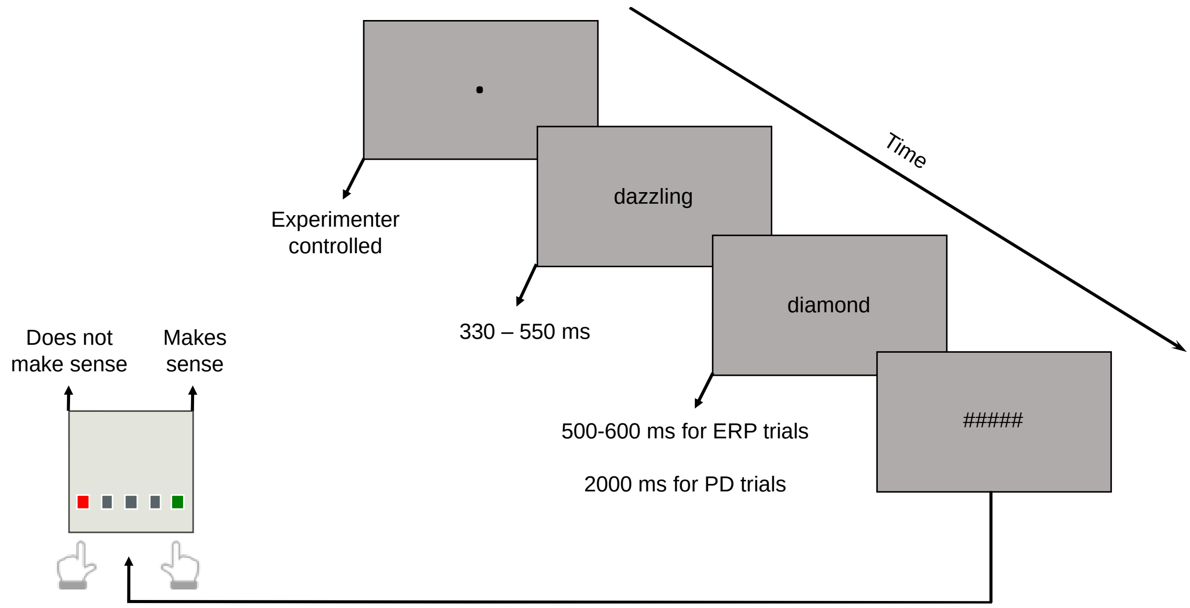

Figure 4. Schematic depicting the experiment procedure. Note that screen background was black and all stimuli were in white. Word size varied in order to keep the number of pixels constant, thus controlling luminance.

Pupillometry Recording

Pupil dilation was recorded using an Eyelink 1000 desktop mounted eye-tracker. Words were presented in white Arial font on a black background in the centre of a 62 x 34 cm monitor with a refresh rate of 60 Hz and a resolution of 1080 x 1920 pixels. Eye movements and pupil dilation were recorded from the participant's right eye, after a 9-point calibration. Baseline correction was performed using a subtractive, pre-stimulus baseline correction (based on the median dilation from the first 10 ms of each trial), as outlined in Mathôt, Fabius, Van Heusden, & Van der Stigchel (2018). Blinks, including small saccades, during a trial were identified and data was marked as missing. An extra 25 samples (25 ms) post blinks were also marked as missing, since pupil size takes time to recover upon opening the eyelid. In order to ensure minimal eye movements during a trial, all visual stimuli were less than 2 degrees of visual angle. Any data marked missing was interpolated using a basic linear interpolation.

ERP Recording

Electrophysiological data were recorded at 2048 Hz with a BioSemi system, using 128 active Ag/AgCl electrodes, positioned according to the 10-10 convention. Data were resampled to 1024 Hz prior to analyses. The common mode sense (CMS) active electrode and the driven right leg (DRL) passive electrode were used as reference and ground electrodes, respectively (www.biosemi.com/faq/cms&drl.htm). Horizontal and vertical electrooculograms (EOGs) were monitored using four facial bipolar electrodes placed on the outer canthi of each eye and in the inferior and superior areas of the left orbit.

Noisy electrodes were replaced by means of spherical interpolation. Data were re-referenced offline to the global average reference (average of all electrodes except for the EOGs) and filtered using a 30 Hz (48 dB/oct) low-pass and 0.01 Hz (12 dB/oct) high-pass zero phase shift filter. Data from a preliminary block in which participants were asked to make specific eye movements and blinks were visually inspected and non-ocular artefacts were discarded. Ocular correction was conducted using Independent Component Analysis (ICA, computed using the AMICA procedure; Palmer, Makeig, Kreutz-Delgado, & Rao, 2008). Data were then segmented into large epochs centred on noun onset starting from 200 ms before stimulus onset and until 800 ms after stimulus onset. Following this, EEG signals were visually inspected and remaining noisy epochs were discarded. After baseline correction relative to a 200 ms pre-stimulus interval, epochs were averaged in each of the four conditions (Mean number of trials = 75 +/- 15) and grand-averages were computed.

Experimental Design and Statistical Analyses

Behavioural accuracy was analysed using generalised linear mixed models, for which the fixed factors were centred and sum-coded (Nieuwenhuis et al., 2017). Fixed factors were

Congruency (Congruent, Incongruent) and Alliteration (Alliterating, Non-alliterating), and the interaction between them. The closest-to-maximal random effects structure with correlations was modelled, consisting of a between-participant intercept and within-participant slopes of Congruency, Alliteration, and their additive contribution (1 + Congruency+Alliteration | participant), plus an intercept for word pairs (1 | WordPair). Reaction times were not analysed, given that participants were asked to provide a delayed response.

ERP mean amplitudes were analysed using repeated measures ANOVA with the factors Congruency (congruent, incongruent) and Alliteration (alliterating, non-alliterating) in the N400 time-window (300–500 ms over 11 centroparietal recording sites, consistent with our a priori expectations given the usual N400 topography: Kutas & Federmeier, 2011). Simple main effects analyses were conducted to further examine the interaction effect.

For the pupillometry data, a procedure similar to that employed by Mathôt et al. (2017) was used: The timeseries was split into time-bins of 10 ms, and generalised linear mixed effects models were run for each bin. The dependent variable was the change in pupil size modelled according to the fixed effects and the interaction between them. As with the accuracy data, the maximal random effects structure was implemented ((1 + Congruence*Alliteration | participant) + (1 | WordPair)). We considered an effect to be significant based on the t-as-z approach where $t > 1.96$ (approx. $\alpha = .05$) in 20 or more contiguous time bins for a minimum effect duration of 200 ms.

Finally, we correlated the N400 ERP amplitude with modulations in pupil size over time. For this analysis, we took mean N400 amplitudes for each participant per condition and correlated this value with changes in pupil size at each 20 ms time step over the course of the trial (2000 ms: i.e., longer presentation trials only).

Results

Behavioural

Accuracy data revealed a significant fixed effect of congruency (β = 1.54, *SE* = 0.19, z = 7.97, $p < .001$), such that accuracy was lower for congruent (*M* = 79.5, *SD* = 9.94) than incongruent (*M* = 94.58, *SD* = 10.37) word pairs. We also found a significant main effect of alliteration (β = 0.55, *SE* = 0.15, z = 3.62, $p < .001$), with more errors for alliterating (*M* = 84.83, *SD* = 11.79) than non-alliterating pairs (*M* = 89.25, *SD* = 13.18). There was also an interaction between congruency and alliteration (β = 1.48, *SE* = 0.15, z = 9.32, $p < .001$), such that the difference between alliterating and non-alliterating stimuli was smaller for congruent than incongruent word pairs (**Figure 5**).

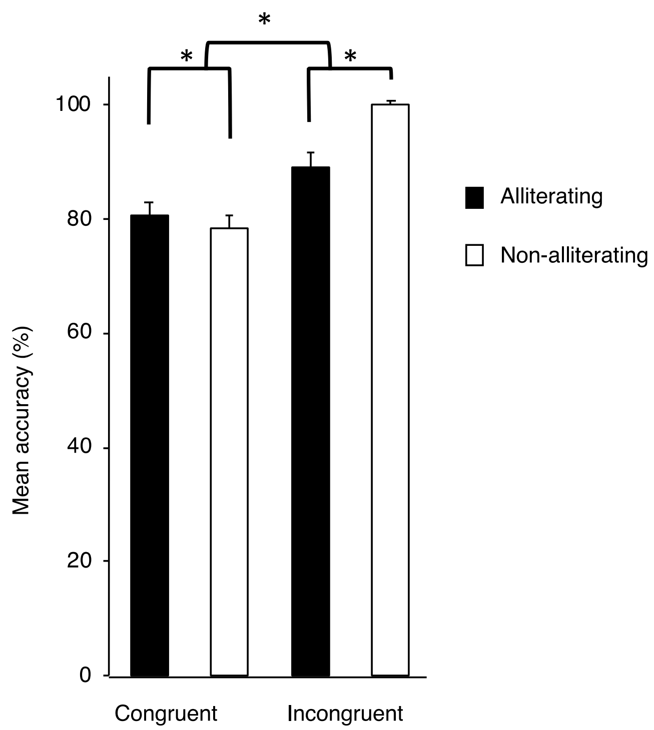

Figure 5. Behavioural accuracy, representing the mean number of trials upon which participants correctly reported that phrases 'made sense' or not. Error bars depict SEM.

ERP

In the N400 time-window there was a main effect of congruency ($F(1, 19) = 23.194$, $p < .001$, $\eta^2 = .55$), and of alliteration ($F(1, 19) = 9.116$, $p = .007$, $\eta^2 = .324$) on the mean ERP amplitudes, such that both congruency and alliteration tended to reduce N400 amplitude. A significant interaction between congruency and alliteration was also found ($F(1, 19) = 5.077$, $p = .036$, $\eta^2 = .211$), such that the effect of congruency for non-alliterating word pairs was significantly greater in magnitude than for alliterating word pairs (**Figure 6**).

Pupillometry

Congruency significantly modulated PD from 980–2000 ms, manifesting as a pupil size increase for congruent relative to incongruent word pairs (**Figure 6**). No other effects emerged.

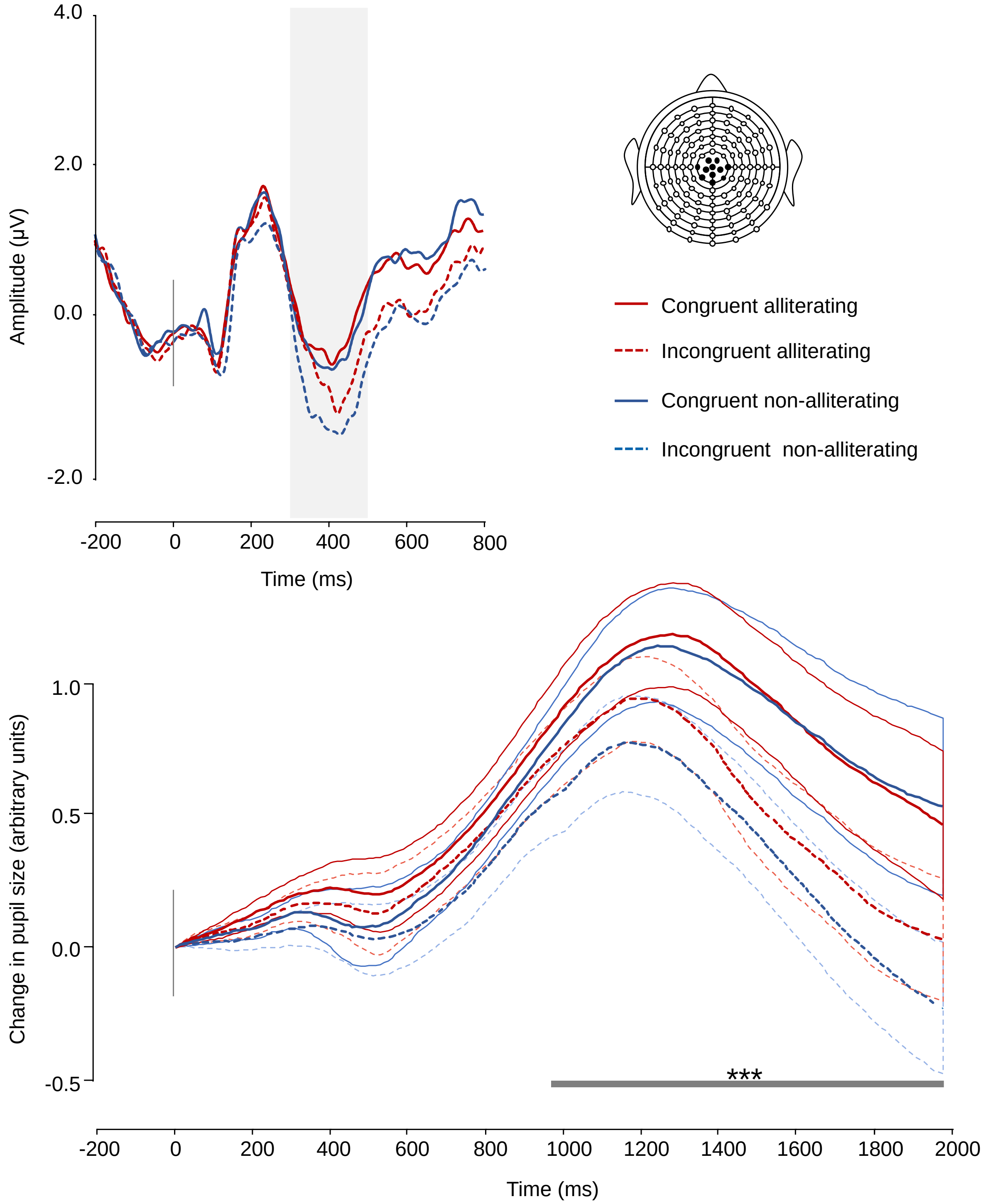

Figure 6. *Top*: Mean ERP amplitudes, the shaded bar representing the area of analysis; *Bottom*: mean pupil dilation change over time. SEM is indicated by the shaded areas for the pupil dilation data, as per usual convention. The grey line indicates the time-window in which the main effect of congruency was significant. In both graphs, 0 ms on the timeline represents noun onset.

Correlation analysis

We next examined the relationship between online semantic processing in the ERP signal and different stages of attentional engagement, reflected in the pupil dilation measure. Mean N400 value significantly correlated negatively with pupil size for incongruent non-alliterating trials between 400–800 ms (early time window), and beyond 800 ms for congruent alliterating trials (late time window) after the former ceased to be significant.

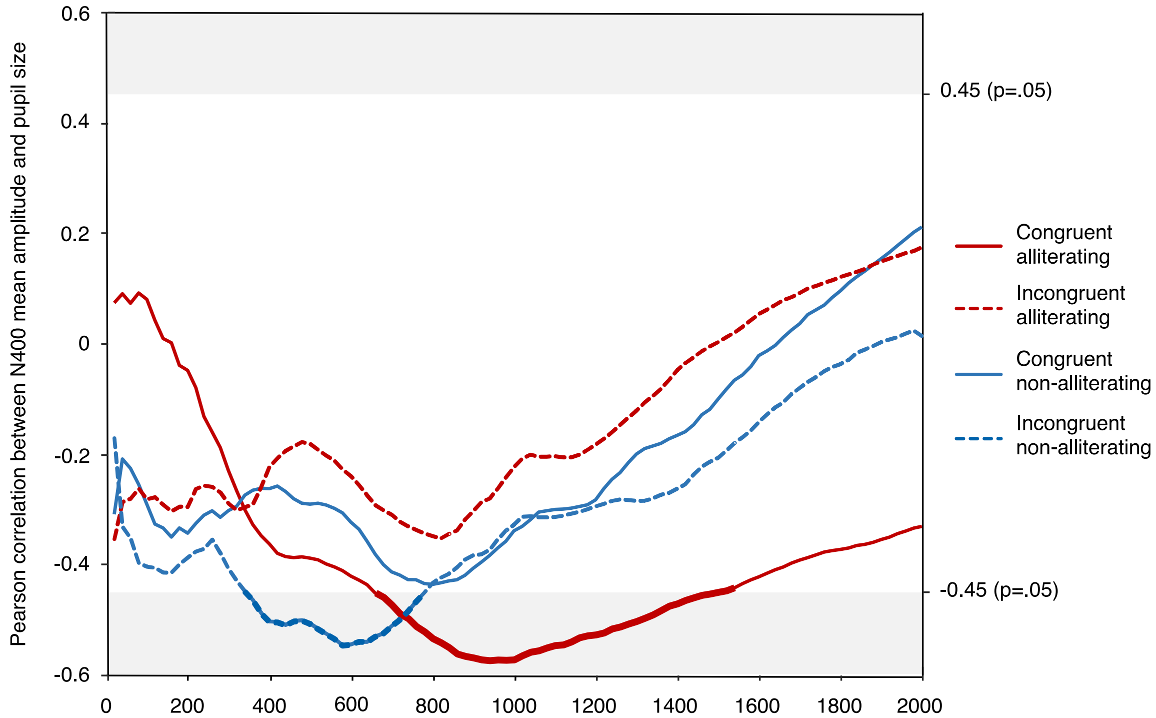

Figure 7. ERP-pupil dilation correlations at 20 ms time bins indicating Pearson correlation coefficients. Thicker lines indicate statistical significance ($r > -0.45$). Significance thresholds are indicated along the righthand Y-axis.

Discussion

Here, we examined how alliteration influences the interplay of semantic and attentional processes during reading as indexed by brain potentials and pupil dilation. We show that (a) alliteration tends to decrease N400 amplitude in the case of unrelated words, (b) semantic relatedness increases PD, and (c) alliteration and semantic relatedness interact such that PD increase is particularly sustained for related words within a phrase.

In the behavioural data, participants were highly accurate in rejecting incongruent phrases (e.g., *creepy-diamond*), as it is easier to assess two concepts as being unrelated than verifying a link between them, this has been previously shown in similar studies (Boutonnet et al., 2014; Wu et al., 2011). However, accuracy was reduced when incongruent phrases were also alliterating (e.g., *dangerous-diamond*), suggesting that alliteration compromised participants' ability to judge a phrase as incongruent. ERP data showed that this uncertainty in the behavioural judgement was underpinned by semantic-level evaluation rather than superficial meta-cognitive judgement. Consistent with a large body of ERP literature detailing the N400 effect (Kutas & Federmeier, 2011), our results showed a generally reduced N400 amplitude for congruent compared with incongruent pairs. However, incongruent alliterating pairs (e.g., *dangerous-diamond*) elicited a reduced N400 amplitude compared to incongruent non-alliterating pairs (e.g., *creepy-diamond*). Thus, when phrases were difficult to understand, repetition of the word-initial phoneme led the reader to consider the pairs as more congruent.

Surprisingly, the pupil dilation data showed the opposite pattern to the ERP data. Indeed, we observed significantly *larger* dilations for congruent than incongruent phrases, peaking at around 1200 ms post stimulus onset. Bearing in mind that the course of pupil dilation manifests as a biphasic pattern, reflecting partially separable processes, this suggests that semantically congruent pairs elicited greater autonomic arousal compared with incongruent pairs (Hess & Polt, 1960; Mathôt, 2018). Whilst no other effects were statistically significant, visual inspection of the data presented in **Figure 6** suggests a trend in which incongruent alliterating phrases were again distinguished from their non-alliterating counterparts.[4]

Together, ERP and PD data suggest that alliteration modulates online semantic processing, with repercussions for participants' ability to accurately judge whether or not phrases were congruent. Our findings therefore lend support to the controversial idea that "similarity in sound can reflect similarity in meaning" (Hanauer, 1998; see also Jakobson, 1960), and also suggest that repetition of sound can lead to an *illusory* impression of meaning relatedness. Moreover, whilst Chen et al. (2016) recently showed that repetition of sound can boost access to meaning for congruent sentences in poetry, we show that it can influence semantics even in the case of absolute minimal phrasal constructions (see also Acheson & MacDonald, 2011 for a similar consideration in the case of declarative sentences).

In order to investigate how semantic integration further relates to attentional engagement, we examined the relationship between mean N400 amplitude and pupil dilation over the entire sequence of the noun duration. Incongruent non-alliterating trials (e.g., *creepy – diamond*) showed early, pronounced negative correlations, which likely reflect an early attentional orienting response to the most semantically challenging condition (Mathôt, 2018; Wetzel et al., 2015). In a second phase, a negative correlation for congruent alliterating stimuli (e.g., *dazzling-diamond*) peaked at ~1000 ms. We tentatively interpret this sustained effect as an indication that semantically and phonologically congruent pairs heighten arousal and interest beyond semantic and phonological links considered separately.

[4] Given that we recorded EEG and pupil dilation simultaneously, we could not impose head restraint – which would have improved PD measures' reliability – without compromising EEG data quality. Thus, a number of trends in the PD data possibly did not reach statistical significance because of the ensuing variance.

Conclusion

In sum, we show that stylistic manipulation of written phrases not only affects semantic processing and attentional orienting, but leads to dynamic interaction between the two. When semantic processing is difficult, inter-word alliteration can incur the illusion of meaning relatedness, which leads to attenuated online processing effort and more errors. And when semantic processing is relatively easy – as in the case of congruent pairs – increased depth of semantic processing leads to sustained cortical arousal. Our findings are consistent with recent evidence for substantial effects of sound symbolism in language comprehension (e.g., Perniss et al., 2010; Monaghan et al., 2014; Asano, et al., 2015), but they also demonstrate for the first time that form-meaning interactions can occur between as well as within words. These data elucidate a key mechanism in neurocognitive poetics: Previous studies examining the cognitive effects of stylized text have reported increased reader engagement as shown separately by slower reading times on the one hand (Hoven et al., 2016) and larger pupil dilation on the other (Scheepers et al., 2013). However, our study is the first to show that extracting meaning from stylized text is crucial in engaging the reader's interest, providing empirical explanation for why stylistic prose is 'savoured' (Jacobs, 2015a).

Chapter 4

How Alliteration Affects Semantic Processing and Attentional Engagement in Typical and Poor readers

Acknowledgements: I would like to thank Josie Chan, Neomi-Jade Calvert, and Archie Samuels for their assistance with data collection for this project, and the Miles Dyslexia Centre for their support with participant recruitment.

Abstract

Developmental dyslexia is a specific reading impairment that is characterised by a phonological deficit (i.e. difficulty in mapping letters to sounds). In the previous chapter, we showed that when typically developed readers read semantically congruent phrases that also alliterate (e.g., dazzling diamond) the attentional system is engaged. When faced with semantically incongruent phrases, alliteration moreover helps readers to link concepts beyond the level of literal semantics. In this study we set out to examine whether these dynamic interactions between word form and meaning are modulated by reading ability; specifically, whether a different pattern of effects can be found in readers with dyslexia. Given dyslexic readers' unstable orthographic/phonological representations, would they display an attenuated effect of alliteration? Or, would the presence of alliteration and its concomitant boost of the attentional system, bootstrap comprehension? In our implicit measures we found no evidence that alliteration modulated semantic processing for either typical or dyslexic readers. However, dyslexic readers appeared generally less responsive, revealed in smaller overall pupil dilations (PDs). In our explicit behavioural measure, dyslexic readers were less able to accurately judge semantic congruency overall. They also showed a marked inability to accurately verify alliterating items, indicating that the presence of alliteration influenced their overt semantic decision making. These findings suggest that reading ability exerts a somewhat subtle influence on responses to sound-semantic interactions. We also discuss inconsistencies in the Experiment 1 and 2 event-related potential (ERP) data for typical readers, in which we discover – via post hoc tests – that verbal IQ modulates the effect of alliteration on the N400.

In Experiment 1, we examined how phonological word-form interacts with semantic congruency to affect semantic integration of, and attentional capture on the noun in the context of its preceding adjective (e.g., *congruent alliterating:* dazzling diamond, *congruent non-alliterating:* sparkling diamond, *incongruent alliterating:* dangerous diamond, *incongruent non-alliterating:* creepy diamond). We found that alliteration captured attention during reading, and that when comprehension was challenged, readers used phonological information to link concepts beyond the level of literal semantics. We tentatively suggested that this gives an insight into the neurocognitive mechanism underlying the effect of phonological repetition in literary devices. This study only tested highly skilled readers however, which left open the question of how such sound-semantic effects might manifest in individuals with poorer reading abilities, such as those with developmental dyslexia.

