The Lateralization of Expectations: Hemispheric Differences in Top-down and Bottom-up Word Processing in Context

Yoana Ilieva Vergilova

Dissertation
zur Erlangung des akademischen Grades
eines Doktors der Philosophie
an den Philosophischen Fakultäten
der Universität des Saarlandes

vorgelegt von
Yoana Ilieva Vergilova
aus Sofia, Bulgarien

Saarbrücken, den 08.09.2020

Dekan der Philosophischen Fakultät II: Univ.-Prof. Dr. Augustin Speyer

Erstgutachter: Prof. Dr. Matthew W. Crocker

Zweitgutachter: Dr. Maria Staudte

Tag der mündlichen Prüfung: 26.04.2021

Acknowledgements

I would like to thank Matt Crocker, Heiner Drenhaus, and Les Sikos for their help, advice, and patience over the years from planning through troubleshooting, presenting, and finally writing up this work. Huge thanks go especially to Maria Staudte for the unwavering support and encouragement she provided on all possible fronts during the writing. Also, thank you to Claudia Verburg for always helping me through tons of administrative hurdles with a reassuring smile.

Thank you to Torsten Jachmann, Iliana Simova, and Corinna Lorenz for having my back with problems great and small and for helping me make this PhD journey so unforgettable. It would not have been easy without you.

Finally, I cannot possibly begin to thank my dears Julia, Leonie, Liesa, and Elena, as well as my parents, for always having faith in me and keeping me grounded.

This work was supported by the LanPercept Marie-Sklodowska Curie ITN and SFB/CRC 1102 Information Density and Linguistic Encoding (Project-ID 232722074), funded by the Deutsche Forschungsgemeinschaft (DFG).

Abstract

The current work investigates how preexisting mental representations of the meaning of an utterance (top-down processing) affect the comprehension of external perceptual properties of the linguistic input (bottom-up processing). When it comes to top-down bottom-up processing in the brain previous findings report a division of focus between left and right hemispheric mechanisms. The PARLO sentence comprehension model posits that the LH employs top-down mechanisms which allow for efficient anticipatory processing, while the RH relies more on bottom-up mechanisms. A shortcoming of the PARLO model is that it's based on experiments manipulating solely top-down contextual constraint, leading to conclusions that hemispheric asymmetries are a function of differences in the efficiency of top-down rather than bottom-up mechanisms. Up until now, there has been no investigation of asymmetries in bottom-up processing, nor an investigation of the potential interactions between that and top-down processing for each hemisphere. This thesis consists of four event-related potential (ERP) experiments divided into two parts. Experiments 1 (central presentation) and 2 (hemispheric presentation) manipulate the bottom-up lexical frequency of critical words in high and low predictability contexts. Experiments 3 (central presentation) and 4 (hemispheric presentation) manipulate bottom-up word status, presenting critical words and pseudowords in the same high and low predictability contexts. The results allow us to extend previous findings and present the Spotlight Theory of Hemispheric Comprehension. We argue that the LH employs a kind of spotlight focus, which affords very efficient top-down processing of the expected input, since only highly predictable inputs receive additional facilitation based their bottom-up features. Alternatively, the RH lack of spotlight mechanism and focus on bottom-up lexical properties allows for the reliable processing of less predictable and irregular inputs. In combination, these complementary processing strategies provide the comprehension system with the efficiency and robustness required in a wide range of communicative situations.

Ausführliche Zusammenfassung

Bei der Bildung von mentalen Repräsentationen verarbeitet man Daten aus vielen disparaten Quellen, die man anschließend zur Strukturierung künftiger Eingaben anwendet, indem man Merkmale von allen zuvor angetroffenen Kontexten mit laufenden Eingaben abstimmt. In Bezug auf das Sprachverständnis wird behauptet, dass sich ein großer Teil der schriftlichen Sprachbearbeitung zusammen mit dem verfügbaren Kontext summiert, bevor das vom Stimulus reflektierte Licht die Retina erreicht. Die vorliegende Arbeit untersucht die Auswirkungen des vorhergehenden Kontextes auf das Verständnis eingehender sprachlicher Stimuli, sei es Wörter mit variabler Häufigkeit im Gesamtlexikon oder subtile Rechtschreibfehler der erwarteten Wörter. Darüber hinaus untersucht die Arbeit die Beiträge jeder Hemisphäre zur Schaffung kontextbezogener Erwartungen und deren Nutzung während der Textverarbeitung.