Developmental dyslexia describes readers with a specific reading impairment (Lyon et al., 2003). Adults with dyslexia read and spell less fluently and accurately, and show consistent deficits on component cognitive skills such as phonological access and awareness (J. Hatcher et al., 2002; Rüsseler et al., 2007). The field of neurocognitive poetics has until this point focused on typical readers, asserting that individuals with dyslexia are not likely to read for pleasure due to their reading impairment (Jacobs & Willems, 2017). But evidence to the contrary suggests that many adults with dyslexia – i.e., so-called 'compensated' dyslexic readers – do in fact read for pleasure (Fink, 1998; Wennås Brante, 2013). Whilst poetic techniques (e.g. alliteration, rhyme) demonstrably affect semantic processing and attention in typical readers (Chen et al., 2016; Egan et al., 2020; Scheepers et al., 2013; Vaughan-Evans et al., 2016), an important question remains to be answered: whether they elicit similar responses – including the magnitude and latency of implicit and explicit responses – in readers with dyslexia.

In Experiment 2, we examine how typically developed and dyslexic adult readers differ in the time course of semantic and phonological processing, including the interactions between these factors. To this end, we compare reading groups on an identical paradigm to that described in Experiment 1. Given what we know of semantic and phonological processing in readers with dyslexia, how might we expect them to perform, compared with typical readers? A common supposition in dyslexia research is that semantic processing is spared, and indeed, that dyslexic readers often use their conceptual level knowledge in order to compensate for their orthographic / phonological processing difficulties (Hulme & Snowling, 2014; Nation & Snowling, 1998; Snowling & Hulme, 2013). Indeed, comprehension difficulties are seen as indicative of a specific language impairment (when a phonological deficit is also present), or of being a 'poor comprehender' (when no phonological deficit is present) both of which are dissociable from developmental dyslexia (Bishop & Snowling, 2004). Despite this dissociation, comprehension difficulties have high comorbidity with dyslexia, and lead to their own set of reading difficulties i.e. poorer reading comprehension and vocabulary knowledge (Snowling & Hulme, 2013). Additionally, recent ERP research on readers with a classic dyslexia profile has shown subtle semantic processing anomalies in the N400 range, including attenuated or delayed responses to incongruent items (Jednoróg et al., 2010; Schulz et al., 2008).

Whilst semantic processing deficits in dyslexia – where they occur at all – are likely to be subtle, one might reasonably make more definite predictions concerning dyslexic readers' phonological processing. Given the prevalence of phonological impairment in dyslexia, even in highly compensated readers, (J. Hatcher et al., 2002; Ramus & Szenkovits, 2008), the preponderance of phonological repetition and patterning in poetry may not elicit similar effects, at least not to the same magnitude as in typically developed readers. This is perhaps even more likely given dyslexic readers' pervasive deficits in orthographic-phonological binding (Blau et al., 2009; Blomert, 2011; Froyen et al., 2008; Jones et al., 2018), leading to a compromised orthographic lexicon (Share, 1995), and reduced sensitivity to repetition in the perceptual input (Ahissar, 2007; Oganian & Ahissar, 2012; Ramus & Ahissar, 2012). It is not our intention to isolate one of these dyslexic characteristics (e.g., phonological processing) as a primary culprit for reduced responsivity to poetry, and we refer the interested reader to the lively debates on the causes of dyslexia (e.g., Ramus et al., 2003; Vellutino et al., 2004; Ramus & Szenkovits, 2008; Stein, 2017). On the contrary, we note that the brace of difficulties commonly found in individuals with dyslexia map rather strikingly with the processing requirements involved when encountering stylistic manipulations such as alliteration. Namely, precise identification of phonological / orthographic representations and sensitivity to the repetition of this information. The deficits characteristic of dyslexia are therefore highly likely to make the dyslexic reader less sensitive to the stylistic phonological properties of poetic text.

However, whilst this is perhaps the most logical hypothesis, given the nature of dyslexic readers' difficulties, there are also sound theoretical grounds to consider the alternative hypothesis: Given that phonological repetition captures readers' attention (Egan et al., 2020; Obermeier et al., 2013; Scheepers et al., 2013), it may also aid comprehension for readers with dyslexia via a top-down attentional boost (Breznitz & Leikin, 2001; Horowitz-Kraus & Breznitz, 2014; Shaywitz & Shaywitz, 2008). Previous studies have shown that both training/procedures which improve attentional skills prior to reading (Bavelier et al., 2013; Franceschini et al., 2013), and rapid reading paradigms which maximise reader attention during reading (Breznitz & Leikin, 2001; Horowitz-Kraus et al., 2014; Horowitz-Kraus & Breznitz, 2014), lead to reading comprehension and fluency improvements in dyslexic readers. Yet no existing research has investigated whether text features that capture attention will also improve reading for this group, thus our paradigm will test whether alliteration will influence reading comprehension in dyslexia.

The Current Study (Experiment 2)

With these theoretical considerations in mind, we now turn to the specific hypotheses. For typical readers, we expect our findings to replicate the results of Experiment 1: alliteration will attenuate the N400 for semantically incongruent adjective-noun phrases, manifest in a congruency-by-alliteration effect in the N400 range. We also expect increased attentional engagement for congruent compared with incongruent items, manifest in increased PD during the later dilation phase. An early negative correlation for incongruent non-alliterating items, and a later negative correlation for congruent alliterating items are expected between mean N400 amplitude and PD. Finally, we expect a congruency effect on behavioural accuracy (i.e. more errors for congruent items), and that the presence of alliteration will once again reduce accuracy in the behavioural (semantic judgement) task.

For dyslexic readers, we make definite predictions for our primary measure – the N400 response – and more speculative predictions for the PD measure, for which there is currently no extant data in a dyslexic sample. We expect that semantic congruency effects will either pattern similarly to typical readers, or show a comparatively moderate reduction for incongruent items, manifest in larger N400 amplitudes to incongruent compared with congruent phrases, resulting in a group * congruency interaction. However, our primary hypotheses concern the alliteration manipulation and its interaction with congruency, for which we make two competing sets of predictions:

(1) That compromised phonological processing in dyslexia will lead to **significantly reduced effects of alliteration**, manifest in statistically identical effects of alliteration on

congruent and incongruent items (a group * alliteration interaction). In this case, in the ERP data, we would not expect alliteration to modulate dyslexic readers' evaluation of semantic congruency. However, if this interaction is further modulated by congruency, we expect a group * alliteration * congruency effect. In the PD measure, we expect that alliteration will exert no effect on dyslexic readers, given that alliteration did not exert a significant effect on PD even in typical readers in Experiment 1. In this instance the correlation between mean N400 amplitude and PD is explorative. However, given that we do not expect alliteration to modulate either measure in isolation, it is also likely that no correlation would emerge. For behavioural accuracy on the semantic judgement task, we predict that dyslexic readers will have generally reduced accuracy (cf. Schulz et al., 2008), but a preserved congruency effect. Reduced sensitivity to phonology should result in comparable effects of alliteration across congruent and incongruent items, unlike the case of typical readers, resulting in a group * alliteration interaction.

(2) That a top-down attentional boost will ameliorate reduced sensitivity to phonological repetition, leading to a similar or **larger effect of alliteration** in the dyslexic group. This would mean a larger difference in the N400 responses to alliterating compared with non-alliterating items, than would be the case with typical readers, manifest in a group * alliteration interaction. If this effect is further modulated by semantic congruency – for example, a particularly ameliorating effect for semantically incongruent items – then we can expect a group * alliteration * congruency interaction. As pupil dilation is an index of attention it would be expected that this top-down attentional boost would be reflected in the dyslexic readers' pupillary responses. In this case, we would expect the pupil dilation responses to map onto the N400 results, consistent with Experiment 1 data (i.e. smaller N400 to alliterating items would be coupled with larger dilation to these items), which would be indicated by a group * alliteration interaction for pupil dilation. In this instance, we also

predict that for alliterating items, N400 amplitude would correlate with pupil dilation for dyslexic readers. On the behavioural task, we predict readers with dyslexia will have generally reduced accuracy, but will show a preserved congruency effect, and a similar effect of alliteration to typical readers.

Materials and Methods

Participants

Thirty-eight native English speakers were included in the analysis, comprising 19 typical readers and 19 readers with developmental dyslexia. The 'dyslexic' group self-reported as having a diagnosis of developmental dyslexia (*n* = 19, 12 females, age: *M* = 21.3, *SD* = 2.6 years). These participants were recruited via the Miles Dyslexia Centre Specific Learning/Socio-communicative Difficulties Panel at Bangor University. The 'typical' group reported no history of developmental dyslexia or learning difficulty (*n* = 19, 8 females, age: *M* = 22.1, *SD* = 2.9 years). A further 12 participants (4 typical, 8 with dyslexia) were excluded due to excessive alpha contamination and four additional typical readers were excluded for having verbal and/or nonverbal IQ scores more than two standard deviations below the general population mean (Wechsler, 1999). All participants had normal or corrected-to-normal vision. Ethical approval was granted by the School of Psychology, Bangor University and all participants provided written informed consent before taking part.

Stimuli and Procedure

The stimuli and procedures were identical to those used in Experiment 1.

Background Cognitive and Literacy Tests

In order to ensure that participants in the 'dyslexic' group had a profile consistent with their assessment of developmental dyslexia, we administered a short battery of cognitive and literacy tests. These tests included both verbal and non-verbal IQ (expressive vocabulary and matrix reasoning) from the Wechsler Abbreviated Scale of Intelligence (WASI, Wechsler, 2011). Literacy measures with an emphasis on latency were also administered, including rapid naming (Comprehensive Test of Phonological Processing; CTOPP; Wagner, Torgesen, & Rashotte, 1999) and word / nonword reading (Test of Word Reading Efficiency; TOWRE; Torgesen, Wagner, & Rashotte, 1999). Performance on these indices are known to discriminate typical and dyslexic performance, even in highly compensated adults (cf. Berninger et al., 2006; Jones, Branigan, Hatzidaki, & Obregón, 2010). The Author Recognition Test (ART; Acheson, Wells, & MacDonald, 2008), a measure of print exposure, and a self-report measure of weekly reading times, was also included as an index of reading exposure, given evidence suggesting that participants with dyslexia typically have lower print exposure and tend to read less than typical readers (cf. The Matthew Effect; Stanovich, 2009).

Pupillometry Recording

Pupil dilation data were recorded and pre-processed using an identical procedure to the one outlined in relation to Experiment 1.

ERP Recording

Electrophysiological data were recorded and pre-processed using an identical procedure to that outlined for Experiment 1. Following artefact rejection typical readers had an average of

85 trials per condition (*SD* = 11), and dyslexic readers had an average of 88 per condition (*SD* = 8).

Experimental Design and Statistical Analyses

Behavioural accuracy was analysed using generalised linear models, for which the fixed factors were centred and sum-coded (Nieuwenhuis et al., 2017). Fixed factors were Group (Dyslexia, Typical), Congruency (Congruent, Incongruent), Alliteration (Alliterating, Non-alliterating), and the interaction between them. A maximal slope was initially specified for 'WordPair' (1+Group | WordPair), but the model failed to converge (Barr et al., 2013). As such the most parsimonious mixed model was used (Matuschek et al., 2017), consisting of a between-participant intercept and within-participant slopes of Congruency and Alliteration, and the contribution of their interaction. The formal specification of the model was:

*Accuracy ~ Group*Congruency*Alliteration + (1+ Congruency*Alliteration | Participant) + (1 | WordPair)*

ERP mean amplitudes were analysed using a mixed factorial ANOVA in the N400 time-window (300–500 ms over the same 11 centroparietal recording sites as the previous experiment). The between-subjects factor was Group (Dyslexia, Typical), and the within-subjects factors were Congruency (Congruent, Incongruent) and Alliteration (Alliterating, Non-alliterating).

For the pupillometry data, the same procedure as Experiment 1 was used (as per Mathôt, Grainger, & Strijkers, 2017). The timeseries was split into time-bins of 10 ms, and linear mixed effects models were run for each bin. The dependent variable comprised changes in pupil size modelled according to the fixed effects and the interaction between them. As with the accuracy data, the most parsimonious mixed model was implemented (Matuschek et al., 2017):

*PupilSize ~ Group*Congruency*Alliteration + (1+ Congruency*Alliteration | Participant) + (1 | WordPair)*

We considered an effect to be significant based on the t-as-z approach where $t > 1.96$ (approx. $\alpha = .05$) in 20 or more contiguous time bins for a minimum effect duration of 200 ms.

Finally, we correlated the N400 ERP amplitude with modulations in pupil size over time. For this analysis, we took mean N400 amplitudes for each participant per condition and correlated this value with changes in pupil size at each 20 ms time step over the course of noun presentation. This analysis was performed separately for both groups.

Results

Background cognitive and literacy tests validated group differences on relevant measures (see **Table 1**). Dyslexic readers had longer rapid naming, word, and nonword reading latencies than typical readers, as well as more word / nonword naming errors. Participants with dyslexia also had lower print exposure, but both groups self-reported spending equivalent time reading in an average week. Importantly both groups had similar verbal and nonverbal IQ.

Table 1: Scores on cognitive and literacy tests. Note: [a] Time in seconds; [b] Number of errors; [c] Number of authors (max 30); [d] Time in hours; [e] WASI subtest scaled score; * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$.

	Mean (SD)			
	Dyslexic *n* = 19	Typical *n* = 19	*t*	*Cohen's d*
RAN [a]	17.62 (4.61)	12.89 (2.52)	3.92^{***}	1.27
Word Reading (Acc) [b]	3.10 (2.35)	0.53 (0.77)	4.537^{***}	1.47
Nonword Reading (Acc) [b]	10.32 (4.15)	1.84 (1.71)	8.229^{***}	2.67
Word Reading (Time) [a]	79.47 (20.70)	53.86 (7.26)	5.09^{***}	1.65
Nonword Reading (Time) [a]	76.49 (26.92)	52.38 (12.79)	3.525^{***}	1.14
ART [c]	5.37 (2.49)	10.84 (5.54)	-3.926^{***}	1.27
Average weekly reading [d]	16.31 (8.62)	16.42 (5.36)	-0.045	0.02
Verbal IQ [e]	5.47 (3.22)	8.74 (2.77)	-1.688	1.09
Matrix Reasoning [e]	11.32 (1.95)	11.05 (1.87)	0.425	0.14

Behavioural

Accuracy data revealed a significant fixed effect of group ($\beta = 0.87$, $SE = 0.33$, $z = 2.62$, $p < 0.01$), such that accuracy was lower for participants with dyslexia ($M = 75.89$, $SD = 21.19$), than for typical readers ($M = 85.59$, $SD = 13.84$). There was also a significant fixed effect of congruency ($\beta = -0.99$, $SE = 0.37$, $z = -2.72$, $p < 0.01$), such that accuracy was lower for congruent ($M = 76.19$, $SD = 15.45$) than incongruent ($M = 85.29$, $SD = 20.19$) word pairs. We also found a significant fixed effect of alliteration ($\beta = -0.47$, $SE = 0.18$, $z = -2.52$, $p < 0.05$) with more errors for alliterating ($M = 78.36$, $SD = 18.15$) than non-alliterating pairs ($M = 83.13$, $SD = 18.64$). There was also an interaction between congruency and alliteration ($\beta = 0.97$, $SE = 0.33$, $z = 2.98$, $p < 0.01$). Finally, there was a marginally significant three-way interaction between group, congruency, and alliteration ($\beta = 0.71$, $SE = 0.36$, $z = 1.96$, $p = 0.05$).

In order to further investigate this three-way interaction, the model was run separately for each group. For typical readers no significant fixed effects emerged, but an interaction between congruency and alliteration emerged ($\beta = 1.24$, $SE = 0.4$, $z = 3.09$, $p < 0.01$).

For dyslexic readers a fixed effect of congruency emerged ($\beta = 1.11$, $SE = 0.44$, $z = 2.52$, $p < 0.05$), once again showing that accuracy was lower for congruent ($M = 69.97$, $SD = 16.05$) than incongruent ($M = 81.82$, $SD = 24.11$) word pairs. We also found a significant fixed effect of alliteration ($\beta = 0.48$, $SE = 0.21$, $z = 2.19$, $p < 0.05$) with lower accuracy for alliterating ($M = 73.29$, $SD = 20.14$) than non-alliterating pairs ($M = 78.5$, $SD = 22.14$). No interaction effect emerged for dyslexic readers. See **Figure 8** below.

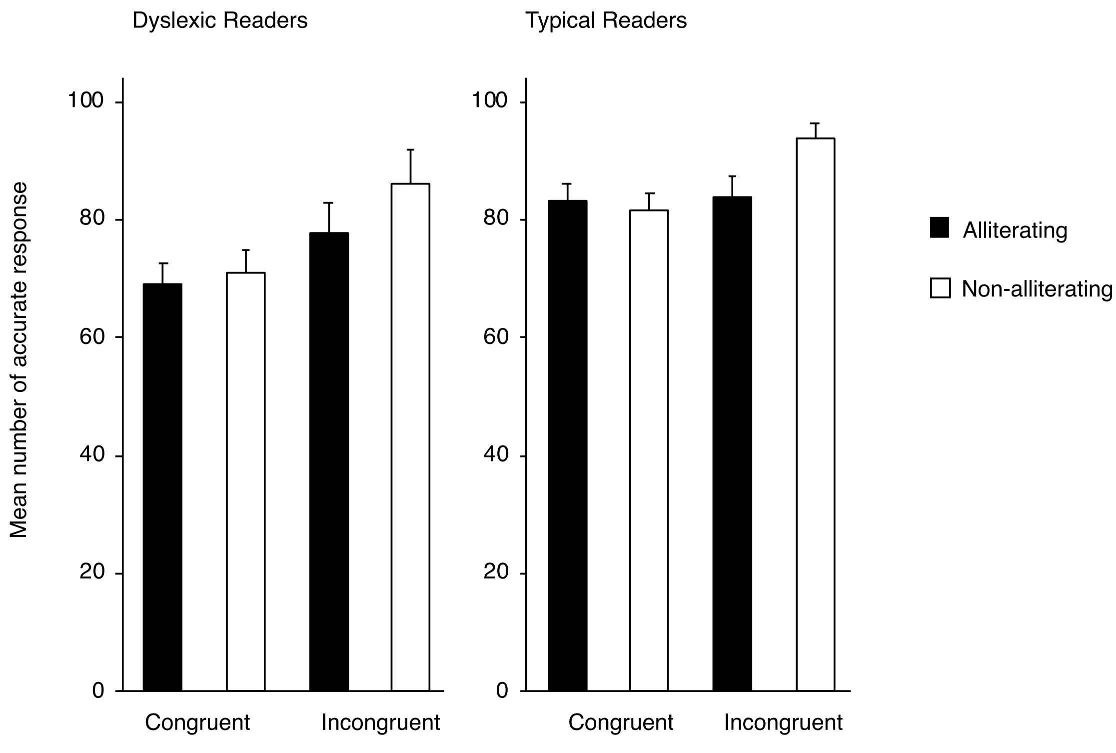

Figure 8. Behavioural accuracy for participants with dyslexia (left) and typical readers (right), representing the number of trials (max 104) upon which participants correctly reported that phrases 'made sense' or not. Error bars depict the standard error of the mean.

ERP

In the N400 time-window there was a main effect of congruency ($F(1, 36) = 15.483$, $p < .001$, $\eta^2 = .301$). No other main effects or interactions reached the significance threshold, see **Figure 9** below.

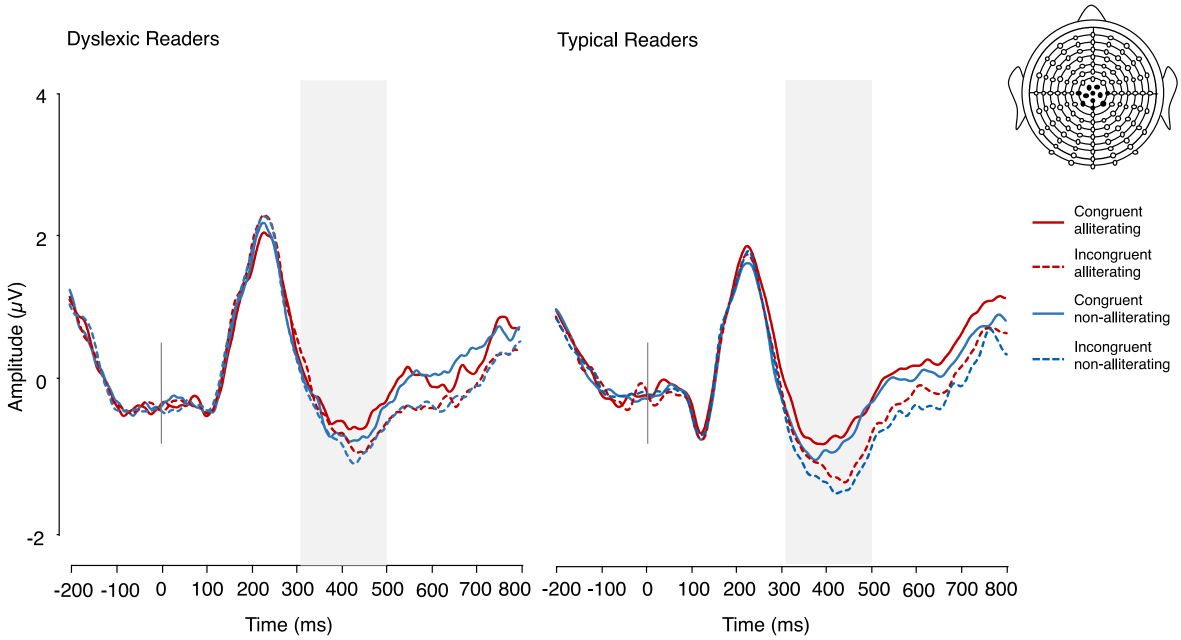

Figure 9. Mean ERP amplitudes for participants with dyslexia (left) and typical readers (right), the shaded bars represent the areas of analysis.

Pupillometry

There was a significant main effect of Group on pupil dilation from 1350 – 2000 ms, such that participants with dyslexia had smaller dilation than typical participants in all conditions. There was also a main effect of Congruency from 1270 - 2000 ms manifesting as a pupil size increase for congruent relative to incongruent word pairs. Finally, an early main effect of Alliteration emerged from 70 - 350 ms. No significant interaction effects emerged. See **Figure 10** below.

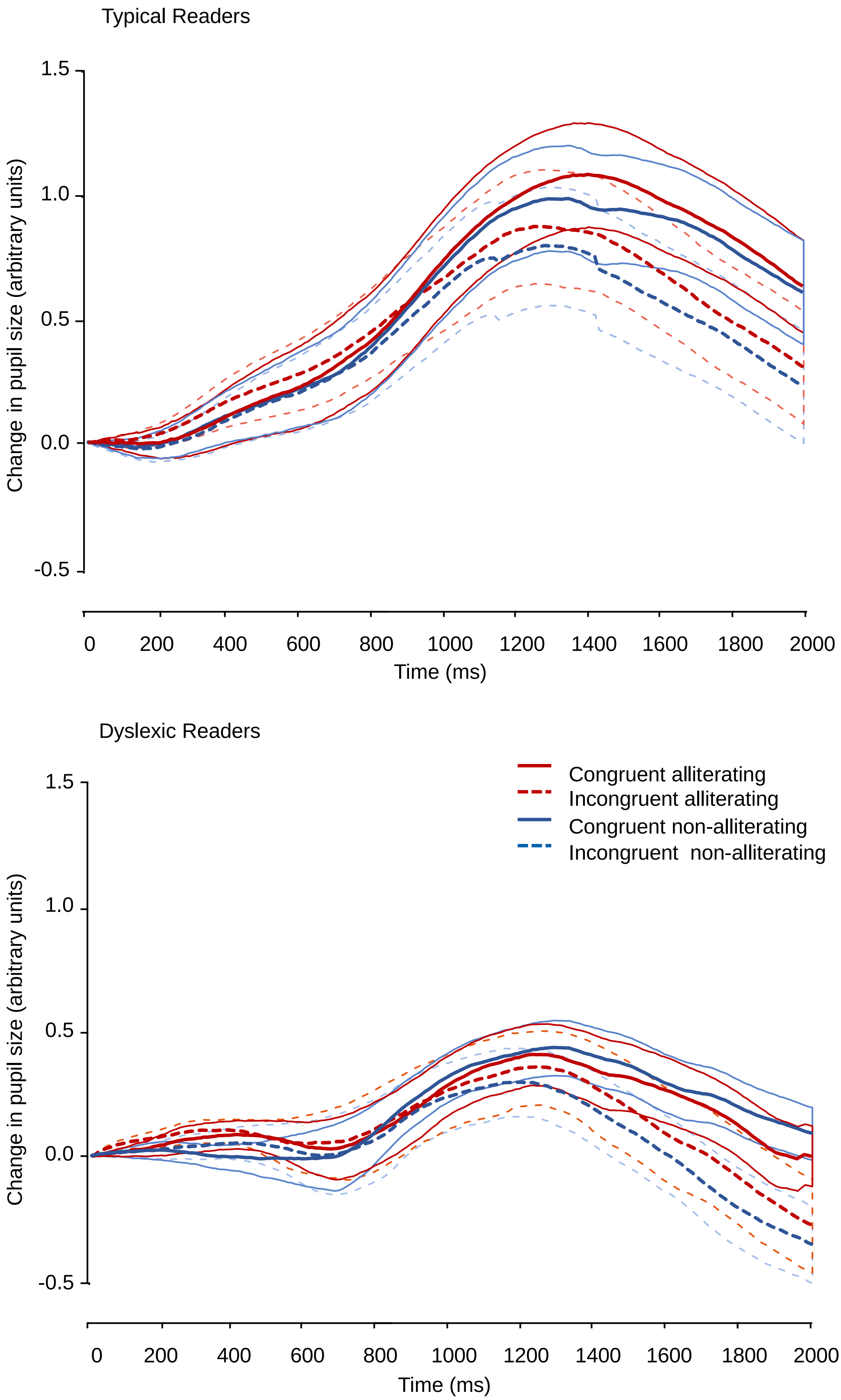

Figure 10. Pupil dilation for typical readers (top) and those with dyslexia (bottom), the shaded areas represent the standard error of the mean.

Correlation analysis

We next examined the relationship between online semantic processing in the ERP signal and different stages of attentional engagement, reflected in the pupil dilation measure. This was conducted separately for each group.

For typical participants, no correlations reached the pre-determined significance threshold (r > -0.45, or r < 0.45), see **Figure 11** below for correlation coefficients.

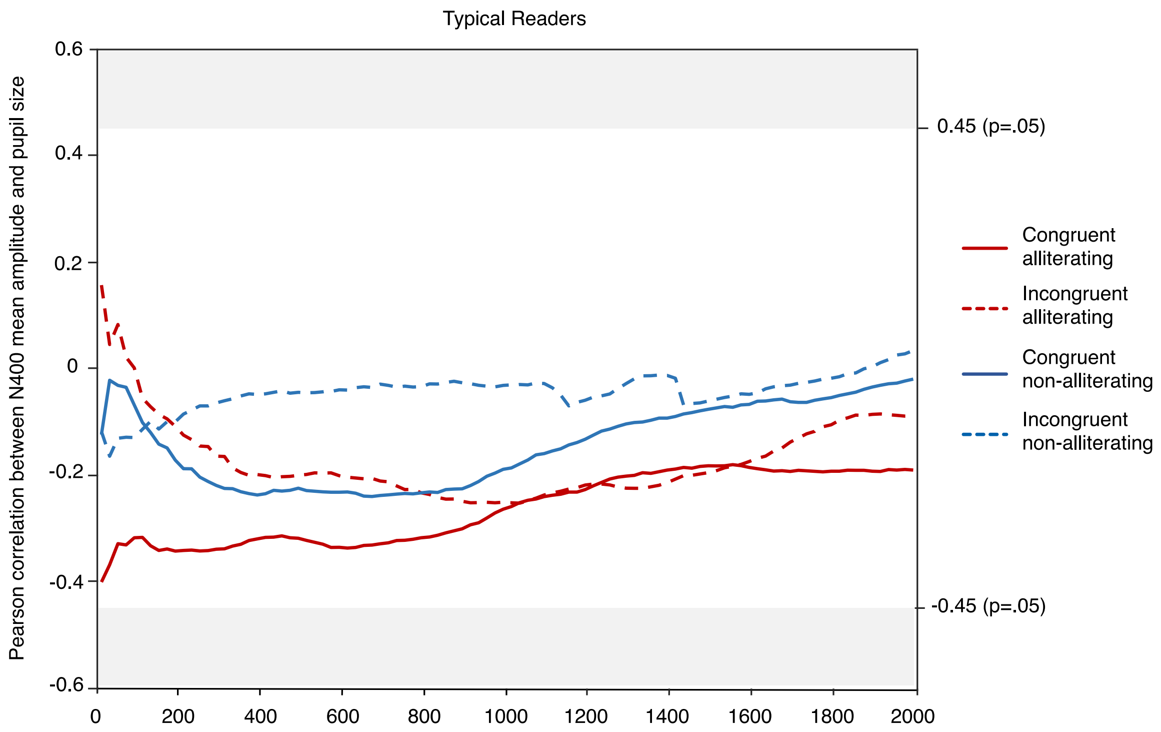

Figure 11. ERP-pupil dilation correlations for typical participants at 20 ms time bins indicating Pearson correlation coefficients. Significance thresholds (r > -0.45, or r < 0.45) are indicated along the righthand Y-axis.

For participants with dyslexia there was a significant positive correlation between mean N400 amplitude and pupil dilation for congruent alliterating items from approximately 1400 ms (see **Figure 12** below). There was also an early negative correlation in the congruent non-alliterating condition from the trials onset to 200 ms. As this early correlation started at trial onset (during the period of pupil dilation baselining) and does not persist across 10 time-bins when discounting the baseline period, it does not cross our pre-determined threshold of significance.

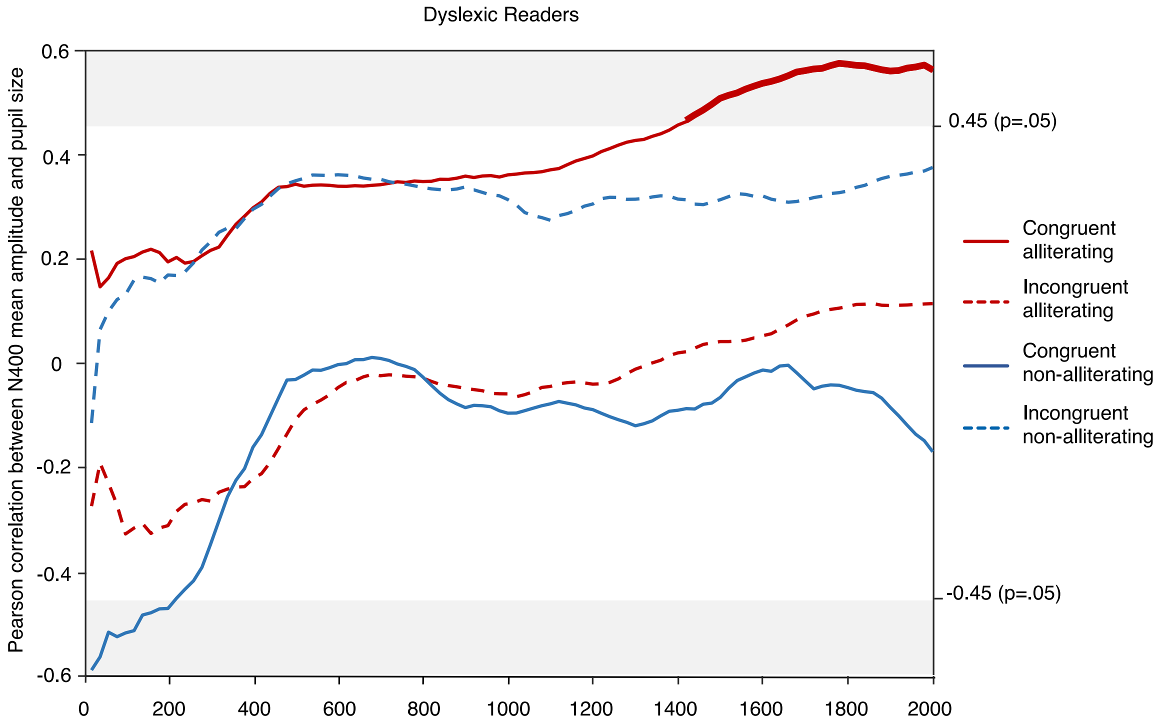

Figure 12. ERP-pupil dilation correlations for participants with dyslexia at 20 ms time bins indicating Pearson correlation coefficients. Thicker lines indicate statistical significance (r > -0.45, or r < 0.45). Significance thresholds are indicated along the righthand Y-axis.

Discussion of a priori analyses

This study examined how alliteration influences the interplay between semantic, phonological and attentional processes during reading in individuals with and without dyslexia, as indexed by behavioural accuracy (explicit responses), brain potentials, and pupil dilation (implicit responses).

Explicit behavioural responses: In the behavioural data, typical readers were highly accurate in rejecting incongruent non-alliterating phrases (e.g., creepy-diamond), but relatively less accurate in rejecting incongruent phrases that were also alliterating (e.g., dangerous-diamond), and in accepting semantically congruent phrases. This is consistent with behavioural data from Experiment 1, in which we showed that alliteration compromised participants' ability to judge a phrase as incongruent.

Dyslexic readers were less accurate overall at making semantic relatedness judgements, compared with the typical group. However, their data patterned similarly to typical readers across conditions, in which both congruent and alliterating items reduced accuracy. However, whilst in typical readers, alliteration elicited a drop in semantic judgement accuracy in incongruent items that was on a par with congruent items, dyslexic readers maintained overall better accuracy for incongruent compared with congruent items. The general pattern of behavioural data is consistent with previous dyslexia studies, which show an overall reduction in accuracy in semantic judgement tasks, but a preserved overt congruency effect (Schulz et al., 2008). Interestingly, alliteration did have a pronounced effect on dyslexic readers' accuracy, for both congruent and incongruent items, which was unexpected, since individuals with dyslexia are expected to show less sensitivity to alliteration (Ahissar, 2007). Thus, dyslexic readers in this study were sensitive to phonological repetition and were moreover susceptible to conflating sound with meaning during the later stages of stimulus processing.

Implicit neurocognitive responses: For both typical and dyslexic readers, we found that the N400 response was modulated by semantic congruency. **Figure 9** also suggests a trend for dyslexic readers to manifest reduced N400 amplitude in response to incongruent items, in line with previous studies (Jednoróg et al., 2010; Schulz et al., 2008) suggesting that semantic integration difficulty in dyslexia may specifically comprise an impaired ability to detect *incongruency* (Schulz et al., 2008). However, we found no indication that phonological repetition, in the form of alliteration, modulated semantic integration in either group. For typical readers, this was contra our predictions and the results of Experiment 1 (which we discuss below and examine further in the 'post hoc examination' section) and shows a dissociation with the behavioural results wherein alliteration interfered with participants' semantic relatedness judgements. The absence of a group-by-alliteration effect also contradicted our expectation of aberrant phonological processing in the dyslexia group, whether in terms of reduced sensitivity to phonology, or an attentional boost. However, this group showed intact sensitivity to alliteration in their behavioural responses. Whilst it is tempting to attribute these intact explicit effects of phonology to delayed manifestation of phonological processing, we note that a comparable dissociation in the implicit / explicit effects of alliteration is also observable in the typical readers group.

Our pupil dilation predictions concerning modulation of PD as a function of reading ability was necessarily more speculative, given the paucity of research in this area. For typical readers, our findings were broadly consistent with Experiment 1 data, in which semantic congruency elicited larger pupil size during the later dilation phase, which is linked with greater autonomic arousal (Hess & Polt, 1960; Mathôt, 2018). This replication buttresses our argument that semantic congruency in text engages readers' attention more intensely compared with incongruency (see also Riese et al., 2014), albeit with a later onset (~ 250 ms later than Experiment 1). Typical and dyslexic readers yielded a similar pattern of dilation across conditions, suggesting intact semantic processing in this group.

Dyslexic readers showed smaller pupil dilation overall than typical readers toward the later phase of dilation (beginning ~1300 ms after noun onset), suggesting that their attention was generally less engaged by the word pairs than was the case for typical readers (Laeng et al., 2012). This was an unexpected but interesting finding, showing that dyslexic readers yield less autonomic arousal from print, as indexed by PD, than typical readers. Further research would be required to ascertain whether this is due to a generalized attentional deficit (Gabrieli & Norton, 2012; Lonergan et al., 2019; Shaywitz & Shaywitz, 2008), which would presumably affect stimulus processing irrespective of the modality, or due to a specific difficulty with processing text, possibly concerning lexical quality (Perfetti, 2007), or the integrity of orthographic representations (Blomert, 2011; Jones et al., 2016). To examine whether this effect is specific to orthographic stimuli, an interesting follow up study might compare PD responses to auditorily and visually presented word pairs. Finally, the analysis yielded a main effect of alliteration, in which alliterating items elicited greater dilation from 70 – 350 ms post noun onset. We are very wary to over-interpret this result, as it is too early to reflect an attentional orientating response (Mathôt, 2018; Wang & Munoz, 2015), or a specific response to the stimuli (Mathôt et al., 2018). Neither can we attribute it to low-level features of the stimuli such as differences in word form nor consequent luminance, since all adjectives and nouns were fully rotated across conditions.

For typical readers, N400 mean amplitude did not correlate with pupil dilation in any condition, again contra predictions derived from the findings of Experiment 1. This is most likely due to the lack of parity between the ERP results for the two studies, stemming from differences in participant demographics, which we elaborate upon in the following section. For readers with dyslexia, there was a positive correlation between N400 amplitude and pupil dilation for congruent alliterating items, beginning ~ 1400 ms. Specifically, larger N400 amplitude was associated with smaller pupil dilation, suggesting that when congruent alliterating items are less easily semantically integrated (larger N400), they also engage less attention (smaller pupil dilation). Interestingly, this pattern is the opposite of that found for typical readers in Experiment 1 (in which a late *negative* correlation emerged in this condition: larger N400 amplitude associated with larger pupil dilation response). Though very tentative at this point, these explorative correlations may suggest a dissociative relationship between semantic processing and attentional engagement, in which difficulty elicits greater engagement or effort in the typical reader, whilst producing more *disengagement* in the dyslexic reader.

In summary, typical readers' behavioural results patterned similarly with those from Experiment 1, with accuracy being comparatively lower for congruent, and alliterating word-pairs. However, for implicit measures no effect of alliteration appeared for these participants, which was contra our predictions based on the previous experiment. Furthermore, our implicit measures provide no evidence, either in the ERP or PD data, that dyslexic readers differentially process alliteration compared with typical readers: in fact, both groups were apparently insensitive to this manipulation in the implicit measures. We also found no statistically significant evidence of impaired semantic-level processing in dyslexia: Despite an observable trend for reduced N400 modulation in response to incongruent items in the N400 averages, PD revealed a normal increase in dilation in response to semantically congruent items, on a par with typical reader responses. However, the PD measure did reveal an overall diminished pupillary response in dyslexic readers, which may either index an attentional deficit (Hari & Renvall, 2001; Lonergan et al., 2019), or may be the product of a less well defined orthographic lexicon (Perfetti, 2007). The diminished pupillary response was matched (though not necessarily yoked) to lower accuracy in judging semantic congruency, and both reader groups demonstrated overt sensitivity to sound information in evaluating the inter-word semantic relationship.

Differences in Experiment 1 and 2 typical readers' N400 results: a post hoc examination

Given that the Experiment 2 paradigm was identical to that implemented in Experiment 1, we expected a straightforward replication of the typical readers' data. We were therefore surprised to find that the N400 results did not replicate across experiments. Specifically, for typical readers in Experiment 1, alliteration influenced semantic level processing, but a comparable interaction in the N400 window was absent for typical readers in Experiment 2. In this section we examine the demographic profiles (performance on cognitive and literacy tests) of the two typical reader groups and report out conclusions concerning the possible mediating factors responsible for these discrepancies.

Although the two groups of typical readers were sampled from the same population of university students, preliminary analyses showed significant differences on an index of verbal IQ, namely the vocabulary subtest of the WASI ($t(37) = 3.506$, $p = .001$, $d = 1.12$; Wechsler, 2006), and on self-reported reading time during an average week ($t(37) = 2.103$, $p = .042$, $d = 0.67$). Specifically, typical readers in Experiment 1 had significantly higher verbal IQ scores than typical readers in Experiment 2 ($M = 11.6$, $SD = 2.32$ vs. $M = 8.74$, $SD = 2.77$) and self-reported longer reading times per week on average ($M = 20.2$, $SD = 5.84$ vs. $M = 8.74$, $SD = 2.77$). The two groups were comparable on all other measures (see **Appendix F** for a table with means and standard deviations for all of the cognitive and literacy tests).

We chose to further investigate verbal IQ and its association with N400 mean amplitudes[5] for both typical reader samples combined ($n = 39$) in the four conditions. Verbal IQ correlated with mean amplitudes in both the congruent alliterating ($r = .363$, $n = 39$, $p = .023$) and congruent non-alliterating ($r = .317$, $n = 39$, $p = .049$) conditions, whilst no significant correlation was found between verbal IQ and the incongruent conditions. We then pooled participants from both experiments and used a median split to create a 'lower' (scaled score of < 11, $n = 18$) and a 'higher' (scaled score of $>=11$, $n = 21$) verbal IQ group. We acknowledge that a median split it not optimal and leads to less statistical power (Aiken & West, 1991) and including IQ as a continuous variable in an ANCOVA analysis would be the theoretically better option. However, the IQ scores were skewed and could not be adequately normalized with transformation. We chose the median split in order to examine the data and

[5] We considered a priori that the self-reported reading measure may have been a less reliable indicator, due to social desirability influences (Acheson et al., 2008; Stanovich & West, 1989), and since a comparable but more objective measure of reading frequency (the ART test) showed no such relationship with the N400. For completeness we checked the self-reported correlations with N400 amplitude, and no significant correlations emerged.

averages from a two-group perspective, ensuring better comparability with our a priori between group (typical / dyslexic reader) analyses. Thus, the 'lower' and 'higher' IQ groups were entered into a factorial group * congruency * alliteration ANOVA.

In the N400 time-window there was a main effect of congruency ($F(1, 37) = 44.886$, $p < .001$, $\eta^2 = .548$), and of alliteration ($F(1, 37) = 10.673$, $p = .002$, $\eta^2 = .224$) on the mean ERP amplitudes, such that both congruency and alliteration tended to reduce N400 amplitude. There was also a significant main effect of verbal IQ group ($F(1, 37) = 6.28$, $p = .017$, $\eta^2 = .145$), in which lower IQ elicited generally larger, more negative amplitudes. No interactions reached the significance threshold. See **Figure 13** below for the grand average waveforms of these two groups separately.

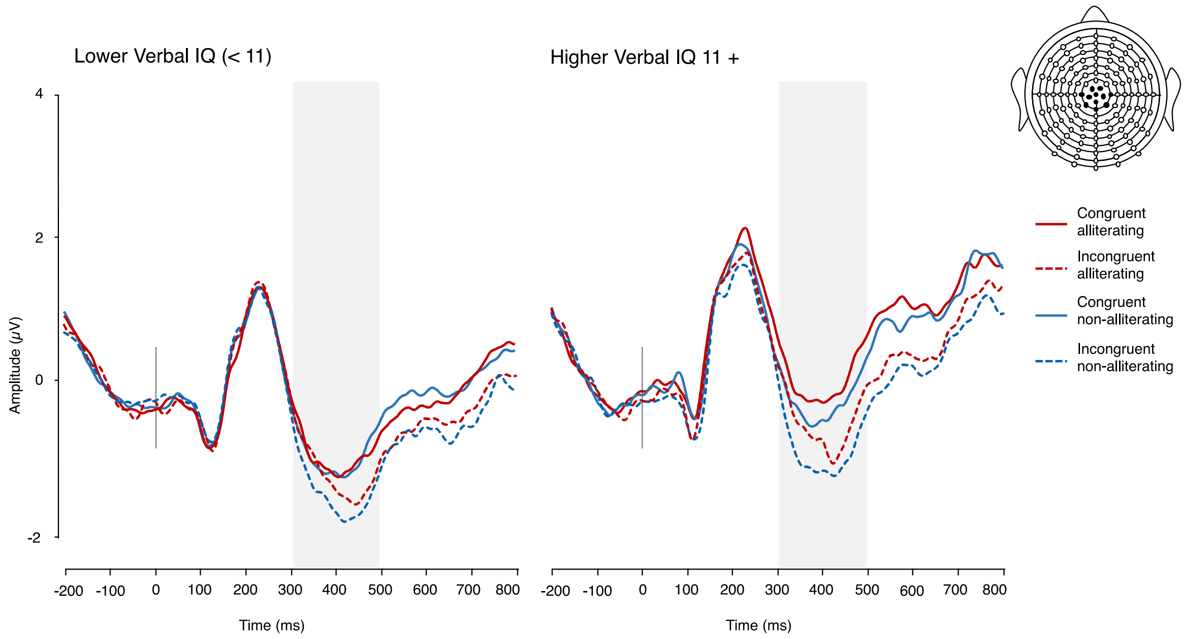

Figure 13. Mean ERP amplitudes for participants with lower verbal IQ (left) and higher verbal IQ (right), the shaded bars represent the areas of analysis.

These results are somewhat revealing firstly in showing that participants with lower verbal IQ tended to have generally reduced mean amplitudes, irrespective of condition, showing a relationship between IQ and N400 magnitude. A similar relationship has previously been shown between nonverbal IQ and N400 amplitude in response to semantic incongruency (Shcherbakova et al., 2019). The relationship between verbal IQ (vocabulary knowledge) and reading comprehension is well documented (Nation et al., 2004; Perfetti, 2007; Ricketts et al., 2007; Snowling & Hulme, 2013), and skilled comprehenders also tend to have more reading experience than less skilled comprehenders (Perfetti, 2007). Indeed, differences in comprehension ability (in otherwise skilled readers) have been shown to affect N400 amplitude for semantically related word-pairs (Landi & Perfetti, 2007; Perfetti, 2007; Perfetti et al., 2005). At a global level, it may therefore be the case that higher verbal IQ readers have better lexical 'quality' (better integrated orthography, phonology, morpho-syntax, and meaning, Perfetti, 2007).

Second, when typical readers from both experiments are analysed together, alliteration has a modulating effect on the N400 (regardless of semantic congruency), suggesting that the absent alliteration effect in Experiment 2 is perhaps due to lack of power. Visual inspection of **Figure 13** suggests – with a caveat, given the non-significant outcome of the interaction – that higher IQ is associated with greater distinction between alliterating conditions in semantically congruent items. This trend is consistent with the correlations cited at the beginning of this section, and may suggest that in high IQ readers, alliteration exerts a more pervasive influence on semantic processing, such that these readers use more sources of information in order to enhance sense when reading.

In summary, we conducted a post hoc investigation for sources of different N400 modulations in our typical reader populations (Experiments 1 and 2). Correlation analysis and factorial ANOVA analysis suggest that verbal IQ may modulate the N400 response in ways compatible with the differences found in typical readers between Experiments 1 and 2.

Conclusion

This study examined whether the interactions found between alliteration and semantic processing in typical readers are further modulated by reading ability. Specifically, whether dyslexia, involving a phonological impairment, impacts this interaction. Alliteration did not impact dyslexic readers' implicit semantic processing, or attentional engagement. Interestingly, alliteration impacted participants' overt semantic judgements in similar ways in both reading groups, indicating that these readers are still sensitive to the presence of alliteration, despite their phonological impairment.

Chapter 5

Investigating How Alliteration Affects Attentional Engagement via a Pupillometry Investigation

Acknowledgements: I would like to thank Glevina Doreen Mckenzie and Elizabeth Cresswell for their assistance with data collection for this project.

Abstract

In the extant literature examining the pupil dilation in response to linguistic stimuli, larger dilation is typically found for unexpected, difficult or interesting items, which is thought to be associated with increased cognitive load or an attention-related increase in arousal. Yet, despite evidence that stylistic techniques boost attention and interest, we have thus far found no effect of alliteration on pupil dilation. In this study we aim to examine whether minimizing noise in the experimental procedures unmasks an effect of alliteration. We therefore present an experiment in which the procedures are identical to Experiment 1 but measuring only pupil dilation under optimized testing conditions. Our pupil dilation data reveals a pattern very similar to the one found in Experiment 1, in which dilation was again greater in response to semantically congruent items, but the alliteration effect failed to reach statistical significance. Our behavioural results again showed greater accuracy for incongruent items. But alliteration this time increased accuracy for congruent items, whilst decreasing accuracy for incongruent items. We discuss whether alliteration can be plausibly linked with pupil dilation. We also discuss possible interpretations of the 'surprising' congruency effect, which at this point in the thesis has been replicated for a third time.