Die Bottom-up-Verarbeitung spiegelt eine Art der Informationsverarbeitung wider, die sich hauptsächlich auf die externen sensorischen Eingaben (Licht oder Ton) konzentriert und von diesen gesteuert wird: von der externen Stimulation zu immer komplexeren Verarbeitungsstufen wie Bedeutungsverständnis, Kontextintegration und allgemeinem Diskurs. Ein vereinfachtes Beispiel wäre ein Kind, das Lesen lernt, indem es sich auf jeden Buchstaben eines Wortes konzentriert und erst dann das gesamte Konzept versteht. Es gibt Hinweise darauf, dass die Bottom-up-Verarbeitung von Feedforward-Netzwerken im Gehirn ausgeführt wird, indem Information beginnend mit Retinaneuronen auf niedriger Ebene (im Fall einer schriftlichen Textverarbeitung) verarbeitet wird und darauf mit zunehmender Komplexität über die visuellen Wege zu den Sprach-, Gedächtnis- oder Kontrollstrukturen des Gehirns auf hoher Ebene (Cattinelli, Borghese, Gallucci, & Paulesu, 2013; Dehaene, Cohen, Sigman, & Vinckier, 2005; Vinckier et al., 2007).

Umgekehrt können Menschen durch vorherige Erfahrung, unmittelbaren Kontext und allgemeinem Sprachwissen Erwartungen darüber erzeugen, welche physischen Merkmale der eingehenden Eingabe vorliegen könnten, bevor die Eingabe für Retinaneuronen verfügbar ist. Dieser Prozess wurde als Top-Down-Verarbeitung bezeichnet. Die Einzelheiten der Erwartungsgenerierung sind umstritten: Einige Autoren weisen neuronalen Feedbackverbindungen zwischen Sprachzentren auf hoher Ebene im Gehirn eine Top-down-Verarbeitung zu, um eine visuelle Verarbeitung auf niedrigerer Ebene zu ermöglichen (Federmeier, 2007), während andere der Ansicht sind, dass eine Erleichterung erwarteter Fortsetzungen während Bottom-up-Verarbeitungsstufen akkumuliert wird (Kuperberg & Jaeger, 2016).

Bottom-Up- und Top-Down-Verarbeitung funktionieren nicht isoliert voneinander. Ein genaues Sprachverständnis erfordert eine ständige Interaktion zwischen externen Eingaben und internen Darstellungen. Interne Darstellungen werden normalerweise basierend auf externen Eingangskonfigurationen gebildet. Die im Prozess gebildeten Erwartungen können wiederum verwendet werden, um eingehende Eingaben zu konkretisieren oder sogar zu überschreiben, wenn diese Eingaben als unzuverlässig angesehen werden, z. B. in lauten Umgebungen.

Ein Ansatz zum Verständnis über die Art der Wechselwirkungen zwischen Bottom-Up-Input und Top-Down-Kontexterwartungen besteht darin, mögliche Unterschiede zwischen Bottom-Up- und Top-Down-Verarbeitung in jeder Gehirnhemisphäre zu untersuchen. Frühere Untersuchungen haben gezeigt, dass Unterschiede in der Art und Weise, wie Sprache in den beiden Hemisphären verarbeitet wird, von einer Tendenz von top-down gegenüber von bottom-up für die linke bzw. rechte Hemisphäre herrühren können. Untersuchungen der hemisphärischen Unterschiede im Satzverständnis zeigen insbesondere, dass aufgrund der Verfügbarkeit von Produktionsfeedbacknetzwerke der linken Hemisphäre (LH) top-down und bottom-up Informationswege möglicherweise nur in Sprachstrukturen dieser Hemisphäre interagieren (Federmeier, 2007; Federmeier, Mai & Kutas, 2005; Wlotko & Federmeier, 2007, 2013). Umgekehrt haben Mechanismen der rechtshemisphärischen (RH) Verarbeitung keinen Zugriff auf die