In Experiment 1, we expected to observe an effect of semantic congruency, such that semantically incongruent items would lead to greater pupil dilation (Krejtz et al., 2018; Scheepers et al., 2013). Interestingly, the opposite effect was found, with semantically congruent items eliciting greater dilation. We concluded that semantically congruent items elicit greater attention and interest compared with incongruent items (Riese et al., 2014). We also expected that alliteration would increase pupil dilation, associated with an increase in readers' attention and interest (Hess & Polt, 1960; Kang et al., 2014; Mathôt, 2018; Riese et al., 2014). But we found no significant effect of alliteration on pupil dilation, despite an observable trend in which alliteration appeared to elicit larger pupil dilation for incongruent items. Given that Experiment 1 testing conditions were configured to maximise signal-to-noise ratio for our EEG data, rather than to optimize minimal noise in the pupil dilation measure, we propose that the effect of alliteration may have been masked. We identified potential head movement as the primary likely source of error in Experiment 1. Head movement is typically minimized in eye-tracking experiments via use of a chin and head rest (*EyeLink®1000 User Manual*, 2005), but these tools were not implemented in our previous studies in order not to interfere with the EEG recording.

The Current Study (Experiment 3)

Here, we ran an experiment that was almost identical to Experiment 1, with the exception that participants' head movements were restricted. We sought to replicate the overall findings of Experiment 1, but by minimizing error in the signal, we also sought to examine whether an effect of alliteration would emerge.

Materials and Methods

Participants

The data of 26 native English speakers (20 females, mean age = 21, SD = 1.69) were included in the analysis (see **Appendix F** for their cognitive and literary test scores). A further 3 were excluded for having verbal IQ scores more than two standard deviations below the general population mean (Wechsler, 1999). All participants had normal or corrected-to-normal vision and reported no past or present diagnosis of a learning difficulty. Ethical approval was granted by the School of Psychology, Bangor University and all participants provided written informed consent before taking part.

Stimuli and Procedure

The same stimuli were used for this experiment as in the previous chapters. However, in this experiment each participant saw only half of the experimental items (and half of the fillers), in order to shorten the testing session and minimize participants' fatigue[6]. Thus, each participant saw a total of 208 experimental items (stimulus presentation was fully counterbalanced across participants).

Participants sat at a distance of 100 cm from the monitor, with their head resting in a head and chin-rest (in order to minimize head movements). Following calibration of the eye-tracker, each trial began with a drift correction (single-point recalibration) also serving as a fixation point in the centre of the screen. Then, the adjective was presented for a random duration in the range of 330–550 ms in 20 ms increments, followed by the noun, which was

[6] Recall that in Experiments 1 and 2, trials were split between 208 PD and 208 ERP trials (PD trials had longer noun presentation times). Thus, in seeing 'half' of the experimental items, an identical number were available for PD analysis as compared with previous experiments.

always presented for 2000 ms. Then, a response cue (#####) prompted the participant to indicate, using a counterbalanced, binary-decision button press, whether or not the two words were related in meaning (see **Figure 14**). Importantly, as in the previous two experiments, the visually presented fixation and response cues also had the exact same number of lit pixels as word stimuli, such that luminance was constant throughout experimental blocks.

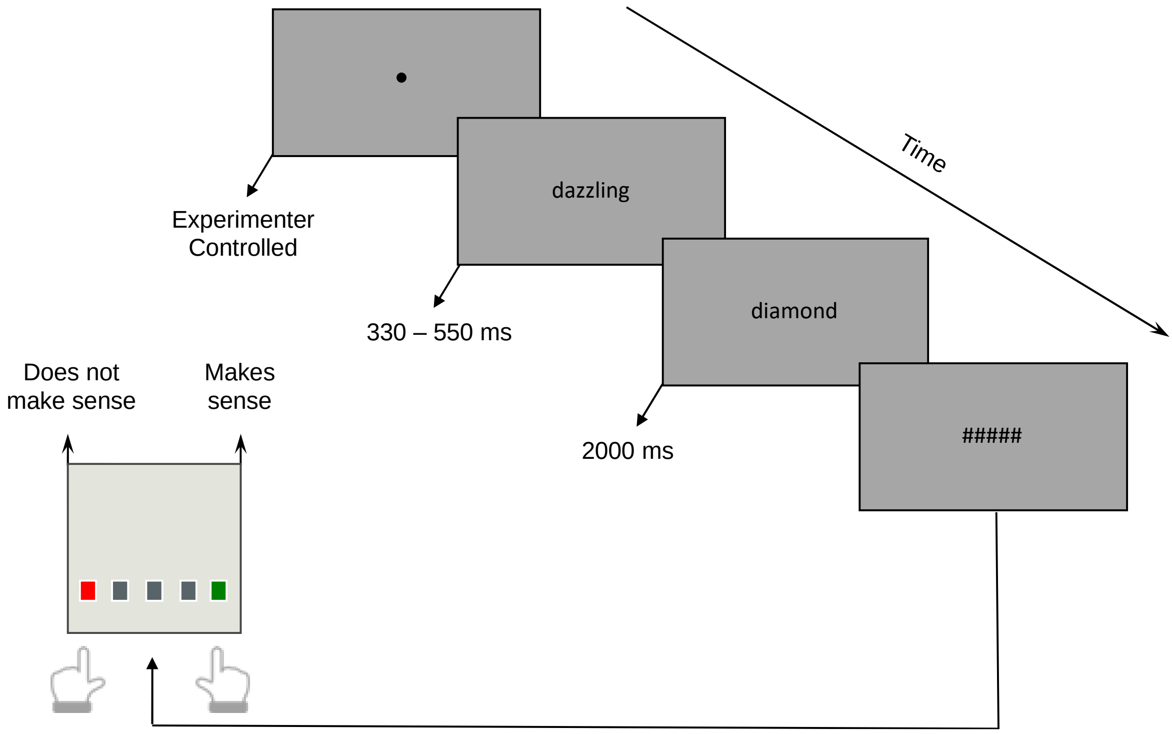

Figure 14: Schematic of the experimental procedure. Please note that all items were presented in white on a black background.

Pupillometry Recording

Pupil dilation data were recorded and pre-processed using an identical procedure to the one outlined in relation to Experiment 1.

Experimental Design and Statistical Analyses

Behavioural accuracy was analysed using generalised linear mixed models, for which the fixed factors were centred and sum-coded (Nieuwenhuis et al., 2017). Fixed factors were Congruency (Congruent, Incongruent) and Alliteration (Alliterating, Non-alliterating), and the interaction between them. The maximal random effects structure with correlations was modelled, consisting of a between-participant intercept and within-participant slopes of Congruency, Alliteration, and their interaction. The formal specification of the model was:

*Accuracy ~ Congruency*Alliteration + (1+ Congruency*Alliteration | Participant) + (1 | WordPair)*

Reaction times were not analysed, given that participants were asked to provide a delayed response.

For the pupillometry data, the same procedure as Experiment 1 was used (as per Mathôt et al. 2017). The timeseries was split into time-bins of 10 ms, and generalised linear mixed effects models were run for each bin. The dependent variable was the change in pupil size modelled according to the fixed effects and the interaction between them. As with the accuracy data, the maximal random effects structure was implemented, formal specification:

*PupilDilation ~ Congruency*Alliteration + (1+ Congruency*Alliteration | Participant) + (1 | WordPair)*

We considered an effect to be significant based on the t-as-z approach where $t > 1.96$ (approx. $\alpha = .05$) in 20 or more contiguous time bins for a minimum effect duration of 200 ms.

Results

Behavioural

Accuracy data revealed a significant fixed effect of congruency (β = 1.761, *SE* = 0.40, *z* = 3.99, *p* < .001), such that accuracy was lower for congruent (*M* = 0.78, *SD* = 0.1) than incongruent (*M* = 0.91, *SD* = 0.11) word pairs. There was no main effect of alliteration (β = -0.27, *SE* = 0.19, *z* = -1.48, *p* = 0.14). A significant interaction between congruency and alliteration also emerged (β = -1.22, *SE* = 0.39, *z* = -3.08, *p* < .001), such that for congruent items accuracy was greater when they alliterated, yet for incongruent items accuracy was lower when they alliterated. See **Figure 15** below.

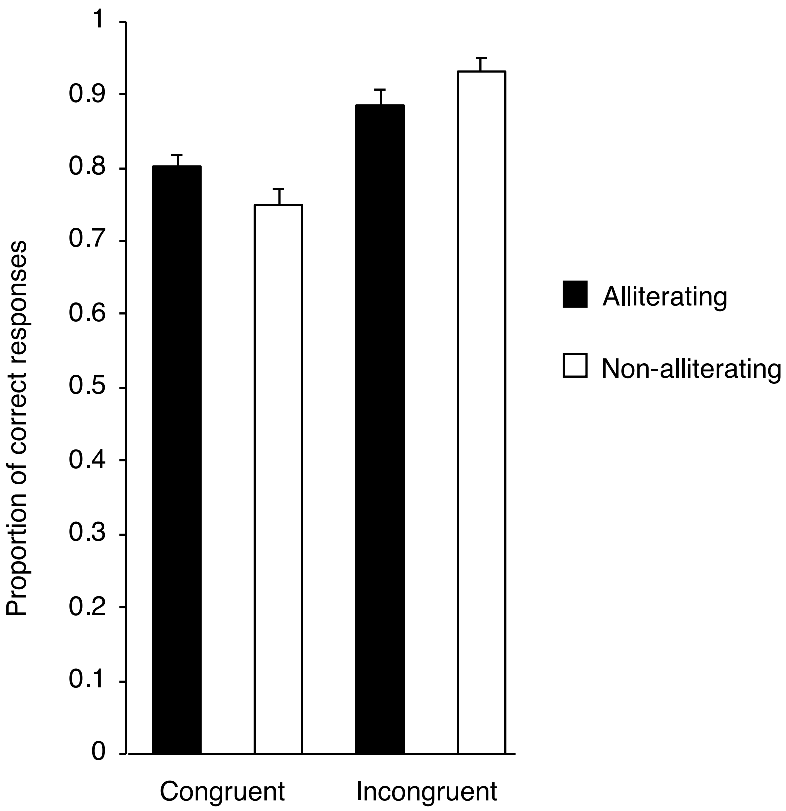

Figure 15. Behavioural accuracy, representing the mean number of trials upon which participants correctly reported that phrases 'made sense' or not. Error bars depict the standard error of the mean.

Pupillometry

Congruency significantly modulated PD from 1620 –2000 ms, manifesting as a pupil size increase for congruent relative to incongruent word pairs (**Figure 16**). No other fixed effects or interactions emerged.

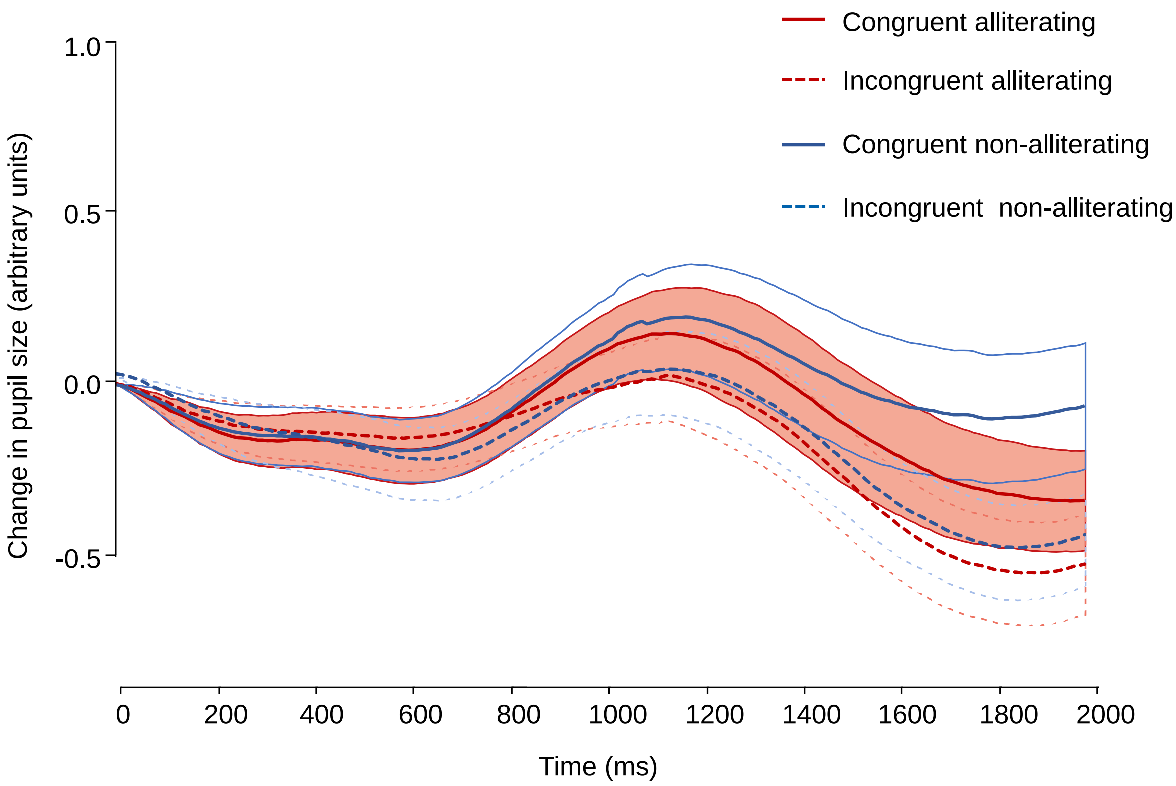

Figure 16. Mean pupil dilation change over time, the shaded areas represent the standard error of the mean.

Discussion

We conducted a near-replication of Experiment 1, in which we minimized variability in the pupil dilation data by constraining participants' head movements. Our primary aim was to obtain a similar overall pattern in the data to that identified in Experiment 1, but with the expectation of obtaining a significant effect of alliteration on pupil dilation; specifically –

given the results of Experiment 1 – greater dilation in response to alliterating incongruent items.

Behavioural responses:

As in our previous experiments, participants were more accurate at rejecting incongruent items compared with semantically congruent items. Also, as before, the presence of alliteration reduced accuracy for incongruent items, leading participants to falsely ascribe semantic congruency to incongruent items. However, in this study we also found an interesting reverse effect for congruent items: whereas in Experiments 1 and 2 there was no apparent effect of alliteration, here, alliteration actually increased accuracy. The most parsimonious explanation is that a similar mechanism is at play, in which phonological repetition bootstraps the already existing semantic link, leading to easier identification of the item as congruent (Egan et al., 2020). Given that the bidirectionality of this effect was not found in our previous studies, however, the effect of alliteration on congruency is clearly less robust than the effect of alliteration on incongruent items.

Pupillary responses:

For pupil dilation, a late main effect of congruency emerged, such that from ~1600 ms there was greater dilation to congruent as compared to incongruent items. This effect was however not significantly modulated by alliteration. Thus, despite an observable trend in Experiment 1, we find no evidence to suggest that alliteration affects pupil size during reading, consistent with the results of Experiments 1 and 2. Globally, the pupil dilation change in this study was also smaller than for typical readers in the previous studies, for which it is difficult to identify the exact cause, but is likely due to the modified task conditions.

The current findings reveal that, when participant head movements are constrained, a very similar pattern of findings emerge as in the non-optimal PD testing environment, suggesting that the proportion of error in Experiments 1 and 2 was not responsible for the effects (and lack of significant effects) found. With these three studies in mind, we now provide our final comments on the effect of alliteration and semantic congruency on pupil dilation.

In the previous studies, visual observation of the data clearly shows a trend in which alliteration, particularly in semantically incongruent items, elicits larger pupil dilation compared with non-alliterating items. However, these trends did not reach statistical significance, and in this study no such trend was apparent. The consistent direction of the findings from our previous studies means we cannot conclusively reject the suggestion that alliteration may exert a small influence on pupil dilation, but it is too weak to be detected according to the criteria for statistical power currently recommended in the pupil dilation literature (Mathôt et al., 2017).

Indeed, the absence of an alliteration effect does not preclude the possibility of a more general effect of *phonological repetition* on pupil dilation. Scheepers et al. (2013) found that when listening to limericks, participants exhibited larger pupil dilation when the rhyme-scheme expectancy – the most salient expectancy in a limerick was violated – than when any other expectancy was violated. Thus, both the poetic context and the larger phonological segment in the word, are both aspects which could increase the phonological effect on pupil dilation found here; both of which are absent in our studies. But in any case, an important difference between Scheepers et al. (2013) and our findings – both in relation to alliteration and the significant effect of semantic congruency – is that, in Scheepers et al., violation of expectancy leads to increased pupil dilation, whereas in our studies, violation of expectancy leads to decreased pupil dilation; certainly in the case of semantic congruency. We now therefore turn to the effect of semantic congruency, which in all three studies has been consistent in revealing larger pupil dilation in response to congruent compared with incongruent items; a surprising finding, considering prior research (Scheepers et al., 2013).

Whilst the semantic congruency effect was initially ‘surprising’, it is nevertheless in line with previous research in which stimuli which are arousing or interesting to participants lead to greater pupil dilation (M. M. Bradley et al., 2008; Hess & Polt, 1960; Murphy et al., 2014; Wang et al., 2018), and this is how we initially interpreted our findings (cf. Experiments 1 and 2).

However, there are at least two alternative interpretations of the increased pupil dilation size in response to congruency, which we will now consider. The first, as with the proposed explanation for differences in the phonological effect, relates to *context*: In our studies, participants are reading short, declarative sentences – with no contextual cues leading to particular expectations of congruency – and it is therefore unlikely that semantic incongruency would lead to the same emotional response in participants to that cited in Scheepers et al.

Second, the increased pupil dilation response to semantic congruency can plausibly be attributed to *cognitive load*. Recall that in all three experiments, participants’ behavioural accuracy was lower in response to congruent compared with incongruent items, suggesting that verifying semantic congruency is more difficult than verifying semantic *in*congruency. Thus, although semantic level processing can proceed more easily in the case of congruency (validated by our N400 results), explicit verification of congruency clearly requires more processing effort. This interpretation is consistent with the findings of Nuthmann and Van Der Meer (2005), in which participants made a relatedness judgement in response to verb-noun pairs that were either temporally congruent (e.g. shrinking – small) or temporally incongruent (e.g. shrinking – large). Semantically unrelated 'filler' items were also presented and were included in additional analyses. In line with our results, greater pupil dilation was associated with more errors for semantically congruent compared to incongruent items. The authors claimed that semantically related items require more processing resources than unrelated items. This interpretation is given further credence still in the context of other studies showing that pupil size increases with task difficulty, e.g. during Stroop tasks, or mental arithmetic etc. (Beatty, 1982; Krejtz et al., 2018; Laeng et al., 2011; Nuthmann & Van Der Meer, 2005; Van Gerven et al., 2004).

We are therefore left with the question of whether increase in pupil size in response to semantically congruent phrases results from increased arousal or interest to the stimuli per se, or increased difficulty in judging their relatedness. As Mathôt (2018) notes, the effects of arousal and mental effort on pupil dilation are similar, both in the size of the effect, and in their cause, i.e. both result from greater mental activity. Indeed, items that lead to greater mental effort, by definition also lead to an increase in attention. In order to attribute the effect to increased interest or difficulty, a follow-up study might require PD responses in contexts in which participants either passively view these items (e.g. Kuipers & Thierry 2011; 2013), or to complete a task that is unrelated to semantic relatedness (such as letter detection in the noun). Greater dilation for semantically congruent items in such tasks that minimize explicit verification would lend support to the interpretation that congruency increases readers' interest (Riese et al., 2014).

Conclusion

In this study, we conducted a near-identical experiment to Experiment 1 but restraining participants' head movements in order to provide optimal conditions for collecting pupil dilation data. Whilst we broadly replicated the findings of Experiments 1 and 2 (typical readers), we still found no statistically significant effect of alliteration on pupil dilation.

Chapter 6

How Alliteration and Semantic Congruency Impact Recognition Memory

Acknowledgements: I would like to thank Dr. Rafal Jonczyk for his advice regarding the design and ERP analysis for this study, and Dr. Paloma Mari-Beffa for her advice regarding the behavioural analyses for this study.

Abstract

Poetic devices which rely on phonological repetition (e.g. alliteration, and rhyme), are generally considered to have mnemonic properties, in that they are more salient and memorable than declarative forms of language. Yet this phenomenon has received little empirical investigation. Here, we asked participants to read serially presented adjective-noun phrases during an encoding phase (Session 1), which were then probed in a recognition phase (Session 2, conducted the following day; the purpose of which was unknown to participants until the task began). Phrases were manipulated orthogonally for the presence vs. absence of semantic congruency and alliteration ("dazzling – diamond", "sparkling – diamond", "dark – diamond", "bad – diamond"), and we anticipated that stylistic language – particularly alliterating phrases – would be more memorable than declarative phrases. Whilst Session 1 data broadly replicated the behavioural patterns and N400 modulations reported in previous chapters, Session 2 data revealed crucial insight into the effect of text style on memory retention: alliteration increased participants' tendency to report items as previously seen (irrespective of whether they had in fact seen the item or not). FN400 data also suggests that alliterating items were more familiar than non-alliterating items. Despite these effects, participants were no more accurate at recognizing alliterating items, suggesting that alliteration leads to an illusion of having previously seen a phrase. Participants were also more accurate and quicker at recognizing semantically congruent items (though an effect was not found in the ERP data), which we interpret as a conceptual priming effect.

Poetic devices that rely on phonological repetition, such as alliteration and rhyme, are thought to have mnemonic properties, meaning that they are particularly salient and memorable (Fabb, 2010; Lindstromberg & Boers, 2008; Rubin, 1995). This idea stems from oral formulaic theory (OFT), which attempts to explain how bards in pre-literate societies memorized epic poems (Boers & Lindstromberg, 2005; Parry & Parry, 1987). OFT posits that phonological repetition is a key part of making these epics memorable (Boers & Lindstromberg, 2005; Parry & Parry, 1987). Whilst OFT has led to longstanding beliefs in the mnemonic properties of alliteration, very little empirical evidence has been acquired to attest to this belief (Boers & Lindstromberg, 2005).

Extant behavioural research shows that alliteration is an effective retrieval cue when presented in the context of either poetry or prose (Lea et al., 2008). Lea et al (2008) presented participants with poetry, and the target word appeared in the context of either a sentence which either had a strong alliteration pattern, or no alliteration (which served as the baseline). Later in the poem they were given a recognition probe, which appeared after a cue sentence. Participants responded more quickly to probes when the cue sentence matched the alliteration pattern of the original sentence. The authors suggest that alliteration acts as a retrieval cue, facilitating recognition (Lea et al., 2008).

Outside of a poetic context, alliteration is a useful mnemonic technique, used by second language English learners to more effectively learn multiword phrases and idioms (Boers et al., 2014; Boers & Lindstromberg, 2005; Lindstromberg & Boers, 2008). Students were better able to recall alliterating compared with non-alliterating phrases during surprise recall tests (Boers et al., 2014; Boers & Lindstromberg, 2005; Lindstromberg & Boers, 2008). Interestingly, these mnemonic effects on recall of word-pairs were still present when the students were unaware of the presence of alliteration, although the effects were muted (Boers et al., 2014). Thus, some behavioural data suggests that alliteration may have mnemonic properties. To our knowledge however, no study has attempted to uncover the neural bases of these effects.

As the previous studies in this thesis have shown that alliteration can interact with semantic processing in interesting ways (Egan et al., 2020), we also wanted to investigate how semantic congruency affected any potential mnemonic effects. Previous research has suggested that semantically congruent items are better recognized and recalled than semantically unrelated items (Desaunay et al., 2017; Dougal & Rotello, 2007; Hawco et al., 2013; Talmi & Moscovitch, 2004). This suggests that any mnemonic effects found with alliteration, may be amplified when phrases are also semantically congruent.

The Current Study (Experiment 4)

Here, we investigated the effect of semantic congruency and alliteration on long-term memory. We therefore measured accuracy and reaction times during a recognition task (explicit measures), and ERP Old/New effects (implicit measures) for word-pairs orthogonally manipulated on the dimensions of semantic congruency and alliteration, twenty-four hours after they were initially encoded. A well-established literature on ERP Old/New effects identifies two dissociable ERP components which index separate memory processes: familiarity (indexed by the FN400) and recollection (indexed by the left parietal effect) (Addante et al., 2012; Rugg & Curran, 2007; Wilding, 2000; Yonelinas, 2002).

Session 1 comprised an encoding session in which we presented the same task used in previous experimental chapters. This session therefore (1) ensured that participants encoded the items without being made aware of the true purpose of the experiment, and (2) allowed an opportunity to replicate the behavioural and N400 results of Experiments 1 and 2.

In Session 2, we predicted that participants' ability to correctly recognize old items would be higher for alliterating, and semantically congruent items than for semantically incongruent, or non-alliterating items. We also predicted a smaller FN400 amplitude for these items, which would indicate that participants' behavioural judgement was underpinned by the memory strength of a previously seen item (i.e. how familiar it is). We deemed it unlikely that significant effects would emerge on the left-parietal effect (indexing recollection) due to the high number of items. There was also a relatively long interval between encoding and testing. However, if alliteration or semantic congruency influence recollection, this would suggest that their mnemonic properties influence active retrieval process.

Materials and Methods

Participants

The data of twenty-four native English speakers (15 females; age: *M* = 20.96, *SD* = 2.29) were included in the analysis (a further two were excluded owing to excessive alpha contamination, and one failed to attend the second session). All participants had normal or corrected-to-normal vision and reported no past or present diagnosis of a learning difficulty. Ethical approval was granted by the School of Psychology, Bangor University and all participants provided written informed consent before taking part. As per the previous experiments, a battery of cognitive and literacy tests was administered (see **Appendix F**) for their scores).

Stimuli and Procedure

In a two-by-two stimulus design manipulating semantic congruency and alliteration (alliterating vs. non-alliterating) orthogonally, a total of 624 adjective-noun word pairs were constructed, resulting in 156 pairs per condition (i.e. congruent alliterating, congruent non-alliterating, incongruent alliterating, and incongruent non-alliterating). All adjectives and nouns were fully rotated across conditions. These word-pairs formed four experimental lists which were used for counterbalancing, with each list containing each adjective and noun once (see **Appendix B** for the full stimulus list).

Stimuli were normed for semantic congruency in a separate study, in which 24 native English speakers completed an online forced-choice task (resulting in 8 full norms of the stimuli), where they responded as to whether the noun "makes sense" in the context of the adjective in each case. Congruent alliterating (M = 0.89, SD = 0.16) and non-alliterating (M = 0.87, SD = 0.21) phrases both had a significantly higher proportion of 'makes sense' responses than pairs from either the incongruent alliterating (M = 0.22, SD = 0.26) or incongruent non-alliterating (M = 0.20, SD = 0.25) conditions ($p < 0.001$). There was no significant difference between the ratings of the two congruent conditions, or between the two incongruent conditions.

The experiment took place over the course of two sessions (Session 1: encoding phase, and Session 2: the test phase). In Session 1 participants saw two experimental lists, which were presented again in Session 2 ('Old' items) along with a third experimental list ('New' items), see **Figure 17** below for an example. It should be noted that the 'New' items were comprised of the same adjectives and nouns as the 'Old' items but recombined to make new word-pairs. This is a common practice in memory research to ensure that any memory effects are due to the item (i.e. a word pair) as opposed to its constituent parts (i.e. the adjective and nouns) (Buchler et al., 2008; Desaunay et al., 2017). In both sessions, participants sat at a distance of 100 cm from the monitor. Following setup of the EEG system, each trial began with a fixation cross in the centre of the screen, which remained in place until participants pressed the space bar. Then, the adjective was presented for a random duration in the range of 500 – 600 ms in 20 ms increments, followed by the noun (without an inter-stimulus interval) for 800 – 900 ms in random 20 ms increments. Following this, a response cue (#####) prompted the participant to make a counterbalanced, binary-decision button press, the instructions for which differed between sessions 1 and 2.

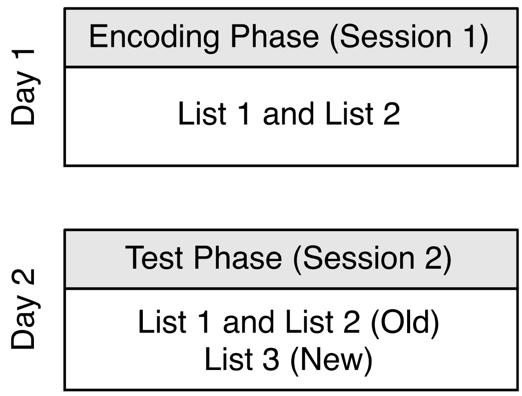

Figure 17. An example of the counterbalancing for one participant.

Session 1 (Encoding phase)

In this session participants saw 312 word-pairs (comprising two full experimental lists), such that they saw each individual adjective and noun twice during the session though in separate conditions, e.g. gloomy castle (congruent non-alliterating) and crisp castle (incongruent alliterating). Each pair was presented twice in order to strengthen encoding (Finnigan et al., 2002). In an identical task to Experiments 1 and 2, following presentation of the response cue (#####), participants had to indicate whether or not the two words were related in meaning (see **Figure 18**).

Session 2 (Test phase)

Session 2 took place twenty-four hours after Session 1 in all cases. Participants were presented with the same 312 word pairs they saw previously, which comprised the 'old' condition. An additional 156 pairs (a third experimental list) were presented, comprising the 'new' condition, which contained the same adjectives and nouns as in Session 1, e.g. healthy castle (incongruent non-alliterating), but recombined. Each word pair was only presented once in this session. Following the presentation of the response cue (#####), participants had to indicate whether or not they had seen the word pair in the previous session (see **Figure 18**).

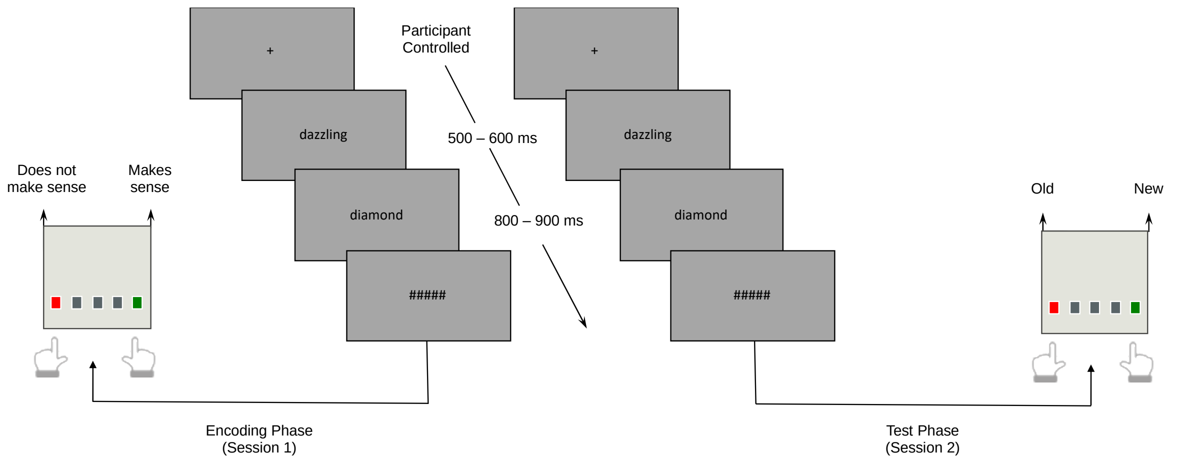

Figure 18: Schematic depicting the experiment procedure. Note that screen background was black and all stimuli were in white size 18 Arial font.

ERP Recording

Electrophysiological data were recorded and pre-processed using the same procedure as the previous experiments. EEG data epochs began 200 ms before noun onset and ended 900 ms after stimulus onset. Following artefact rejection there was an average of 130 trials per condition in Session 1 (*SD* = 10), and an average of 66 old items (of a possible 78, *SD* = 7), and 33 new items (of a possible 39, *SD* = 4) for Session 2.

Experimental Design and Statistical Analyses

Session 1 (Encoding)

For the analyses of behavioural accuracy and reaction times, the fixed factors were Congruency (Congruent, Incongruent), Alliteration (Alliterating, Non-alliterating), and the interaction between them.

Accuracy data were analysed using generalised linear models, for which the fixed factors were centred and sum-coded. The maximal random effects structure with correlations was modelled, consisting of a between-participant intercept and within-participant slopes of Congruency, Alliteration, and their interaction, plus an intercept for word pairs. The formal specification for the accuracy model was:

*Accuracy ~ Congruency*Alliteration + (1+ Congruency*Alliteration | Participant) + (1 | WordPair)*

Reaction times were also analysed using linear models, and were log transformed prior to analysis. Again, the maximal random effects structure with correlations was modelled, consisting of a between-participant intercept and within-participant slopes of Congruency, Alliteration, and their interaction, plus an intercept for word pairs. The formal specification of the model for reaction times was as follows:

*Log(ReactionTime) ~ Congruency*Alliteration + (1+ Congruency*Alliteration | Participant) + (1 | WordPair)*

ERP mean amplitudes were analysed using a repeated measures ANOVA in the N400 time-window (300–500 ms over the same 11 centroparietal recording sites as the previous experiments). The within-subjects factors were Congruency (Congruent, Incongruent) and Alliteration (Alliterating, Non-alliterating).

Session 2 (Test)

For the behavioural analyses, separate procedures were performed for accuracy and reaction times based on convention within the recognition memory literature (Curran & Friedman, 2004; Danker et al., 2008; Snodgrass & Corwin, 1988; Stanislaw & Todorov, 1999; Tsivilis et al., 2015; Võ et al., 2008).

For accuracy data, a paired-samples t-test was initially conducted comparing participants' hits (the proportion of accurately recognized old items) and false alarms (the proportion of incorrectly 'recognized' new items), in order to ensure above-chance performance.

Sensitivity measure: We then calculated the discriminability score (*d'*) for each participant per condition, which is calculated as: $d' = z(\text{Hits}) - z(\text{False Alarms})$ (Brophy, 1986; Stanislaw & Todorov, 1999). This is a measure of discriminability, which gives an insight into participants' sensitivity at recognizing items, and as such may be used to assess task performance (Brophy, 1986). *d*' scores increase with sensitivity, with any score above 0 indicating that participants were able to effectively discriminate signal from noise (Brophy, 1986; Võ et al., 2008; Yonelinas et al., 2010).

Response bias measure: We also calculated decision criteria (c) scores, which is calculated as: $c = 0.5 * z(\text{Hits}) + z(\text{False Alarms})$ (Snodgrass & Corwin, 1988; Võ et al., 2008). C scores give an insight into participants response criterion and biases, with negative values indicating more liberal decision making, and positive values indicating more conservative decision making (Võ et al., 2008).

The sensitivity and response bias measures reported here are independent from one another and as such were analysed separately (Snodgrass & Corwin, 1988; Stanislaw & Todorov, 1999; Võ et al., 2008). Differences between conditions on proportion of hits, proportion of false alarms, *d'*, and c were analysed via repeated measures ANOVA, with the fixed factors of Congruency and Alliteration (see Võ et al., 2008 for similar behavioural analyses).

Reaction times were once again analysed using linear models, and were log transformed prior to analysis. As per convention reaction times were only analysed for hits and correct rejections (Curran & Friedman, 2004; Danker et al., 2008; Tsivilis et al., 2015). The maximal random effects structure with correlations was modelled, consisting of a between-participant intercept and within-participant slopes of Novelty (Old, New), Congruency (Congruent, Incongruent), Alliteration (Alliterating, Non-alliterating), and their interaction, plus an intercept for word pairs. The formal specification of the model for reaction times is as follows:

*Log(ReactionTime) ~ Novelty*Congruency*Alliteration + (1 + Novelty*Congruency*Alliteration | Participant) + (1 | WordPair)*

For Session 2, the two separate components of the ERP Old/New effect were analysed by two repeated measures ANOVAs. The within-subjects factors were Novelty (Old, New), Congruency (Congruent, Incongruent) and Alliteration (Alliterating, Non-alliterating). For the FN400 analysis the time-window was 300 – 500ms, over fronto-central electrodes (A01, C01, CO2, C11, C22, C23, C24, D01, D02). The analysis for the left-parietal effect was performed on left-parietal electrodes (500 – 800ms, from electrodes A06, D17, D18, D19, D20, D27, D28). These regions and time-windows were chosen on the basis that they are commonly used in the Old/New effect literature (Curran, 2000; Curran & Friedman, 2004; Rugg & Curran, 2007; Wilding, 2000).

Convention within Old/New effect studies is to only analyse correct trials as these reflect instances wherein participants genuinely recognize an item, which appears to be particularly important for eliciting the left parietal effect (Rugg & Curran, 2007; M. E. Smith, 1993; Wilding et al., 1995). However, Finnigan et al. (2002) argued that only including correct trials in ERP Old/New effects analyses leads to item selection artefacts, since only a subset of experimental items are analysed. Additionally, for this experiment there were a small number of correct trials available for analysis, particularly in the New condition (Old: $M = 66.48$, $SD = 6.71$, New: $M = 33.32$, $SD = 3.83$), which might have led to reduced statistical power. As such we conducted our analyses on only correct trials as per convention, but additional analyses including all experimental trials are included in **Appendix G**.

Results

Session 1 Behavioural

Accuracy data revealed a significant fixed effect of congruency ($\beta = 0.91$, $SE = 0.40$, $z = 2.27$, $p < 0.05$), such that there was greater accuracy for incongruent ($M = 0.86$, $SD = 0.1$) compared to congruent ($M = 0.78$, $SD = 0.09$) word-pairs. No significant effect of alliteration emerged, but there was a significant interaction between congruency and alliteration ($\beta = 1.04$, $SE = 0.33$, $z = 3.11$, $p < 0.01$) such that accuracy was reduced for congruent non-alliterating items. No significant fixed effects or interactions emerged for reaction time data, see **Figure 19** below for behavioural data.

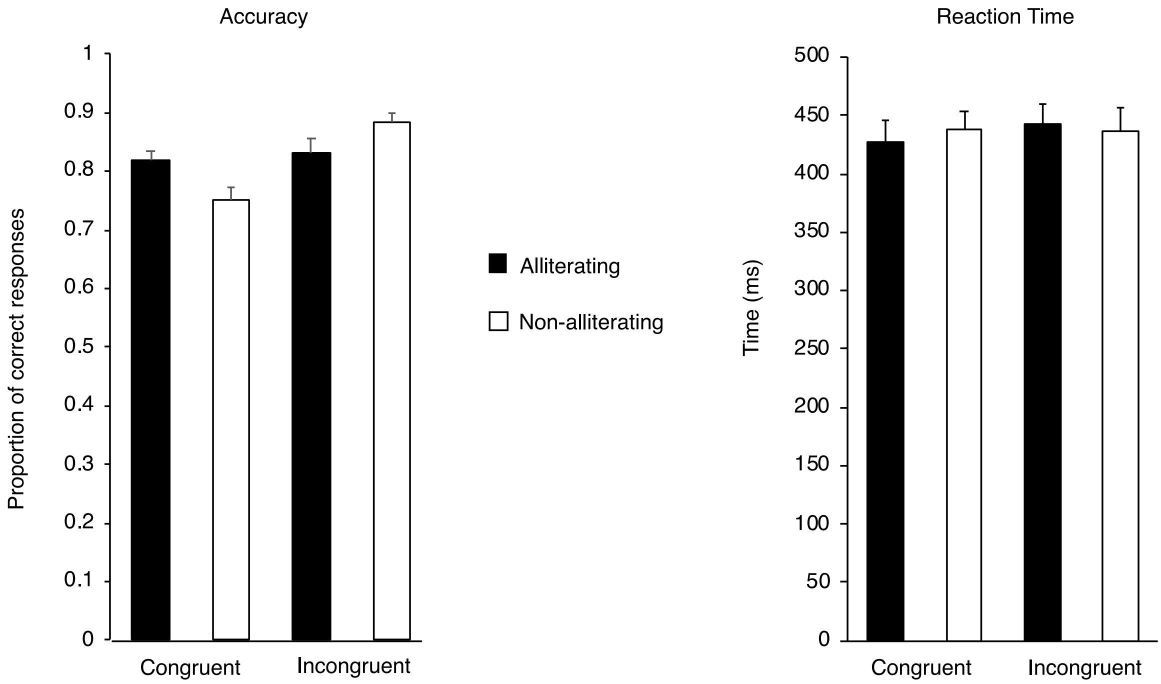

Figure 19: Behavioural accuracy (left) and reaction times in milliseconds (right). Error bars depict SEM.

Session 1 ERP

In the N400 time-window there was a main effect of congruency ($F(1, 23) = 28.95$, $p < .001$, $\eta^2 = .557$), such that N400 amplitude was reduced for semantically congruent items, and a main effect of alliteration ($F(1, 23) = 25.955$, $p < .001$, $\eta^2 = .53$) such that amplitude was lower for alliterating items. The interaction between congruency and alliteration did not reach the significance threshold. See **Figure 20** below for the waveform.

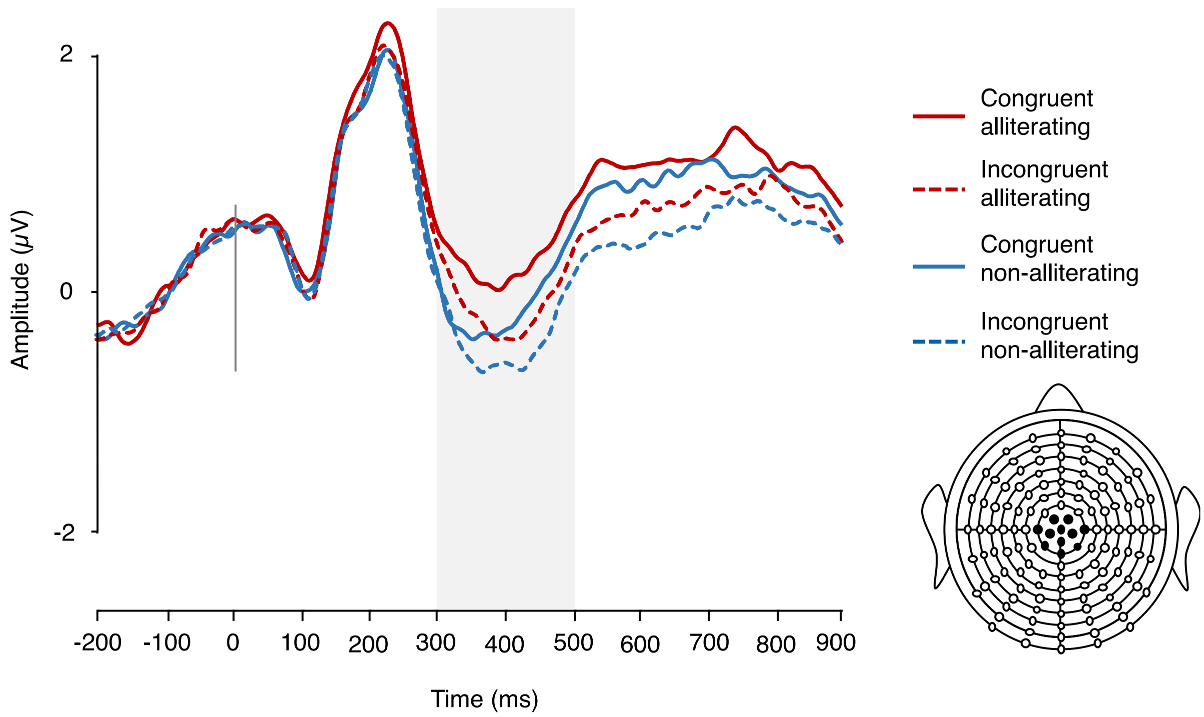

Figure 20: Mean ERP amplitude from session 1, shaded area represents the window of analysis.

Session 2 Behavioural

Accuracy

For accuracy, participants had a significantly higher proportion of hits (*M* = 0.62*, SD* = 0.15*)* than false alarms (*M* = 0.26*, SD* = 0.09; *t*(23) = 13.894, p < 0.001, *d* = 2.92*)*, indicating that recognition performance was above chance. See **Figure 21** below for session 2 accuracy data presented as hits, false alarms, d' scores and C scores.

Hits

For hits there was a main effect of congruency (F(1, 23) = 84.572, p < .001, η^2 = .786) such that there were more hits for congruent (*M* = 0.72, *SD* = 0.14) compared to incongruent (*M* = 0.51, *SD* = 0.18) items. There was also a main effect of alliteration (F(1, 23) = 12.387, p =

.002, $\eta^2 = .350$) such that there were more hits for alliterating (*M* = 0.64, *SD* = 0.19) compared to non-alliterating (*M* = 0.59, *SD* = 0.19) items. The interaction between congruency and alliteration did not reach significance, however.

False Alarms

For false alarms there was a main effect of congruency ($F(1, 23) = 68.394$, $p < .001$, $\eta^2 = .748$) such that there were more false alarms for congruent (*M* = 0.33, *SD* = 0.13) compared to incongruent (*M* = 0.19, *SD* = 0.11) items. There was also a main effect of alliteration ($F(1, 23) = 26.196$, $p < .001$, $\eta^2 = .532$) such that there were more false alarms for alliterating (*M* = 0.29, *SD* = 0.14) compared to non-alliterating (*M* = 0.22, *SD* = 0.13) items. The interaction between congruency and alliteration did not reach significance, however.

Discriminability (*d'*)

When comparing *d'* between conditions a significant main effect of congruency emerged ($F(1, 23) = 4.716$, $p = 0.04$, $\eta^2 = .170$) such that congruent items (*M* = 1.15, *SD* = 0.48) were more frequently remembered than incongruent items (*M* = 1.00, *SD* = 0.49). No other significant fixed effects or interactions emerged.

Decision criterion (C)

When comparing C between conditions a significant main effect of congruency emerged ($F(1, 23) = 89.15$, $p < .001$, $\eta^2 = .795$) such that congruent items (*M* = -0.08, *SD* = 0.39) elicited a more liberal response criterion than incongruent items (*M* = 0.48, *SD* = 0.43). A significant main effect of alliteration also emerged ($F(1, 23) = 33.139$, $p < .001$, $\eta^2 = .59$)

such that alliterating items (M = 0.09, SD = 0.48) elicited a more liberal response criterion than non-alliterating items (M = 0.30, SD = 0.49). No significant interaction effect emerged, however.

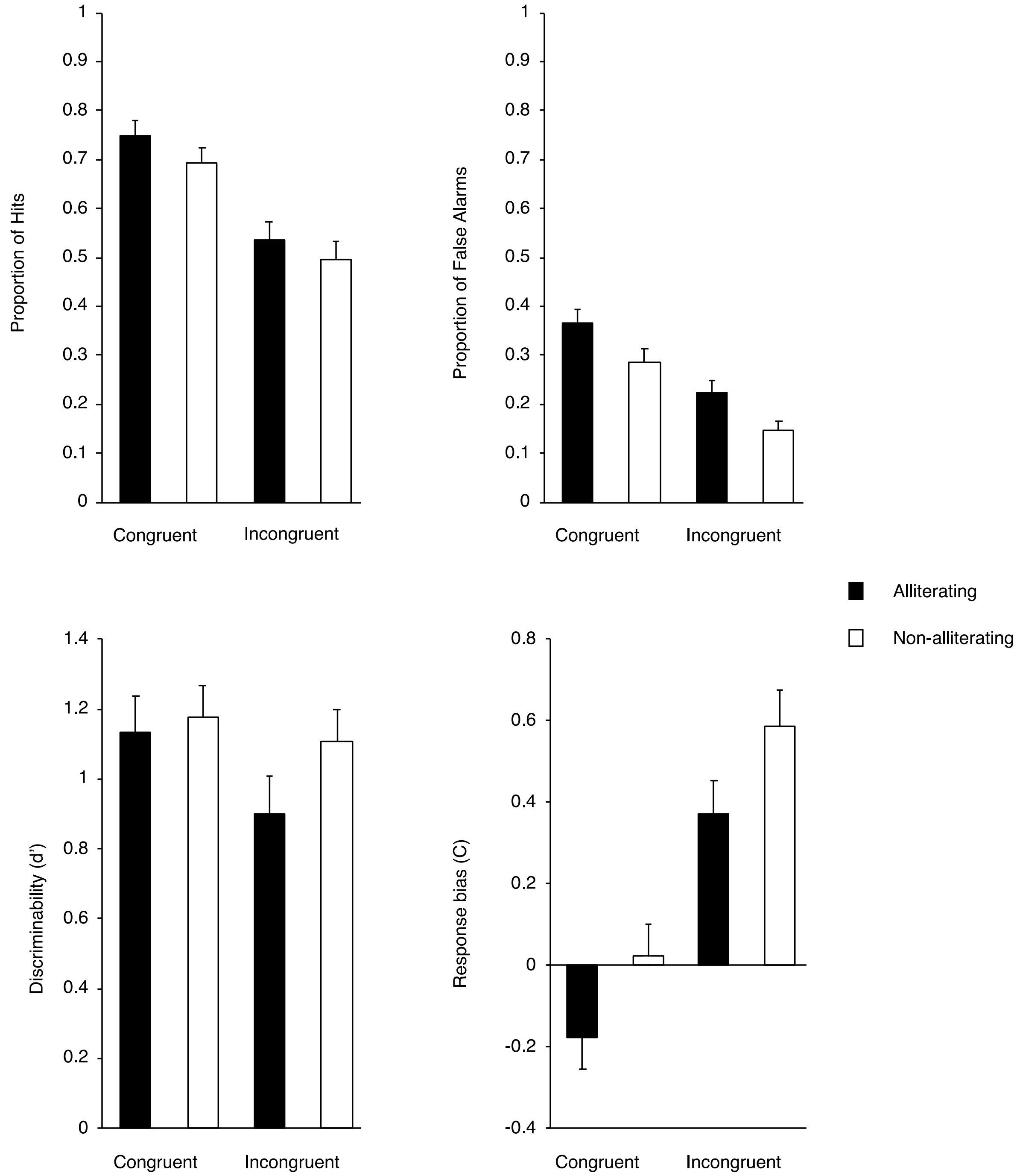

Figure 21: Behavioural accuracy, with proportion of hits (top left), proportion of false alarms (top right), d’ scores (bottom left), and C scores (bottom right). Error bars depict standard error of the mean in all cases.