Produktionsfeedbacknetzwerke, obwohl sie sowohl für kontextbezogene als auch für eingabebezogene Faktoren empfindlich sind, und stützen sich daher weitgehend auf die Bottom-up-Verarbeitung zur Erfassung der Eingabe.

Die Literatur zeigt, dass die Vorhersagbarkeit nicht nur die Textverarbeitung über mehrere Zeitfenster beeinflusst, sondern auch häufig die Bottom-up-Verarbeitung von Form, Länge oder Frequenz von Worten erleichtert, wenn Menschen Sprache lesen oder hören. Die Schwerpunktuntersuchung der aktuellen Arbeit wird die Überschneidung zwischen der Top-Down-Verarbeitung der Vorhersagbarkeit des Satzkontexts und der Bottom-Up-Verarbeitung der eingehenden Wörter sein. Insbesondere fragen wir: a) ob Leser die Vorhersagbarkeit des Kontexts nutzen, um zukünftige Fortsetzungen einzugrenzen, die sich in der Schwierigkeit der Bottom-up-Verarbeitung unterscheiden, b) welchen Beitrag jede Gehirnhemisphäre während der Verarbeitung der Bottom-up-Eingabe zu unterschiedlicher kontextbezogener Unterstützung leistet und c) wie Top-Down- und Bottom-Up-Verarbeitung von der Worterkennung bis zum semantischen Zugriff auf die Integration auf Nachrichtenebene über einen größeren Verarbeitungszeitraum miteinander interagieren.

Zur Beantwortung unserer Forschungsfragen wurden vier EKP-Experimente (Ereigniskorrelierte Potentiale) entwickelt. Die hohe zeitliche Empfindlichkeit der EEG-Methode war von entscheidender Bedeutung für das Ziel, die neurophysiologische Aktivität in verschiedenen Verarbeitungsstadien zu indizieren. Die Experimente 1 und 2 konzentrieren sich auf die Wechselwirkung zwischen Erwartungen, die sich aus der Vorhersagbarkeit des Satzkontexts und der Häufigkeit der gesamten Wortform der nachfolgenden Eingabe ergeben, während die Experimente 3 und 4 testen, wie sich solche kontextgebildeten Erwartungen auf die Pseudowortverarbeitung auswirken und die Wiederherstellung von falsch geschriebenen Wort-Eingängen erleichtern.

In Experiment 1 und 2 wurde die Art der möglichen Wechselwirkung zwischen Bottom-up-Mechanismen (mit lexikalischen Informationen) und Top-down-Mechanismen (mit Informationen auf der Satzebene) in mehreren Phasen des Sprachverständnisses (Worterkennung, semantischer Zugriff und Integration auf Nachrichtenebene) untersucht. Sowohl die Bottom-Up- als auch die Top-Down-Verarbeitung wurden manipuliert, um die Bedeutung und Empfindlichkeit der Hemisphären (zusammen und getrennt) für diese beiden qualitativ unterschiedlichen Informationsquellen besser zu verstehen. Bottom-up-Mechanismen wurden über die Zielwortfrequenz (hoch, niedrig) untersucht, eine Schlüsseldeterminante der lexikalischen Verarbeitung; Top-down-Mechanismen über die Wortvorhersagbarkeit (hoch, niedrig), indem Zielwörter in kleine Diskurskontexte eingebettet wurden, welche die Erwartungen entweder an das Zielwort oder an ein anderes Wort stark einschränkten.