For reaction times significant fixed effects of novelty (β = 0.12, *SE* = 0.05, *t* = 2.63, *p* < 0.05) emerged such that participants responded more slowly to new (*M* = 420.57*, SD* = 146.26) than old items (*M* = 375.76*, SD* = 113.98). A significant main effect of congruency (β = 0.08, *SE* = 0.03, *t* = 3.00, *p* < 0.05) also emerged such that participants responded more slowly to semantically incongruent items (*M* = 401.62*, SD* = 115.87) as compared to semantically congruent items (*M* = 394.71*, SD* = 148.15). There was also a significant interaction between novelty and congruency (β = -0.19, *SE* = 0.06, *t* = -3.07, *p* < 0.05) reflecting that whilst for old items participants responded more slowly when they were semantically incongruent (*M* = 398.68*, SD* = 115.59) as compared to if they were semantically congruent (*M* = 352.83*, SD* = 108.74). For new items the opposite pattern emerged, and they responded more quickly to semantically incongruent (*M* = 404.56*, SD* = 117.29) as compared to semantically congruent items (*M* = 436.58*, SD* = 170.17). No other significant fixed effects or interactions emerged, see **Figure 22** below for session 2 reaction time data.

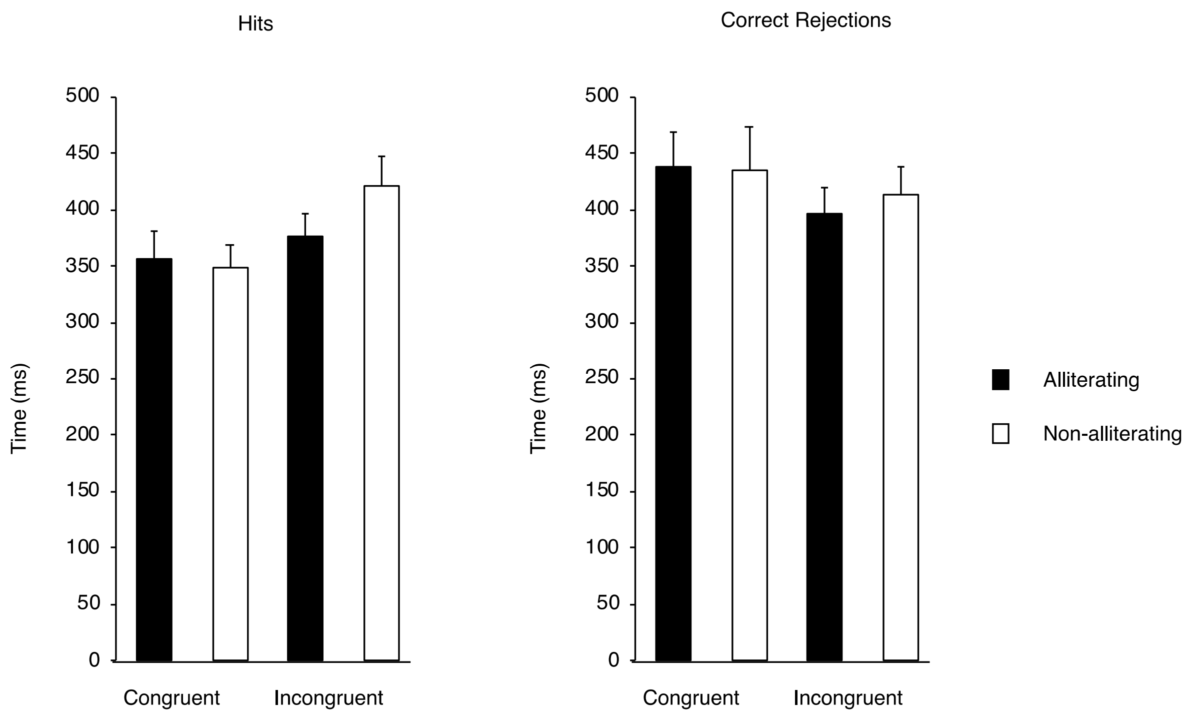

Figure 22: Reaction times in milliseconds for old (left) and new items (right). Error bars depict standard error of the mean.

Session 2 ERP

For the FN400 analysis a significant main effect of novelty ($F(1, 23) = 14.033$, $p < 0.001$, $\eta^2 = .379$), such that there was greater FN400 amplitude for new compared to old items. There was also a significant main effect of alliteration ($F(1, 23) = 26.495$, $p < 0.001$, $\eta^2 = .535$), such that FN400 amplitude was lower for alliterating compared to non-alliterating items. No other main effects of interactions reached the threshold for significance. See **Figure 23** below for the FN400 Old and New waveforms.

Figure 23: Mean ERP amplitudes from the electrodes selected for the FN400 analysis, for old items (left), and new items (right). Shaded areas represent the window of analysis.

For the left parietal effect no significant main effects or interactions reached the significance threshold. See **Figure 24** below for the waveforms for the parietal effects.

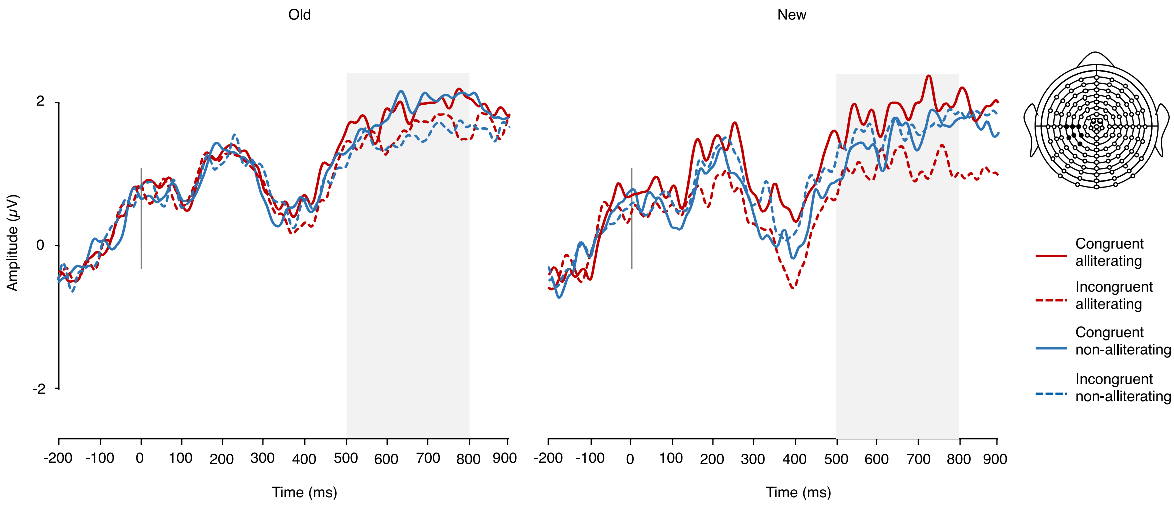

Figure 24: Mean ERP amplitudes from the electrodes selected for the left parietal analysis, for old items (left), and new items (right). Shaded areas represent the window of analysis.

Discussion

This study examined whether the presence of alliteration, in combination with semantic congruency, would boost participants' memory for short phrases, compared to more declarative phrases, as indexed by explicit (behavioural responses) and implicit (ERP) responses.

Discussion of Session 1 Results

Session 1 primarily entailed an encoding session, from which we could measure participants' memory of these 'old' items, compared with 'new' items, the following day. The session was presented as a language experiment, which crucially did not alert participants that their memory would be tested the following day. Given that the session was also identical to the experiments presented in the previous chapters, we also took the opportunity to attempt to examine the consistency of our previous findings via a replication.

For accuracy measures, a congruency effect again emerged, with greater accuracy for incongruent compared to congruent items. Alliteration modulated this effect in an interesting way as it appeared to boost performance for congruent items, consistent with Experiment 3 results. This lends further support to our claim that alliteration causes participants to associate the adjective and noun beyond the level of semantic association (Egan et al., 2020). As such the presence of alliteration leads to more accurate responses for semantically congruent pairs, but fewer accurate responses for incongruent items. Response times were similar across conditions.

Consistent with our expectations, semantic congruency also modulated the N400 response, such incongruent items elicited greater mean amplitudes. Alliteration also modulated N400 mean amplitude, such that alliterating items elicited smaller mean amplitudes, irrespective of whether the items were congruent or not. This suggests that alliterating phrases were processed as more related than their non-alliterating counterparts, reflecting what was shown in the accuracy data. Thus, alliteration modulates semantic integration for both congruent and incongruent items, which differs from what was found in Experiment 1 (Egan et al., 2020).

There were some procedural differences between this study and the previous chapters which may have contributed to the different results observed here. Firstly, no filler items were included in this experiment, and the ratio of alliterating to non-alliterating stimuli was therefore higher: half of the items alliterated, which may have caused higher expectation and awareness of alliteration that was not present in our previous studies (in which only a third of all items alliterated). It is possible that this higher proportion of alliterating items created an alliteration-expectancy that was not present in our previous studies, which may account for the greater N400 amplitude seen for non-alliterating as compared to alliterating items in this study, which was absent in previous studies (though it should be noted that a similar pattern was seen when the data from typical readers in experiments 1 and 2 were pooled). However, it is important to note that the context was still not overtly biasing towards the presence of our phonological manipulation, as it typically is in studies that use excerpts from poetry as their stimuli (cf. Chen et al., 2016; Obermeier et al., 2015). Indeed, the nature of the behavioural task in session 1 would likely cause participants to focus their attention on the semantic relationship between the adjective and the noun. Overall, the results of Session 1 bolster the findings from previous experiments which showed through both explicit and implicit measures, that alliteration can modulate semantic processing (Egan et al., 2020).

Discussion of Session 2 Results

The primary purpose of this study was to examine whether alliteration and semantic congruency had an impact on participants' ability to recognize items.

Explicit behavioural responses: Based on the pattern of results from participants' proportion of hits and false alarms, and their decision criteria scores, it appears that their response bias was affected by both alliteration and semantic congruency. Participants were more likely to respond that an item was old when it was semantically congruent or when it alliterated. This is reflected both in the C scores, and in the fact that there were both more hits and more false alarms for congruent and alliterating items. It should be noted that response bias is independent of participants' actual accuracy/sensitivity to detecting previously seen stimuli (Snodgrass & Corwin, 1988; Stanislaw & Todorov, 1999). As such participants' sensitivity must be discussed to fully understand the pattern of results.

Analysis of *d'* revealed that participants were better at accurately detecting old items when they were semantically congruent than when they were semantically incongruent. This is interesting, firstly as it indicates that there is a genuine effect of semantic congruency on participants' ability to recognize whether or not they had previously encountered a word pair. This is in line with previous research indicating that semantic relatedness improves both recognition and recall, when compared to semantically unrelated items (Desaunay et al., 2017; Dougal & Rotello, 2007; Hawco et al., 2013; Talmi & Moscovitch, 2004).

The response bias and sensitivity analyses indicate that alliteration does not actually improve participants' recognition memory performance. Instead it makes them more likely to *respond* that they have seen an item before, regardless of whether this is actually the case. As such, these results suggest that the presence of alliteration increases the familiarity of an item, as opposed to increasing recollection of the item (Dougal & Rotello, 2007; Yonelinas et al., 2010). This is perhaps analogous to the effect of emotionally arousing words, which also lead to a more liberal response bias in the absence of increased sensitivity (Dougal & Rotello, 2007).

The reaction time data revealed that for hits, participants responded more quickly to semantically congruent than incongruent items, whereas the opposite was true for correct rejections. This is in line with the accuracy results, as participants were both more sensitive to, and had a response bias towards semantically congruent items. As such, it might make sense that they would be primed to respond more quickly to items that were in line with their bias, i.e. congruent items when they are old and incongruent items when they are new. No effect of alliteration emerged for reaction times, once again suggesting that it did not have an overt influence on participants' recognition memory.

Implicit neurocognitive responses: As discussed previously the FN400 ERP effect is an index of familiarity, which may be conceptualised as the quantitative strength of a memory trace as opposed to the experience of actively remembering encountering something (Yonelinas et al., 2010). As expected, there was greater FN400 amplitude for new than for old items, indicating that participants found old items more familiar (Rugg & Curran, 2007; Yonelinas, 2002). There was also a larger FN400 to non-alliterating, as compared to alliterating items. This is in line with the accuracy results, indicating that participants found alliterating items more familiar than non-alliterating items (Addante et al., 2012; Dougal & Rotello, 2007). There was no effect of semantic congruency on familiarity, however.

The left-parietal ERP effect, is thought to index recollection, with greater relative positivity reflecting items recognized based on explicit recollection of the context in which it was previously encountered (Wilding, 2000; Yonelinas, 2002). There was no difference in amplitude between old and new items for this effect, which would indicate that participants did not recall having previously encountered items. This is not surprising given both the large number of stimuli in this experiment, and the long delay between testing sessions. As such participants may not have been able to specifically recall encountering each word pair, instead making their decisions based on memory strength (Addante et al., 2012; Yonelinas et al., 2010).

Alliteration: For alliteration, the results are quite interesting, as alliteration appears to have a strong effect on participants' perception of item familiarity, which in turn led to erroneous reporting of having previously seen 'new' items. However, alliteration did not actually boost participants' ability to detect the presence of a previously encountered item. In this way, it appears that alliteration leads to an *illusion* of memory. This is contrary to what was predicted based on previous behavioural research (Boers et al., 2014; Boers & Lindstromberg, 2005; Lea et al., 2008; Lindstromberg & Boers, 2008). However, this previous research either focused solely on short-term memory and/or had a small number of items to encode. As such, it is possible that alliteration has genuine mnemonic effects for short-term memory and when the recognition task is easier, but at longer retention intervals merely leads to a strong feeling of familiarity.

Semantic Congruency: Overall, the results for semantic congruency are surprising, as behaviourally semantic congruency appears to boost recognition memory, but it had no effect on the neural indexes of recollection *or* familiarity. This was particularly surprising as previous research indicated that semantic congruency boosted both familiarity and recollection (Desaunay et al., 2017). One possible interpretation of this is that our task (which was designed to measure explicit memory processes), is also indexing implicit memory processes, specifically conceptual priming (Voss et al., 2012; Voss & Paller, 2006). Conceptual priming refers to the phenomenon in which exposure to a stimulus influences subsequent conceptual processing of that stimulus (Voss et al., 2012; Voss & Paller, 2006).

This phenomenon has been shown to be related to familiarity, although the two are thought to be distinct processes (Voss et al., 2012). Research on this form of priming has shown that when items are encoded with semantically relevant information, this leads to greater accuracy in recognition judgements, and faster reaction times for correct recognition judgements (Voss & Paller, 2006). As such, it seems likely that this is driving the behavioural effects that are appearing for our semantically congruent items, as the reaction time data appear to suggest a clear priming effect is at play. This is interesting, as this priming effect led to a genuine improvement in recognition judgement accuracy, which was not seen in other conditions.

Conclusion

The results of this study give an interesting insight into the effects of both alliteration and semantic congruency on recognition memory. Contrary to what was predicted based on previous research alliteration did not improve participants' ability to recognize previously seen items. Interestingly however, alliterating phrases made participants more likely to *think* that they had seen the phrases previously. These familiarity effects were observed in both explicit behavioural responses and their neurocognitive responses. In contrast, semantic congruency improved participants' ability to detect old items, but not at the level of online semantic integration. We posit that this is due to conceptual priming effects.

Chapter 7

General Discussion

7.0. Chapter Overview

The aim of this thesis was to build on recent findings from neurocognitive poetics and to investigate ways in which sound and semantics interact outside of the context of poetry. In Chapter 1, I outlined my three primary research questions as follows:

RQ1 How does phonological repetition between words affect semantic processing and attentional engagement?

RQ2 How does phonological repetition between words affect semantic processing and attentional engagement in poor readers?

RQ3 How does the relationship between sound and meaning affect memory?

The answers to these questions were sought in four empirical studies. I will now summarise how the findings from this work, combined with the extant literature, shed light on these issues. I finish by outlining directions for future research.

7.1. How does phonological repetition between words affect semantic processing and attentional engagement?

Recent work in neurocognitive poetics suggests that phonological repetition in poetry can attract reader attention, and help to link otherwise unrelated concepts (Carminati et al., 2006; Chen et al., 2016; Hanauer, 1998; Jakobson, 1960; Scheepers et al., 2013; Vaughan-Evans et al., 2016). Much of this research concludes that poetry creates a special context wherein the expectation of specific phonological repetition is greater than the expectation for semantic congruency, which is at the forefront in typical declarative language (Chen et al., 2016; Hanauer, 1998; Jakobson, 1960; Scheepers et al., 2013). Here, we wanted to investigate whether alliteration, which is a form of phonological repetition that is often used in poetry (Fabb, 2010), would attract additional reader attention, and influence semantic comprehension *outside* of the context of poetry.

This research question was addressed in each of the four experiments of the thesis. Overall, our results indicated that alliteration created the *illusion* of meaning, but only semantic congruency significantly affected attentional processing. The main findings and conclusions relating to these findings are summarised below.

Behavioural effects: Participants performed a semantic relatedness judgement task, in which they judged whether a word-pair 'made sense'. Participants consistently judge incongruent items more accurately on such tasks (Boutonnet et al., 2014; Nuthmann & Van Der Meer, 2005; Schulz et al., 2008; Wu et al., 2011), and this effect emerged in all four of the studies reported here. However, we also found that overall, alliteration consistently reduced participants' accuracy: an interesting and novel finding emerging from this series of studies, suggesting that alliteration caused participants to erroneously think that the word pairs shared a semantic relationship.

Despite this overall trend, the specific effect of alliteration did vary somewhat across experiments. In all cases, alliteration decreased accuracy for incongruent items, yet its effect on congruent items was more variable: Alliteration had no effect on accuracy for semantically congruent items in Experiments 1 and 2, but alliteration then *increased* accuracy for semantically congruent items in Experiments 3 and 4. This finding is consistent with our interpretation, as the phonological association assists participants in judging whether or not a word pair is semantically related. The effect is clearly less robust than that for incongruent items, however, which may be due in part to small modifications to the paradigm made across experiments. There were proportionally more alliterating items in Experiment 4, which may have increased alliteration saliency. However, this account does not explain a similar pattern of effects in Experiment 3, since the proportion of alliterating items was similar to those in Experiments 1 & 2. To conclude this section on the behavioural findings, we find that alliteration consistently creates ambiguity for semantically incongruent phases, suggesting that phonological repetition creates the illusion of meaning, manifest even at the level of overt semantic judgements. However, the effect of sound on semantically congruent phrases remains unclear.

N400 effects (Experiments 1, 2 & 4): Consistent with our predictions, we found that semantic congruency consistently modulated online semantic processing: semantically incongruent items elicited larger mean amplitudes in all experiments (Kutas & Federmeier, 2011). Whilst the impact of alliteration on the N400 was somewhat less consistent, a general pattern emerged in which alliteration modulates online semantic processing in a similar fashion to semantic congruency. Specifically, alliteration appeared to reduce the N400 mean amplitude (Experiments 1 & 4); most consistently reducing amplitudes for semantically incongruent item (cf. the interaction effect in Experiment 1), again suggesting – considering the behavioural findings we just reviewed – that the effect of phonological repetition on semantic processing and judgement is more likely when there is ambiguity concerning the semantic link, as is the case with incongruent items. However, we must also consider that the effect of alliteration on semantic congruency is simply less robust, and that more power would yield effects (when the data from Experiments 1 & 2 are pooled we see a similar pattern to Experiment 4).

However, the N400 results from Experiment 2 did not fit this overall pattern. An effect of congruency was found, but with no alliteration effect, as seen in the other studies. In

Chapter 4, we proposed that verbal IQ may play a key role in modulating N400 effects in our current paradigm, owing to poorer lexical quality in the case of low IQ; analogous to 'poor comprehenders' (typical readers, who are less skilled at reading comprehension; Perfetti, 2007). Indeed, N400 differences have been previously shown between good and poor comprehenders, which are similar to our results (Landi, 2010; Landi & Perfetti, 2007; Perfetti et al., 2005). See section **7.4. Directions for Future Research** for a suggestion on how to further study this relationship between verbal IQ and N400 amplitude. However, our N400 results generally suggest that alliteration causes participants to perceive meaning in phrases even when there is none.

Pupil dilation: In **RQ1** we also asked whether phonological repetition attracts readers' attention, based on the idea that foregrounding techniques attract readers attention (Jacobs, 2015b, 2015a; Miall & Kuiken, 1994), and previous research which found greater dilation to rhyme-scheme incongruencies (Scheepers et al., 2013).. We investigated this issue over three experiments (1, 2 & 3), through the use of pupil dilation: an index of autonomic arousal and attention (Laeng et al., 2012; Mathôt, 2018; Wang et al., 2018). We found no effect of phonological repetition on pupil dilation across all three experiments. However, phonological repetition may be more salient in the context of poetry (Chen et al., 2016; Hanauer, 1998; Jakobson, 1960; Scheepers et al., 2013) than in short declarative phrases, and the disparity between our results and others (Scheepers et al, 2013) may prove to be a matter of context.

A surprising result across experiments was that semantic *congruency* was the condition that resulted in increased pupil dilation. This was contra our predictions, based on previous research in which expectancy violations increase pupil dilation (Kuipers & Thierry, 2011; Laeng et al., 2011; Scheepers et al., 2013). However, our findings are in fact in line with previous research, and there are two possible interpretations for this result: First, greater dilation is observed in response to particularly interesting stimuli (M. M. Bradley et al., 2008; Hess & Polt, 1960; Murphy et al., 2014; Wang et al., 2018), which is how we initially interpreted this result (cf. Experiments 1 and 2).

Second, that larger dilation indexes greater cognitive load (Beatty, 1982; Hess & Polt, 1964; Krejtz et al., 2018; Nuthmann & Van Der Meer, 2005; Van Gerven et al., 2004). Indeed, Nuthmann and Van Der Meer (2005) found strikingly similar results to ours, in that participants had greater pupil dilation to semantically related than unrelated word-pairs, which they interpreted as greater resource demand for related compared with unrelated items. Further support for this interpretation comes from our behavioural results, wherein accuracy was consistently worse for congruent items (this is again observed in Nuthmann & Van Der Meer, 2005). It is difficult to distinguish between these alternatives, based on the current data.

Correlation analyses: In Experiments 1 and 2 we conducted correlation analyses between pupil dilation and mean N400 amplitude, in order to examine whether ease of semantic integration affected attentional engagement. We did not have an a priori directional hypothesis for this relationship. In Experiment 1, we reported two significant correlations. The first was in the time-window for the pupil orienting response, which indexes involuntary shifting of attention towards a stimulus (Mathôt, 2018; Wang & Munoz, 2015; Wetzel et al., 2016). This was a negative correlation for the incongruent non-alliterating condition, meaning that as N400 amplitude increased, so did pupil dilation. This effect often emerges in response to surprising stimuli (Wetzel et al., 2016), and we interpreted this effect as a measure of participants' perception of maximal unrelatedness / unexpectedness, as stimuli were neither semantically congruent or alliterating.

A second correlation – also negative – appeared in the later time-window, indicating that for semantically congruent alliterating stimuli, greater N400 amplitude was also associated with greater pupil dilation. In other words, when phrases were more difficult to process, more attention was recruited. The exact mechanism underlying this attentional increase is unclear (see section above, in which our pupillary results and cognitive correlates are outlined). Under one of our proposed accounts, semantically and phonologically congruent pairs engage attention beyond that of semantic and phonological congruency considered separately (Egan et al., 2020). Alternatively, this correlation simply indexes greater cognitive load, associated with greater semantic integration difficulty. Additionally, no similar correlations emerged for Experiment 2. While we propose that this may be due to inconsistencies in the N400 results, we exercise caution in overinterpreting these effects.