Die Ergebnisse von Experiment 1 zeigten, dass bei nahezu normalen Leseraten die Kontextvorhersagbarkeit bereits vor der lexikalischen Frequenz die Textverarbeitung zu beeinflussen begann, jedoch später als durch die Ergebnisse von Dambacher et al. (2012, 2009) angegeben. Der Effekt der Vorhersagbarkeit begann bei P2-Amplituden und setzte sich über N400-Zeitfenster in dieselbe Richtung fort. Die beiden Faktoren interagierten über N400-Zeitfenster. Während des semantischen Zugriffs (N400-Effekt) in unterstützenden Kontexten brachte die lexikalische Eingabenfrequenz der Eingabe keine zusätzliche Erleichterung, da der im vorherigen Satz festgelegte Kontext ausreichte, um die Eingabebedeutung zu aktivieren. Wenn das präsentierte Wort nicht mit dem vorherigen Satzkontext übereinstimmte, führte seine Frequenz zu einem zusätzlichen Schub für die semantische Verarbeitung, sodass unerwartete niederfrequente Wörter mit dem höchsten Grad an Verarbeitungsschwierigkeiten zurückblieben. Diese Ergebnisse stützen frühere Erkenntnisse darüber, dass die lexikalische Frequenz nur bei knappem Kontext eine untergeordnete Rolle bei der Satzverarbeitung spielt (Dambacher et al., 2006; Van Petten & Kutas, 1990). Schließlich wurde festgestellt, dass die Vorhersagbarkeit bei der Integration auf Mitteilungsebene (anteriorer PNP-Effekt) immer noch eine Rolle spielt und die Integration von erwarteten Fortsetzungen mit hoher und niedriger Frequenz im allgemeinen Kontext weiter erleichtert, während Fortsetzungen mit niedriger Vorhersagbarkeit wahrscheinlich aufgrund ihrer kontextbasierten Unvorhergesehenheit schwieriger zu integrieren waren.

Experiment 2 warf mehr Licht auf die Art der Interaktion zwischen Kontextbeschränkung und Frequenz während des semantischen Zugriffs (N400). Die Interaktion zwischen Frequenz und Vorhersagbarkeit war nur für Stimuli auf der linken Hemisphäre vorhanden, während auf der rechten Hemisphäre präsentierte Wörter nur die zwei Haupteffekte hervorriefen, jedoch keine Wechselwirkung zwischen beiden. Frequenz und Vorhersagbarkeit lösten additive Effekte über die semantischen Zugriffsamplituden von N400 auf RH-präsentierte Stimuli aus. Es zeigte sich einerseits, dass dafür jede unterstützende Information unabhängig von ihrer Quelle vorteilhaft war. Für LH-präsentierte Stimuli traten andererseits die semantischen Zugriffsvorteile für hochfrequente Wörter nur in Kontexten mit hoher Vorhersagbarkeit auf. Die semantische Verarbeitung von LH-präsentierten Hochfrequenzwörtern wurde ohne die Unterstützung des Kontexts nicht erleichtert. Wir interpretierten dies als Beweis dafür, dass die LH Kontext verwendete, um den Bereich des semantischen Zugriffs auf eine Teilmenge von Wörtern zu beschränken, die durch die vorhergehenden Inhalte bereits eine hohe Erwartung aufwiesen. Infolgedessen schienen nur die Wörter, die in dieses kontextabhängige „Spotlight" fallen, für eine weitere Erleichterung durch Frequenzinformationen geeignet zu sein, während Wörter außerhalb des Spotlights unabhängig von ihrer Frequenz gleichermaßen schwierig zu verarbeiten sind. Die Vorteile dieses Spotlight-Effekts spielen weiterhin eine Rolle bei der LH-Verarbeitung während der Integrationsphase auf Nachrichtenebene, werden jedoch in der RH nicht beobachtet.

Zusammengenommen zeigen die Ergebnisse der Experimente 1 und 2, dass die LH empfindlicher auf die Wechselwirkungen zwischen Kontexterwartungen und Bottom-up-Input reagiert (im Fall von Experiment 2: lexikalische Häufigkeit), während die beiden Faktoren einen additiven Einfluss auf die RH ausüben. Basierend auf den Ergebnissen von Experiment 2 und früheren Theorien über hemisphärische Asymmetrien beim Satzverständnis (Federmeier, 2007) und der semantischen Aktivierung (Jung-Beeman, 2005) wird eine vereinheitlichende Spotlight-Theorie vorgeschlagen. Gemäß dieser Spotlight-Theorie ist die Verarbeitung potenzieller Fortsetzungen in der LH aufgrund ihrer Vorhersagbarkeit im vorhergehenden Kontext eingeschränkt, ähnlich wie bei einem Schlaglicht über einen gesamten Satz an plausiblen Fortsetzungen. Nur die Wörter, die in dieses kontextbezogene LH-Spotlight fallen, profitieren von weiterer frequenzbasierter Erleichterung. Die Verarbeitung von den Wörtern außerhalb des Spotlights ist unabhängig von ihrer Frequenz gleichermaßen schwierig. Wir argumentieren, dass das LH-Spotlight eine sehr effiziente Top-Down-Verarbeitung für erwartete Eingaben ermöglicht, da nur hoch vorhersehbare Wörter zusätzliche Erleichterung basierend auf ihrer aktuellen Wortformfrequenz erhalten. Ähnlich wie bei der Fein-/ Grobkodierungstheorie (Jung-Beeman, 2005) ermöglicht jedoch das Fehlen eines alternativen RH-Spotlight-Mechanismus eine flexible Verarbeitung, bei der Eingaben aufgrund ihrer Vorhersagbarkeit im Kontext sowie ihrer Gesamtfrequenz erleichtert werden.

Das Ziel der Experimente 3 und 4 war es, die Untersuchung der Vorhersagbarkeit des Effektkontextes gegenüber der Bottom-up-Verarbeitung zu erweitern. Dabei wurden den Teilnehmern korrumpierte Eingaben (Pseudowörter) präsentiert und es wurde gemessen, wann und in welchem Umfang sie diese wahrnehmen und überwinden konnten. Zu diesem Zweck wurden die Hochfrequenzwörter aus dem Potsdamer Satzkorpus 3 geändert, indem ein Mittelbuchstabe durch einen ähnlich aussehenden Buchstaben ersetzt wurde, um ein aussprechbares auf Deutsch unzulässiges Wort zu erhalten, das dem Zielwort visuell ähnelte (eine Methode ähnlich der von Kim & Lai (2012).

Die Ergebnisse des Experiments 3 folgten weitgehend den früheren Ergebnissen (Kim & Lai, 2012). Die EKP-Modulationen der Teilnehmer zeigten, dass sie unabhängig von der Kontextvorhersagbarkeit bereits 170 ms nach der Stimuluspräsentation (N170) zwischen Wörtern und Pseudowörter unterschieden. Dieser Befund zeigt, dass selbst in unterstützenden Kontexten der Wortstatus (Wort und Pseudowort) im Vergleich zur Vorhersagbarkeit einen frühen, unabhängigen Effekt auf die Textverarbeitung hervorruft. In Experiment 1 die Kontextvorhersagbarkeit und die lexikalische Frequenz übten während der Phasen der Verarbeitungsphasen des semantischen Zugriffs additive Einflüsse auf die N400-Amplituden aus. Obwohl es unmöglich war, auf die nichtexistierende Bedeutung von Pseudowörtern zuzugreifen, beeinflusste die korrumpierte Eingabe nicht wesentlich die Verarbeitung in unterstützenden Kontexten. Die Unabhängigkeit des Wortstatus und der Kontextvorhersagbarkeit herrschte in späten

Positivitätsphasen vor, in denen sich herausstellte, dass Bedingungen mit geringer Vorhersagbarkeit zwar größere anteriore PNP-Ampituden hervorriefen. Gleichzeitig hatten Pseudowort Fortsetzungen größere posteriore P600-Amplituden zur Folge. Die Teilnehmer griffen in erwarteten Kontexten nahtlos sowohl auf Wörter als auf Pseudowörter zu und rekrutierten gleichzeitig Ressourcen, um den Wortstatus erneut zu analysieren.