In sum, the evidence presented in this thesis suggests that alliteration can create the *illusion* of meaning, both at the behavioural and implicit neurocognitive level. But there is insufficient evidence to suggest that phonological repetition modulates attentional processing.

7.2. How does phonological repetition between words affect semantic processing and attentional engagement in poor readers?

Having examined the effect of phonological repetition on the semantic and attentional aspects of reading phrases in typical readers (**RQ1**), we then examined the relationship – and any deviations – in poorer readers, namely adults with developmental dyslexia. In Experiment 2, we therefore compared typical readers with adults with developmental dyslexia on the same procedure as in Experiment 1. Overall our results suggest that phonological repetition has no effect on implicit semantic or attentional processing for readers with dyslexia, but that their overt semantic relatedness judgements were influenced by alliteration. In regard to implicit semantic processing this was contrary to the pattern for typical readers overall, but not for experiment 2 (see section above). The main findings and conclusions relating to this will now be outlined below.

Behavioural effects: Participants with dyslexia were poorer at accurately judging semantic relatedness compared to typically developed readers, in line with previous research (Schulz et al., 2008). Their pattern of results for behavioural accuracy was similar to that shown by typical readers however, with reduced accuracy for semantically related, and alliterating pairs. This was an interesting finding as individuals with dyslexia are thought to have a phonological deficit, and as such, it might have been expected that they would be less sensitive to the presence of alliteration, but this was not the case (Ahissar, 2007).

N400 effect: The ERP results revealed a classic semantic congruency effect for participants with dyslexia, in which semantically incongruent items elicited greater N400 mean amplitudes (Kutas & Federmeier, 2011), similar to typical reading peers. Whilst visual inspection of the data suggested that N400 amplitude may have been reduced in participants with dyslexia in line with previous research (Schulz et al., 2008), which would be indicative of impaired ability to detect semantic incongruency (Schulz et al., 2008), the effect did not reach statistical significance, and participants were behaviourally better at detecting semantic incongruency than congruency. Alliteration did not modulate N400 amplitude for participants with dyslexia, suggesting that phonological repetition does not influence ease of semantic processing for this group (in contrast with the behavioural data). At first glance, this pattern may suggest a delayed effect of phonological repetition in dyslexia, manifest only in behavioural measures. Yet, a similar effect was seen in the Experiment 2 typical group (see section above), suggesting that this pattern may be indicative of reading difficulty and/or low IQ.

Pupil dilation: Our predictions for dyslexic participants' pupillary responses were explorative, given that this was the first study to test the method in the context of dyslexia. The pupillary pattern was broadly consistent with that found for typical readers throughout the thesis, with larger pupil dilation for semantically congruent as compared to incongruent words. Whilst there remains some uncertainty as to what this effect indexes (i.e. an attentional increase due to interest *or* due to difficulty), what clearly emerges from the pupillary data, combined with the preserved congruency effects on accuracy and the N400, that participants with dyslexia had similar semantic processing to typical readers. An unexpected finding was that participants with dyslexia had generally reduced pupillary responses as compared to typical readers, regardless of condition. Our explanation for this global effect is necessarily speculative, but it may reflect a generalized attentional deficit (Gabrieli & Norton, 2012; Hari & Renvall, 2001; Krause, 2015; Lonergan et al., 2019; Shaywitz et al., 1998), or a diminished attentional response specific to orthographic stimuli. Under the latter account, their reduced attentional response to words may reflect specific deficits regarding orthographic binding (Blomert, 2011; Jones et al., 2016) or lexical quality (Landi & Perfetti, 2007; Perfetti, 2007). See section **7.4. Future Directions** below, for a suggested experiment to isolate the factors driving this unexpected finding.

In contrast with typical readers, dyslexic readers yielded a significant correlation for congruent alliterating items, between N400 mean amplitude and pupil dilation. Specifically, a smaller change in pupil dilation when semantic integration was difficult (as indexed by a larger N400). Whilst exercising caution in interpreting these results, we propose that when sematic processing of phrases is difficult, dyslexic participants recruit less attention. Interestingly, this is the exact opposite of what we found for typical readers in Experiment 1 (Egan et al., 2020). Semantically congruent phrases with alliteration therefore appear to result in a reading-ability-dependent dissociation, wherein more semantically difficult recruits more attention for typical readers, but less attention for readers with dyslexia.

Overall, our results suggest that implicit semantic and attentional processes are not affected by phonological repetition for participants with dyslexia. As such we suggest that different features of a text may be mainly involved in engaging these readers, such as backgrounding features (e.g. plot, characterisation), or non-phonological foregrounding (e.g. metaphor) (Jacobs, 2015b, 2015a). Phonological repetition did influence participants overt behavioural responses however, contradicting the idea that participants are completely insensitive to the presence of alliteration.

7.3. How does the relationship between sound and meaning affect memory?

Based on the findings in relation to **RQ1**, and the previous literature surrounding the potential mnemonic effects of alliteration (Fabb, 2010), we next set out to study how the relationship between sound and meaning impacts *memory*. In Experiment 4, we tested participants' ERP responses related to recognition memory for word-pairs that were orthogonally manipulated across the dimensions of semantic congruency and alliteration. Based on previous research, we predicted better memory for word-pairs that were semantically congruent (Desaunay et al., 2017; Dougal & Rotello, 2007; Hawco et al., 2013; Talmi & Moscovitch, 2004) and alliterating (Boers et al., 2014; Boers & Lindstromberg, 2005; Fabb, 2010; Lea et al., 2008; Lindstromberg & Boers, 2008). Whilst we did not find a mnemonic effect of phonological repetition overall, alliteration made items seem more familiar, regardless of whether or not they had been previously seen. Additionally, semantic congruency appeared to lead to a conceptual priming affect that improved recognition accuracy. The main findings and conclusions relating to these effects will now be outlined below.

Behavioural effects: We showed that semantic congruency, but not alliteration, influenced participants ability to quickly and accurately recognize previously encountered word-pairs. However, participants' response bias (i.e. their tendency to overestimate the likelihood of an item being old) was influenced by both semantic congruency and alliteration (Stanislaw & Todorov, 1999). As such, participants were more likely to respond that they had previously seen an item if it was semantically congruent, or alliterating, but were also only more likely to correctly judge whether an item was previously encountered if it was semantically congruent. For semantic congruency, these effects were in line with predictions (Desaunay et al., 2017), but the alliteration results were unexpected, and suggest that alliteration made participants more likely to *think* that they had previously encountered an item, regardless of whether this was the case. Participants therefore had more hits, but also more false alarms to items that alliterated.

ERP Old/New effects: The ERP Old/New effect results showed no effect of semantic congruency on either the index of familiarity (the FN400) or recollection (the left parietal effect). This pattern suggests that the increase in recognition speed and accuracy that we see for semantically congruent word pairs is due to neither familiarity nor recollection (Addante et al., 2012; Skinner & Fernandes, 2007), but rather emerges as a result of conceptual priming (Voss et al., 2012; Voss & Paller, 2006). This is a dissociable process from familiarity (although the two are related), and reflects easier processing of a stimulus on the second presentation when it has previously been encoded with semantically relevant information (Voss et al., 2012; Voss & Paller, 2006). Thus, it appears likely that our congruency results reflect priming effects, as opposed to the dual-processes that we intended to measure (Voss et al., 2012; Yonelinas et al., 2010). The results are still interesting, however, as semantic congruency led to a genuine increase in recognition accuracy and speed, regardless of the underlying mechanism.

The ERP results suggest that alliteration modulated item familiarity, with alliterating items being more familiar (FN400; again, no effects were shown for recollection). Our original hypothesis, derived from literary theory, proposed that alliteration could serve as a mnemonic device; built into epic poetry in order to aid memory for long pieces (Fabb, 2010; Rubin, 1995). Indeed, alliteration is an effective memory cue in second language learning, even when presented covertly (Boers et al., 2014; Boers & Lindstromberg, 2005; Lea et al., 2008; Lindstromberg & Boers, 2008). It therefore seems somewhat surprising that the alliteration effects that we see are related to response bias and familiarity alone, as opposed to indexing any real improvements in recognition memory.

Previous literature examining the mnemonic effects of alliteration solely use behavioural methods, usually with a small number of items (~ 30; Boers & Lindstromberg, 2005; Boers et al., 2014; Lindstromberg & Boers, 2008; Lea et al., 2008). Our results should therefore be considered in the context of a relatively more difficult recognition task, since there were many more items to be encoded (312 items). Additionally, no previous studies included alliterating foil items. As such, it is difficult to ascertain whether previous studies showed genuine alliteration-driven improvements in recollection, or an increased sense of familiarity. Indeed, rather than comprising a mnemonic device, our results suggest that alliteration can actually be misleading in causing participants to erroneously think that they have encountered an item. Increased familiarity may indeed be the mechanism underpinning the mnemonic effects of alliteration that are typically reported (Fabb, 2010; Rubin, 1995), in aiding recognition of the alliterating item when compared to non-alliterating items that would also fit within the context of the poem/idiom (Boers et al., 2014; Boers & Lindstromberg, 2005; Lindstromberg & Boers, 2008).

7.4. Directions for Future Research

In this section, I outline some potential directions for future research stemming from the overall conclusions of the thesis. The first two proposed experiments attempt to explain the unexpected findings in this thesis. The final experiment then attempts to bridge the gap between the findings of this thesis, and the more traditional research conducted in neurocognitive poetics (i.e. investigating stylistic techniques in the context of poetry).

One question that arose throughout the thesis was the relationship between verbal IQ, and semantic integration. This factor emerged as an unexpected finding from the post-hoc analyses of Experiment 2, which suggested that individuals with lower verbal IQ had generally more difficulty with semantic integration. We tentatively suggested that lower IQ may incur poorer comprehension skills, which is known to affect N400 amplitude, and which correlates with measures of verbal IQ (Landi & Perfetti, 2007; Nation et al., 2004; Perfetti, 2007; Perfetti et al., 2005; Ricketts et al., 2007; Snowling & Hulme, 2013). However, since we did not measure comprehension directly, we can make few further speculations on this point from the current data. In order to further examine the relationship between the N400 and verbal IQ (and indeed, how this affects sensitivity to alliteration), I suggest a pseudo-replication of Experiment 2, including groups of equivalent N low and high verbal IQ participants. Participants should be pre-screened for verbal IQ score to ensure equal numbers between groups, and a measure of reading comprehension should also be administered, to isolate whether the verbal IQ effect that we found here is indeed indicative of the underlying deficit of poor comprehension (Landi, 2010; Landi & Perfetti, 2007; Perfetti, 2007; Perfetti et al., 2005).

Another question that arose relates to the unexpected finding from Experiment 2, in which individuals with dyslexia manifested generally reduced pupil dilation compared with typically developed readers. As we suggest in the discussion of Experiment 2, the reduced pupillary response may emerge from an attentional deficit (Gabrieli & Norton, 2012; Lonergan et al., 2019; Shaywitz & Shaywitz, 2008), or a specific difficulty in processing text (Perfetti, 2007). Here I propose an experiment that would isolate whether this reduced pupillary response is elicited by linguistic input in general, or whether it is specific to orthographic input. In a similar paradigm as implemented in the thesis (e.g., Experiment 4), I would examine pupil dilation in a between groups design (readers with or without dyslexia). Participants would be shown word-pairs orthogonally manipulated for semantic congruency, presented visually and auditorily. If participants with dyslexia show a diminished pupillary response to all stimuli, then this would indicate generally lower engagement with, and arousal to, linguistic stimuli, lending weight to the argument that dyslexia implicates impaired attention (Doyle et al., 2018; Hari & Renvall, 2001; Krause, 2015; Lonergan et al., 2019; Shaywitz & Shaywitz, 2008). If, however, dyslexic readers' pupil responses to auditory stimuli are similar to typical readers, but reduced for visual stimuli, then the evidence would indicate a specific deficit for written words. This findings would indicate a deficit in consolidating orthographic information, similar to the argument of poor lexical quality (Perfetti, 2007) or the integrity of orthographic representations (Blomert, 2011; Jones et al., 2016). The latter seems the most likely outcome, given that dyslexia is a specific reading impairment (Lyon et al., 2003).

Finally, a third experiment would extend the findings of the current thesis, bridging the gap between these experiments, and those which utilize poetry as stimuli. The experiments contained in this thesis shed light on the neurocognitive effects of alliteration in short two-word phrases and were designed as such in order to obtain maximal experimental control over the stimuli. However, most current research on the effects of such phonologically based stylistic techniques have embedded in the context of poetry (Carminati et al., 2006; Chen et al., 2016; Obermeier et al., 2013; Scheepers et al., 2013, see Vaughan-Evans et al., 2016 for a notable exception). As such, we now have an understanding of how such stylistic techniques function both within a poem, and in declarative word-pairs. Future research could focus on bridging the gap between these approaches, to see for example how much poetic context is needed in order for the genre expectation to supersede the expectation for semantic congruency (Chen et al., 2016; Scheepers et al., 2013). In our experiments there was very little expectancy for alliteration, whereas previous research has used types of poetry with a very salient rhyme-scheme (Chen et al., 2016; Scheepers et al., 2013). As such, an interesting avenue for future research could be to investigate the effects of phonological repetition within poetry, in which there is a lower expectancy. For example, alliteration within poetry can create a different level of expectancy depending on how many words share the same initial sound. Poems could therefore be modified, so that the effects of phonological repetition and semantic congruency could be examined within the context of poems, with differing levels of alliteration expectancy. See this excerpt from ‘Paradise Lost’ for an example of alliteration within a poem:

“**B**ut **b**lessed forms in whistling storms

Fly o’er **w**aste **f**ens and **w**indy **f**ields” (Milton, 2000)

In the above example the final word “fields” is in-line with the alliteration expectancy built up by “fly” and “fens”. However, it is less of a biasing context than rhyme-scheme in a Limerick would be (cf. Scheepers et al., 2013), and more biasing than if only one word shared the alliteration scheme, as in “but blessed” in the line before it. Such a situation could be utilized experimentally, by using similar manipulations to those used in this thesis, with the final word of that excerpt being manipulated for semantic congruency and alliteration. For example; “Fly o’er waste fens and windy fields” (congruent alliterating), “Fly o’er waste fens and windy hills" (congruent non-alliterating), "Fly o'er waste fens and windy fears" (incongruent alliterating), "Fly o'er waste fens and windy tricks" (incongruent non-alliterating). By measuring N400 mean-amplitude to the final word in each case, we would be able to ascertain whether the findings of this thesis, which suggest that alliteration can cause an illusion of meaning, still stand in the context of poetry. In such a case we would expect greater N400 amplitude in response to semantic incongruency, but that this would be modulated by the presence of alliteration (cf. Egan et al., 2020). If, however, a larger N400 is only seen for semantically unrelated items that also alliterate (analogous to Chen et al., 2016) then this would suggest that genre is influencing processing of the text, such that adherence to stylistic language is more salient than semantics. This would lend support for the genre specific hypothesis, and extend previous findings by showing that it is not only the case when a very strong expectancy is established (Chen et al., 2016; Hanauer, 1998; Scheepers et al., 2013).

7.5. Final Summary

In this thesis, my overall aim was to investigate the effects of phonological repetition on semantic processing and attention. This aim was achieved via three main research questions: 1) How does phonological repetition between words affect semantic processing and attentional engagement? 2) How does phonological repetition between words affect semantic processing and attentional engagement in poor readers? 3) How does the relationship between sound and meaning affect memory? Over four experiments I have established that: 1) for typical readers, phonological repetition in the form of alliteration creates an illusion of meaning, linking words beyond the level of semantic relatedness, 2) this is not the case for readers with dyslexia, though alliteration does impact their semantic relatedness judgements,

3) semantic congruency recruits additional reader attention but phonological repetition does not, and 4) the presence of alliteration creates a false sense of familiarity for word-pairs, but does not improve recognition memory. Finally, I outlined proposals for future research, which would clarify two outstanding questions from this thesis, and help to link it with the existing literature on neurocognitive poetics.

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Appendix A

Word-pairs used in Experiments 1, 2 & 3

Adjective				
Congruent Alliterating	**Congruent Non-alliterating**	**Incongruent Alliterating**	**Incongruent Non-Alliterating**	**Noun**
agile	friendly	abrasive	packed	ally
abrasive	teenage	agile	crisp	art
artistic	reckless	adorable	nasty	acrobat
adorable	wild	artistic	rigid	animal
baked	crisp	bewitching	cruel	bread
bewitching	loving	baked	marshy	bride
blue	red	busy	comfy	balloon
bitter	tasty	boring	tired	beer
bleak	dark	bitter	maternal	building
brown	nice	beastly	reckless	biscuit
boring	spellbinding	broken	tender	book
broken	meaty	blue	winter	bone
beastly	mature	bleak	family	bear
busy	flying	brown	fun	bee
crazy	fun	caring	grumpy	carnival
caring	virtuous	clumsy	meaty	community
crass	sarcastic	colourful	gleaming	convict
colourful	lighthearted	cruel	wealthy	cartoon
comfy	winter	crisp	lively	coat
clumsy	large	creepy	spellbinding	cow
creepy	haunted	curious	devastating	castle
crisp	vile	crazy	lost	cold
cruel	polite	comfy	slow	comment
curious	adorable	crass	rational	cat
dangerous	brown	devastating	bleak	dog
dazzling	sparkling	dangerous	creepy	diamond
delicious	spicy	dark	teenage	dinner
delightful	rational	delicious	red	discussion
devastating	bleak	delightful	adorable	disease
dark	cruel	dazzling	brown	depression

faded	velvety	faithful	volatile	fabric
faithful	caring	fresh	vivid	friend
flimsy	wooden	feral	caring	furniture
feral	hunted	flimsy	sparkling	fox
family	marshy	faded	smart	farm
flying	national	frightening	warmhearted	flag
fresh	colourful	friendly	handsome	fruit
friendly	pudgy	family	busy	face
frightening	dangerous	fun	national	fire
fun	private	flying	growing	fact
gleaming	bewitching	grouchy	crazy	gold
grumpy	maternal	gleaming	dangerous	girlfriend
growing	trampled	grumpy	mischievous	grass
grouchy	faithful	growing	colourful	grandfather
handsome	warmhearted	haunted	wooden	husband
haunted	family	handsome	vicious	house
hunted	agile	hostile	faded	hare
hostile	wounded	hunted	polite	horse
large	romantic	loving	broken	lunch
lighthearted	mischievious	lost	baked	laugh
lively	baked	lethargic	boring	lamb
lethargic	slow	lively	abrasive	limp
lost	packed	lighthearted	raw	luggage
loving	tender	large	vile	lullaby
mature	lethargic	marshy	stormy	man
meaty	fresh	mesmerizing	grouchy	mutton
mesmerizing	sad	mischievous	large	music
mischievious	noisy	maternal	flimsy	male
maternal	smelly	mature	artistic	mare
marshy	stormy	meaty	clumsy	mountain
national	devastating	noisy	wounded	news
nasty	frightening	nice	dazzling	nightmare
nice	lost	nasty	wild	necklace
noisy	handsome	national	velvety	neighbour

packed	rigid	polite	mature	prison
pudgy	curious	principled	romantic	puppy
plump	comfy	private	mesmerizing	pillows
polite	crass	plump	smelly	personality
principled	abrasive	packed	tasty	politician
private	crazy	pudgy	beastly	party
raw	bitter	reckless	frightening	radish
reckless	nasty	rational	friendly	rebellion
romantic	busy	rigid	curious	restaurant
rigid	boring	red	sarcastic	routine
red	delightful	raw	talented	rose
rational	broken	romantic	bewitching	rule
sad	vivid	smart	principled	song
sarcastic	tired	spitting	trampled	secretary
spitting	beastly	sarcastic	private	snake
sparkling	gleaming	slow	haunted	star
slow	plump	spellbinding	noisy	snail
smart	artistic	smelly	flying	scholar
smelly	faded	stormy	crass	socks
spellbinding	mesmerizing	sparkling	plump	story
spicy	raw	sad	hostile	soup
stormy	blue	spicy	pudgy	sea
teenage	volatile	talented	blue	taunt
tired	grumpy	teenage	bitter	toddler
trampled	growing	tired	sad	tulip
talented	wealthy	trampled	dark	tycoon
velvety	grouchy	volatile	fresh	voice
vile	clumsy	velvety	delightful	villain
vicious	creepy	vivid	faithful	vulture
vivid	dazzling	vicious	agile	view
winter	vicious	wooden	loving	weather
wealthy	principled	wild	feral	widow
wild	feral	warmhearted	nice	wolf
warmhearted	smart	winter	spicy	wizard

wooden	flimsy	wounded	hunted	wardrobe
wounded	hostile	wealthy	delicious	warrior
tasty	delicious	tender	virtuous	toast
tender	lively	tasty	lethargic	tune
volatile	spitting	virtuous	lighthearted	volcano
virtuous	talented	vile	spitting	vet

Appendix B

Experiment 4 Stimuli and Counterbalancing

Counterbalancing

The experimental items for this experiment comprised 4 experimental lists. Each participant saw the items from 2 lists in session 1 (the encoding stage), and then again in the second session (as the old condition). An additional third list was presented in the second session comprising the new condition. See below for the 12 versions of the experiment, which were created in order to fully counterbalance presentation of the lists.

Day 1

Learning Phase (Session 1)					
Versions 1 & 2	Versions 3 & 4	Versions 5 & 6	Versions 7 & 8	Versions 9 & 10	Versions11 & 12
List 1 and List 2	List 2 and List 3	List 1 and List 4	List 2 and List 4	List 1 and List 3	List 3 and List 4

Day 2

Test Phase (Session 2)					
Version 1	Version 2	Version 3	Version 4	Version 5	Version 6
List 1 and List 2 (Old) List 3 (New)	List 1 and List 2 (Old) List 4 (New)	List 2 and List 3 (Old) List 1 (New)	List 2 and List 3 (Old) List 4 (New)	List 1 and List 4 (Old) List 2 (New)	List 1 and List 4 (Old) List 3 (New)
Version 7	Version 8	Version 9	Version 10	Version 11	Version 12
List 2 and List 4 (Old) List 1 (New)	List 2 and List 4 (Old) List 3 (New)	List 1 and List 3 (Old) List 2 (New)	List 1 and List 3 (Old) List 4 (New)	List 3 and List 4 (Old) List 1 (New)	List 3 and List 4 (Old) List 2 (New)

All experimental items from this experiment are on the following page, with experimental list indicated in superscript

Adjective				
Congruent Alliterating	**Congruent Non-alliterating**	**Incongruent Alliterating**	**Incongruent Non-Alliterating**	**Noun**
accomplished[1]	gracious[2]	angry[3]	feral[4]	artist
adorable[4]	vicious[1]	accomplished[2]	rusty[3]	animal
affirmative[3]	spitting[4]	artistic[1]	large[2]	answer
angry[2]	feral[3]	ardent[4]	frothy[1]	ape
ardent[1]	fervent[2]	adorable[3]	velvety[4]	ally
artistic[4]	strong[1]	awful[2]	rigid[3]	acrobat
awful[3]	horrible[4]	affirmative[1]	faded[2]	affliction
bad[2]	revolting[3]	big[4]	favourite[1]	bacteria
baked[1]	fresh[2]	bleak[3]	faithful[4]	bread
beastly[4]	maternal[1]	boring[2]	treasured[3]	bear
big[3]	rusty[4]	bitter[1]	perpetual[2]	boat
bitter[2]	frothy[3]	busy[4]	wooden[1]	beer
bleak[1]	wooden[2]	brutal[3]	fast[4]	building
blue[4]	nice[1]	broken[2]	horrible[3]	balloon
boring[3]	printed[4]	beastly[1]	crabby[2]	book
breathtaking[2]	ardent[3]	brown[4]	lighthearted[1]	bravery
bright[1]	pretty[2]	bad[3]	talented[4]	blouse
broken[4]	cracked[1]	blue[2]	stormy[3]	bone
brown[3]	favourite[4]	breathtaking[1]	gloomy[2]	biscuit
brutal[2]	vile[3]	bright[4]	fabulous[1]	burglary
busy[1]	tiny[2]	baked[3]	vivid[4]	bee
caring[4]	tight[1]	curious[2]	plastic[3]	community
clumsy[3]	mature[4]	confusing[1]	polite[2]	cow
colourful[2]	lively[3]	crabby[4]	private[1]	cartoon
comfy[1]	velvety[2]	caring[3]	hunted[4]	coat
confusing[4]	awful[1]	creepy[2]	fantastic[3]	clutter
crabby[3]	grumpy[4]	cruel[1]	strong[2]	commuter
cracked[2]	red[3]	crazy[4]	reckless[1]	cup
crazy[1]	busy[2]	crunchy[3]	wounded[4]	carnival
creepy[4]	gloomy[1]	crisp[2]	healthy[3]	castle

crisp[3]	stormy[4]	colourful[1]	teenage[2]	cold
cruel[2]	sarcastic[3]	cracked[4]	meaty[1]	comment
crunchy[1]	spicy[2]	comfy[3]	tired[4]	cashews
curious[4]	adorable[1]	clumsy[2]	packed[3]	cat
dangerous[3]	smart[4]	devious[1]	sarcastic[2]	dog
dark[2]	bitter[3]	dazzling[4]	wealthy[1]	depression
dazzling[1]	sparkling[2]	dark[3]	bad[4]	diamond
deafening[4]	noisy[1]	delightful[2]	soft[3]	disturbance
deep[3]	national[4]	delicious[1]	nice[2]	disgrace
delicious[2]	large[3]	dangerous[4]	angry[1]	dinner
delightful[1]	private[2]	devastating[3]	greasy[4]	discussion
devastating[4]	bad[1]	deep[2]	spellbinding[3]	disease
devious[3]	nasty[4]	deafening[1]	noisy[2]	deception
early[2]	vivid[3]	explicit[4]	lost[1]	ending
explicit[1]	flimsy[2]	early[3]	snowy[4]	evidence
fabulous[4]	winter[1]	family[2]	trampled[3]	fashion
faded[3]	soft[4]	fervent[1]	public[2]	fabric
faithful[2]	warmhearted[3]	flying[4]	wasted[1]	friend
family[1]	marshy[2]	frightening[3]	devious[4]	farm
fantastic[4]	sudden[1]	feral[2]	grouchy[3]	fortune
fast[3]	great[4]	fragile[1]	personal[2]	football
favourite[2]	sad[3]	friendly[4]	hot[1]	film
feral[1]	hunted[2]	faithful[3]	crisp[4]	fox
fervent[4]	virtuous[1]	frothy[2]	mechanical[3]	faith
flimsy[3]	boring[4]	fresh[1]	maternal[2]	furniture
flourishing[2]	breathtaking[3]	faded[4]	blue[1]	forest
flying[1]	artistic[2]	fabulous[3]	deep[4]	flag
fragile[4]	deep[1]	fun[2]	wild[3]	fracture
fresh[3]	crunchy[4]	fast[1]	smart[2]	fruit
friendly[2]	delightful[3]	flimsy[4]	boring[1]	face
frightening[1]	devastating[2]	favourite[3]	colourful[4]	fire
frothy[4]	smelly[1]	fantastic[2]	national[3]	foam
fun[3]	lighthearted[4]	furnished[1]	haunted[2]	fact
furnished[2]	huge[3]	flourishing[4]	grumpy[1]	flat

gleaming^{1}	fabulous^{2}	gloomy^{3}	vile^{4}	gold
gloomy^{4}	haunted^{1}	great^{2}	artistic^{3}	garage
gracious^{3}	wealthy^{4}	greasy^{1}	volatile^{2}	guardian
greasy^{2}	meaty^{3}	gracious^{4}	curious^{1}	grill
great^{1}	vital^{2}	grumpy^{3}	spicy^{4}	gain
grouchy^{4}	crabby^{1}	gleaming^{2}	winter^{3}	grandfather
growing^{3}	trampled^{4}	grouchy^{1}	mature^{2}	grass
grumpy^{2}	perfect^{3}	growing^{4}	broken^{1}	girlfriend
handsome^{1}	grouchy^{2}	hunted^{3}	maroon^{4}	husband
happy^{4}	snowy^{1}	hostile^{2}	rational^{3}	holiday
haunted^{3}	furnished^{4}	healthy^{1}	explicit^{2}	house
healthy^{2}	plump^{3}	hot^{4}	creepy^{1}	hen
horrible^{1}	frightening^{2}	happy^{3}	romantic^{4}	homicide
hostile^{4}	faithful^{1}	horrible^{2}	cracked^{3}	horse
hot^{3}	mechanical^{4}	huge^{1}	dazzling^{2}	heater
huge^{2}	wounded^{3}	haunted^{4}	flourishing^{1}	hog
hunted^{1}	fast^{2}	handsome^{3}	frightening^{4}	hare
large^{4}	romantic^{1}	loaded^{2}	confusing^{3}	lunch
lethargic^{3}	slow^{4}	large^{1}	caring^{2}	limp
lighthearted^{2}	teenage^{3}	lost^{4}	brutal^{1}	laugh
lively^{1}	baked^{2}	lighthearted^{3}	cruel^{4}	lamb
loaded^{4}	plastic^{1}	lively^{2}	great^{3}	lorry
lost^{3}	packed^{4}	lethargic^{1}	handsome^{2}	luggage
maroon^{2}	colourful^{3}	meaty^{4}	gracious^{1}	mat
marshy^{1}	big^{2}	maternal^{3}	lively^{4}	mountain
maternal^{4}	brown^{1}	murky^{2}	family^{3}	mare
mature^{3}	handsome^{4}	maroon^{1}	raw^{2}	man
meaty^{2}	greasy^{3}	marshy^{4}	flimsy^{1}	mutton
mechanical^{1}	silent^{2}	momentous^{3}	accomplished^{4}	motor
momentous^{4}	public^{1}	mechanical^{2}	printed^{3}	marathon
murky^{3}	dark^{4}	mature^{1}	virtuous^{2}	mist
national^{2}	explicit^{3}	noisy^{4}	friendly^{1}	news
nasty^{1}	crazy^{2}	nice^{3}	pretty^{4}	nightmare
nice^{4}	treasured^{1}	nasty^{2}	busy^{3}	necklace

noisy[3]	clumsy[4]	national[1]	sudden[2]	neighbour
packed[2]	volatile[3]	principled[4]	early[1]	prison
perfect[1]	momentous[2]	perpetual[3]	lethargic[4]	present
perpetual[4]	dangerous[1]	perfect[2]	gleaming[3]	pest
personal[3]	rational[4]	packed[1]	happy[2]	problem
plastic[2]	broken[3]	public[4]	red[1]	pistol
plump[1]	comfy[2]	polite[3]	vicious[4]	pillows
polite[4]	happy[1]	plump[2]	loaded[3]	personality
pretty[3]	gleaming[4]	personal[1]	revolting[2]	pixie
principled[2]	accomplished[3]	plastic[4]	silent[1]	politician
printed[1]	lost[2]	private[3]	comfy[4]	pamphlet
private[4]	fun[1]	printed[2]	fervent[3]	party
public[3]	rapid[4]	pretty[1]	tight[2]	panic
rapid[2]	tired[3]	red[4]	dark[1]	run
rational[1]	confusing[2]	rapid[3]	fun[4]	rule
raw[4]	crisp[1]	rational[2]	sparkling[3]	radish
reckless[3]	angry[4]	rigid[1]	crunchy[2]	rebellion
red[2]	flourishing[3]	revolting[4]	murky[1]	rose
revolting[1]	beastly[2]	raw[3]	breathtaking[4]	rodents
rigid[4]	perpetual[1]	romantic[2]	deafening[3]	routine
romantic[3]	family[4]	rusty[1]	smelly[2]	restaurant
rusty[2]	blue[3]	reckless[4]	growing[1]	railing
sad[1]	deafening[2]	smelly[3]	plump[4]	song
sarcastic[4]	polite[1]	snowy[2]	marshy[3]	secretary
silent[3]	bleak[4]	spicy[1]	adorable[2]	sob
slow[2]	fragile[3]	sudden[4]	devastating[1]	snail
smart[1]	rigid[2]	spitting[3]	huge[4]	scholar
smelly[4]	faded[1]	sad[2]	crazy[3]	socks
snowy[3]	murky[4]	sarcastic[1]	warmhearted[2]	summit
soft[2]	maroon[3]	silent[4]	rapid[1]	soil
sparkling[1]	bright[2]	strong[3]	awful[4]	star
spellbinding[4]	principled[1]	stormy[2]	furnished[3]	story
spicy[3]	delicious[4]	slow[1]	bleak[2]	soup
spitting[2]	creepy[3]	sparkling[4]	momentous[1]	snake

stormy[1]	wild[2]	smart[3]	fresh[4]	sea
strong[4]	raw[1]	spellbinding[2]	principled[3]	spirits
sudden[3]	brutal[4]	soft[1]	brown[2]	scream
talented[2]	cruel[3]	tiny[4]	spitting[1]	tycoon
teenage[1]	reckless[2]	tight[3]	baked[4]	taunt
tight[4]	loaded[1]	treasured[2]	bright[3]	timetable
tiny[3]	wasted[4]	tired[1]	affirmative[2]	torch
tired[2]	curious[3]	teenage[4]	vital[1]	toddler
trampled[1]	growing[2]	talented[3]	bitter[4]	tulip
treasured[4]	spellbinding[1]	trampled[2]	nasty[3]	tiara
velvety[3]	affirmative[4]	vivid[1]	flying[2]	voice
vicious[2]	flying[3]	vital[4]	clumsy[1]	vulture
vile[1]	devious[2]	virtuous[3]	delightful[4]	villain
virtuous[4]	caring[1]	vile[2]	beastly[3]	vet
vital[3]	healthy[4]	velvety[1]	ardent[2]	vitamin
vivid[2]	dazzling[3]	volatile[4]	hostile[1]	view
volatile[1]	hot[2]	vicious[3]	sad[4]	volcano
warmhearted[4]	talented[1]	winter[2]	delicious[3]	wizard
wasted[3]	early[4]	warmhearted[1]	fragile[2]	wages
wealthy[2]	friendly[3]	wild[4]	big[1]	widow
wild[1]	lethargic[2]	wealthy[3]	perfect[4]	wolf
winter[4]	fantastic[1]	wasted[2]	slow[3]	weather
wooden[3]	personal[4]	wounded[1]	dangerous[2]	wardrobe
wounded[2]	hostile[3]	wooden[4]	tiny[1]	warrior

Appendix C

Example Stimuli with Number of Lit Pixels Standardized

dazzling	diamond
sparkling	diamond
dangerous	diamond
creepy	diamond

Appendix D

The Author Recognition Test

(ART; Acheson, Wells, & MacDonald, 2008)

Below is a list of names. Some of them are authors of books, and some of them are not. Please put a check mark next to the ones that you know for sure are authors. There is a penalty for guessing, so you should check only those names about which you are absolutely certain. Thank you.

___Patrick Banville
___Kristen Steinke
___Ernest Hemingway
___Clive Cussler
___Hiroyuki Oshita
___Kurt Vonnegut
___Anne McCaffrey
___Elinor Harring
___Sue Grafton
___Lisa Woodward
___David Harper Townsend
___Anna Tsing
___T.C. Boyle
___Jonathan Kellerman
___Cameron McGrath
___F. Scott Fitzgerald
___A.C. Kelly
___Peter Flaegerty
___Kazuo Ishiguro
___Jane Smiley
___James Patterson
___Martha Farah
___Craig DeLord
___Nora Ephron
___Ann Beattie
___Stewart Simon
___Danielle Steel
___Dick Francis
___Ted Mantel
___I.K. Nachbar
___Judith Krantz
___Thomas Pynchon
___Wayne Fillback

___Harry Coltheart
___Gary Curwen
___Herman Wouk
___Geoffrey Pritchett
___Ray Bradbury
___Jay Peter Holmes
___Christina Johnson
___Jean M. Auel
___Judith Stanley
___Gloria McCumber
___James Joyce
___Robert Ludlum
___Larry Applegate
___Keith Cartwright
___Jackie Collins
___Umberto Eco
___David Ashley
___Jack London
___Seth Bakis
___Padraig O'seaghdha
___E.B. White
___Giles Mallon
___Raymond Chandler
___Isabel Allende
___Amy Graham
___Marion Coles Snow
___George Orwell
___Maya Angelou
___Bernard Malamud
___John Grisham
___Erich Fagles
___Walter Dorris
___Gabriel Garcia Marquez

___Virginia Woolf
___John Landau
___Toni Morrison
___Harriet Troudeau
___Roswell Strong
___J.R.R. Tolkien
___Margaret Atwood
___Seamus Huneven
___Harper Lee
___Chris Schwartz
___Walter LeMour
___Alice Walker
___Elizabeth Engle
___T.S. Elliot
___Marvin Benoit
___Joyce Carol Oates
___Jessica Ann Lewis
___Nelson Demille
___Arturo Garcia Perez
___S.L. Holloway
___John Irving
___Stephen Houston
___Marcus Lecherou
___Valerie Cooper
___Tom Clancy
___Vladimir Nabokov
___Pamela Lovejoy
___Vikram Roy
___Saul Bellow
___Stephen King
___Elizabeth May Kenyon
___Frederick Mundow

___Tony Hillerman
___Amy R. Baskin
___James Clavell
___Salman Rushdie
___Maryann Phillips
___Scott Alexander
___Ayn Rand
___Alex D. Miles
___Margaret Mitchell
___Leslie Kraus
___Ralph Ellison
___Sidney Sheldon
___ Brian Herbert
___Sue Hammond
___Jared Gibbons
___Michael Ondaatje
___Thomas Wolfe
___Jeremy Weissman
___Willa Cather
___J.D. Salinger
___ Antonia Cialdini
___ Lisa Hong Chan
___Samuel Beckett
___Beatrice Dobkin
___Wally Lamb
___Katherine Kreutz
___James Michener
___William Faulkner
___Isaac Asimov
___Lindsay Carter
___Paul Theroux
___Francine Preston

Appendix E

Self-Report Reading Measure

(adapted from Acheson, Wells, & MacDonald, 2008)

Section I: Reading Time Estimates

Please tick the appropriate box to indicate how many hours you spend per week reading each type of material listed below:

	0	1	2	3	4	5	6	7+
Textbooks								
Academic materials other than textbooks								
Magazines								
Newspapers								
E-mail								
Internet media (all subjects not including e-mail)								
Fiction books								
Nonfiction/special interest books								
Other reading material (Please name if applicable):								

Section II: Writing Time Estimates

Please tick the appropriate box to indicate how many hours you spend writing each type of material listed below in a typical week:

	0	1	2	3	4	5	6	7+
All forms of writing assignments required for classes								
Newspaper articles or Internet media not required for class (not including e-mail)								
Personal material (e.g., diaries, journals, letters)								
E-mail								
Creative writing not required for classes (e.g., fiction, poetry, plays)								
Job-related material not including e-mail (e.g., memos, reports, transcripts, etc.)								

Other writing material (Please name if applicable):								

Section III: Comparative Reading Habits

Compared to other university students, how much time do you spend reading all types of materials? Please circle the number which corresponds with your answer with 1 indicating comparatively less time and 7 indicating comparatively more time.

1 2 3 4 5 6 7

Compared to the reading material of other university students, how complex do you think your reading material is? Please circle the number which corresponds with your answer with 1 indicating comparatively less complex and 7 indicating comparatively more complex.

1 2 3 4 5 6 7

Compared to other university students, how much do you enjoy reading? Please circle the number which corresponds with your answer with 1 indicating comparatively less and 7 indicating comparatively more.

1 2 3 4 5 6 7

Compared to other university students, how fast do you normally read? Please circle the number which corresponds with your answer with 1 indicating comparatively slower and 7 indicating comparatively faster.

1 2 3 4 5 6 7

Compared to other university students, when reading at your normal pace, how well do you understand the reading material? Please circle the number which corresponds with your answer with 1 indicating comparatively less and 7 indicating comparatively more.

1 2 3 4 5 6 7

Appendix F

Scores on Cognitive and Literacy Tests for All Experiments

Scores on cognitive and literacy tests. Note: [a] Time in seconds; [b] Number of errors; [c] Number of authors (max 30); [d] Time in hours; [e] WASI subtest scaled score.

	Mean (SD)				
	Exp 1 n = 20	Exp 2 Dyslexic n = 19	Exp 2 Typical n = 19	Exp 3 n = 26	Exp 4 n = 24
RAN[a]	13.66 (2.49)	17.62 (4.61)	12.89 (2.52)	13.86 (3.24)	
Word Reading (Acc)[b]	0.55 (1.19)	3.10 (2.35)	0.53 (0.77)	0.6 (0.89)	0.42 (0.65)
Nonword Reading (Acc)[b]	2.15 (3.01)	10.32 (4.15)	1.84 (1.71)	5.48 (6.18)	2.71 (3.47)
Word Reading (Time)[a]	53.78 (5.55)	79.47 (20.70)	53.86 (7.26)	53.27 (8.26)	57.96 (9.76)
Nonword Reading (Time)[a]	54.66 (6.16)	76.49 (26.92)	52.38 (12.79)	52.02 (19.26)	56.61 (11.54)
ART[c]	12.35 (4.33)	5.37 (2.49)	10.84 (5.54)	8.07 (5.04)	9.5 (4.36)
Average Weekly Reading[d]	20.2 (5.84)	16.31 (8.62)	16.42 (5.36)	16.3 (8.18)	18.75 (5.49)
Verbal IQ[e]	11.6 (2.32)	5.47 (3.22)	8.74 (2.77)	8.56 (2.12)	10.83 (2.63)
Matrix Reasoning[e]	11.8 (2.21)	11.32 (1.95)	11.05 (1.87)	11.22 (1.88)	11.33 (1.83)

Appendix G

Full Results from All Behavioural or ERP Statistical Analyses

Behavioural accuracy from Experiment 1.

	β	***SEM***	***z***	***p***
Congruency	1.54	0.19	7.97	< .001
Alliteration	0.55	0.15	3.62	< .001
Congruency*Alliteration	1.48	0.15	9.32	< .001

N400 results from Experiment 1.

	df	***F***	η^2	***p***
Congruency	(1, 19)	23.194	.55	< .001
Alliteration	(1, 19)	9.116	.324	.007
Congruency*Alliteration	(1, 19)	5.077	.211	.036

Behavioural accuracy from Experiment 2.

	β	***SEM***	***z***	***p***
Group	0.87	0.33	2.62	< .01
Congruency	-0.99	0.37	-2.72	< .01
Alliteration	-0.47	0.18	-2.52	< .05
Group*Congruency	0.23	0.67	0.35	0.73
Group*Alliteration	-0.06	0.25	-0.25	0.80
Congruency*Alliteration	0.98	0.33	2.98	< .01
Group*Congruency*Alliteration	0.71	0.36	1.96	0.05

N400 results from Experiment 2.

	df	*F*	η^2	*p*
Group	(1, 36)	3.496	.070	0.09
Congruency	(1, 36)	15.483	.301	< .001
Alliteration	(1, 36)	3.039	.078	0.09
Group*Congruency	(1, 36)	3.005	.077	0.09
Group*Alliteration	(1, 36)	0.135	.004	0.72
Congruency*Alliteration	(1, 36)	0.204	.006	0.65
Group*Congruency*Alliteration	(1, 36)	0.291	.008	0.59

N400 results from Experiment 2 post-hoc analyses.

	df	*F*	η^2	*p*
VerbalIQ	(1, 37)	6.280	.145	0.17
Congruency	(1, 37)	44.886	.548	< .001
Alliteration	(1, 37)	10.673	.224	< .001
VerbalIQ *Congruency	(1, 37)	2.978	.074	0.09
VerbalIQ *Alliteration	(1, 37)	2.355	.060	0.13
Congruency*Alliteration	(1, 37)	3.640	.090	0.06
VerbalIQ *Congruency*Alliteration	(1, 37)	0.321	.009	0.58

Behavioural accuracy from Experiment 3.

	β	*SEM*	*z*	*p*
Congruency	1.61	0.40	3.99	< .001
Alliteration	-0.27	0.19	-1.48	0.14
Congruency*Alliteration	-1.22	0.39	-3.08	< .01

Behavioural accuracy from Experiment 4 Session 1.

	β	***SEM***	***z***	***p***
Congruency	0.91	0.40	2.27	< .05
Alliteration	-0.00	0.16	-0.03	0.97
Congruency*Alliteration	1.04	0.33	3.11	< .01

Reaction times from Experiment 4 Session 1.

	β	***SEM***	***t***
Congruency	0.01	0.03	0.32
Alliteration	0.01	0.02	0.68
Congruency*Alliteration	-0.04	-0.04	-0.83

N400 results from Experiment 4 Session 1.

	df	***F***	$\boldsymbol{\eta^2}$	***p***
Congruency	(1, 23)	28.950	.557	< .001
Alliteration	(1, 23)	25.955	.530	< .001
Congruency*Alliteration	(1, 23)	.993	.041	0.33

Behavioural accuracy from Experiment 4 Session 2

		df	*F*	η^2	*p*
	Congruency	(1, 23)	84.572	.786	< .001
Hits	Alliteration	(1, 23)	12.387	.350	0.02
	Congruency*Alliteration	(1, 23)	.388	.017	0.54
	Congruency	(1, 23)	68.394	.748	< .001
False Alarms	Alliteration	(1, 23)	26.196	.532	< .001
	Congruency*Alliteration	(1, 23)	.000	.000	1.00
	Congruency	(1, 23)	4.716	.170	0.04
Discriminability (*d'*)	Alliteration	(1, 23)	3.456	.131	0.08
	Congruency*Alliteration	(1, 23)	2.389	.094	0.14
	Congruency	(1, 23)	89.150	.795	< .001
Decision Criterion	Alliteration	(1, 23)	33.139	.590	< .001
(C)	Congruency*Alliteration	(1, 23)	.089	.004	0.77

Reaction times from Experiment 4 Session 2.

	β	***SEM***	***t***
Novelty	0.12	0.05	2.63*
Congruency	0.08	0.03	3.00*
Alliteration	0.04	0.03	1.24
Novelty*Congruency	-0.19	0.06	-3.07*
Novelty*Alliteration	-0.05	0.05	-1.06
Congruency*Alliteration	0.04	0.06	0.07
Novelty* Congruency*Alliteration	0.05	0.11	0.43

FN400 results from Experiment 4 Session 2.

	df	***F***	η^2	***p***
Novelty	(1, 23)	12.598	.354	0.002
Congruency	(1, 23)	1.386	.057	0.25
Alliteration	(1, 23)	38.805	.628	< .001
Novelty*Congruency	(1, 23)	3.088	.118	0.09
Novelty*Alliteration	(1, 23)	.191	.008	0.67
Congruency*Alliteration	(1, 23)	.600	.025	0.45
Novelty* Congruency*Alliteration	(1, 23)	.025	.001	0.88

FN400 (only correct trials) results from Experiment 4 Session 2.

	df	*F*	η^2	*p*
Novelty	(1, 23)	14.033	.379	< .001
Congruency	(1, 23)	.000	.000	0.99
Alliteration	(1, 23)	26.495	.535	< .001
Novelty*Congruency	(1, 23)	.063	.003	0.80
Novelty*Alliteration	(1, 23)	.098	.004	0.76
Congruency*Alliteration	(1, 23)	.723	.030	0.40
Novelty* Congruency*Alliteration	(1, 23)	.176	.008	0.68

Left parietal analysis results from Experiment 4 Session 2.

	df	*F*	η^2	*p*
Novelty	(1, 23)	.168	.007	0.69
Congruency	(1, 23)	3.756	.140	0.65
Alliteration	(1, 23)	.047	.002	0.83
Novelty*Congruency	(1, 23)	.166	.007	0.69
Novelty*Alliteration	(1, 23)	.908	.038	0.35
Congruency*Alliteration	(1, 23)	2.793	.108	0.11
Novelty* Congruency*Alliteration	(1, 23)	10.762	.319	0.003

Left parietal analysis (Old items only) results from Experiment 4 Session 2.

	df	*F*	η^2	*p*
Congruency	(1, 23)	2.433	.096	0.13
Alliteration	(1, 23)	.549	.023	0.47
Congruency*Alliteration	(1, 23)	.554	.024	0.46

Left parietal analysis (New items only) results from Experiment 4 Session 2.

	df	*F*	η^2	*p*
Congruency	(1, 23)	2.251	.089	0.15
Alliteration	(1, 23)	.576	.024	0.46
Congruency*Alliteration	(1, 23)	8.550	.271	0.008

Left parietal analysis (correct items only) results from Experiment 4 Session 2.

	df	*F*	η^2	*p*
Novelty	(1, 23)	1.637	.066	0.21
Congruency	(1, 23)	3.581	.135	0.71
Alliteration	(1, 23)	.212	.009	0.65
Novelty*Congruency	(1, 23)	.075	.003	0.79
Novelty*Alliteration	(1, 23)	.049	.002	0.83
Congruency*Alliteration	(1, 23)	2.464	.097	0.13
Novelty* Congruency*Alliteration	(1, 23)	2.546	.100	0.12