In Experiment 4 wurde die Hypothese aufgestellt, dass die widersprüchlichen Ergebnisse von Experiment 3 auf eine hemisphärische Kooperation zurückzuführen sein könnten, die den Ergebnissen von Experiment 2 ähnelt: Während LH-präsentierte Stimuli basierend auf ihrer Anpassung an den vorhergehenden Kontext verarbeitet werden (Experiment 3 und 4 verwendeten nur hochfrequente Wörter), sollten RH-präsentierte Stimuli einen größeren Effekt des Wortstatus zeigen. Die Ergebnisse von Experiment 4 zeigen eine frühe Empfindlichkeit von LVF / RH-präsentierten Stimuli gegenüber dem Wortstatus (P2), der für RVF / LH-präsentierte Ziele nicht vorhanden war und als anfänglicher Bottom-up-Fokus für die RH interpretiert werden könnte. Während des semantischen Zugriffs interagierten die Vorhersagbarkeit und der Wortstatus für beide Hemisphären nicht, was darauf hinweist, dass die Hypothese, dass zentrale Präsentationsergebnisse unterschiedliche Beiträge der Hemisphären darstellen, falsch war. Stattdessen schienen die beiden Hemisphären sowohl von der kontextuellen Unterstützung als auch vom Wortstatus zu profitieren.

Die aktuellen Ergebnisse zeigen, dass die Gehirnhälften während der verschiedenen Phasen der Textverarbeitung lexikalische und kontextbasierte Informationen unterschiedlich koordinieren. Während die LH Kontextinformationen über bottom-up lexikale Verarbeitung priorisiert; behält die RH größtenteils die Fähigkeit sowohl von der kontextuellen Unterstützung als auch von den spezifischen Bottom-up-Merkmalen der Eingabe beeinflusst zu werden. Wir spekulieren, dass diese unterschiedlichen Verarbeitungsstrategien auch in typischeren Sprachverständnissituationen funktionieren, in denen die Hemisphären zusammenarbeiten müssen, und daher wichtige Vorteile für Verständnisprozesse im Allgemeinen bieten.

Wenn die den Lesern präsentierten Stimuli in Abhängigkeit von ihrer Frequenz im Gesamtlexikon (Experiment 2) für die RH variieren, wird ein hochfrequentes Wort wie „Spiel“ sowohl während der Worterkennungs- als auch der semantischen Zugriffsphase der Verarbeitung erleichtert, unabhängig davon, ob der vorherige Kontext die Erwartungen an *„Spiel“* erhöht (z. B. *Caroline liebte es, sich die Zeit mit Schach, Dame oder Mühle zu vertreiben.*) oder nicht (z. B. *Caroline liebte es, die Fotos aus ihrer Kindheit anzusehen.*). Diese „Bottom-up-first“-Strategie kann besonders in Situationen nützlich sein, in denen eingehende Wörter nicht sehr vorhersagbar sind, z. B. wenn neues Vokabular erlernt oder Bildsprache verwendet wird (z. B. Metapher, Ironie, Witze, Poesie, neuartige Bereiche). In der Tat haben frühere Arbeiten darauf hingewiesen, dass die RH eine wichtige Rolle bei der Verarbeitung der Bildsprache spielen könnte (Coulson und Williams, 2005; Davenport und Coulson, 2013). Dies bedeutet jedoch nicht, dass die RH nicht von kontextbezogener Unterstützung profitieren kann. Entsprechend dem geeigneten Kontext (z. B. *Caroline liebte es, die Fotos aus ihrer Kindheit anzusehen.*) wird auch ein niederfrequentes Wort wie "*Album*" erleichtert, jedoch nur während der semantischen Zugriffsphase der Verarbeitung und nur in Kombination mit Frequenzinformationen. Obwohl die RH lexikalische Informationen zu priorisieren scheint, ist sie somit nicht streng darauf beschränkt.

Dies wird noch deutlicher, wenn die lexikalischen Informationen, die die Leser erhalten, unzuverlässig sind, aber nicht so sehr, dass sie nicht wiederzuerkennen sind. Wenn einige der vorgestellten Eingaben leicht modifizierte Rechtschreibfehler der erwarteten Ziele waren, zeigte die RH-Verarbeitung nicht nur keine Schwierigkeiten, sich von den Rechtschreibfehlern zu erholen, sondern verlagerte auch den Fokus auf eine frühzeitige Abhängigkeit von kontextbezogener Unterstützung. Zusammen zeichnen die Ergebnisse der Experimente 2 und 4 ein Bild einer viel flexibleren RH-Verarbeitung, bei der sogar Faktoren auf Metaebene, wie die allgemeine Rechtschreibfehlerhäufigkeit im gesamten Experiment und allgemeine Verarbeitungsschwierigkeiten, berücksichtigt werden können. Die aktuellen RH-Ergebnisse spiegeln ein Verarbeitungsmuster wider, das der von Jung-Beeman (2005) oder sogar McGilchrist (2019) vorgeschlagenen gröberen und globaleren Wachsamkeit ähnlicher ist, die nichtsdestotrotz auf die kontextbezogene Unterstützung eines größeren Diskurses abzielen kann.

Im Gegensatz dazu scheint die LH gemäß den Ergebnissen von Experiment 2 Kontextinformationen unter Verwendung einer feinkörnigen, akut trainierten Spotlight-Strategie zu priorisieren. Zum Beispiel der Kontext „Caroline liebte es, sich die Zeit mit Schach, Dame oder Mühle zu vertreiben.“ hebt verwandte Wörter wie "Spiel", "Würfel" und "Schachbrett" hervor, was den semantischen Zugriff erleichtert, wenn das erwartete Wort dann in der Eingabe gefunden wird. Eine solche „Kontext zuerst“-Strategie wäre perfekt für die alltägliche Kommunikation geeignet, die typischerweise viele sprachliche Regelmäßigkeiten enthält und reich an kontextbezogenen Hinweisen ist. Folglich kann die LH-Verarbeitung unter solchen Umständen extrem schnell und effizient sein, da das kontextbezogene Spotlight die Notwendigkeit einer lexikonweiten Suche überflüssig macht. Entscheidend ist jedoch, dass die Frequenz allein den semantischen Zugriff in der LH nicht erleichtert. Das gleiche Hochfrequenzwort, "Spiel", erhält keine zusätzliche Erleichterung, wenn es unvorhersagbar ist (z. B. in dem Kontext „Caroline liebte es, die Fotos aus ihrer Kindheit anzusehen.“).

Zusammenfassend argumentieren wir, dass die in der aktuellen Studie identifizierten hemisphärischen Unterschiede beim normalen Sprachverständnis wichtige und komplementäre Funktionen erfüllen. In typischen Situationen ist die eingehende Information weitgehend vorhersagbar. Daher kann sich das Verständnissystem in erster Linie auf die LH-Verarbeitung verlassen, die aufgrund ihres Fokus auf Kontextinformation schnell und effizient ist. Andererseits kann die RH eine größere Rolle spielen, wenn die Eingabe weniger unvorhersagbar oder unzuverlässig ist oder wenn die Vorhersage gänzlich fehlschlägt, weil sie die lexikalischen Eigenschaften der Eingabe im Fokus behält. In Kombination können diese komplementären Verarbeitungsstrategien dem Verständnissystem die Robustheit und Effizienz verleihen, die für den Kommunikationserfolg in einer Vielzahl von Kommunikationssituationen erforderlich sind.

Table of Contents

List of Figures

List of Tables

Chapter 1

Introduction

Reading or written language comprehension relies on a combination of two sources of information: the external perceptual properties of the linguistic input and preexisting mental representations based on the meaning of the current utterance, the content of our mental lexicon and our overall knowledge of language structure. Neither is completely successful in isolation of the other. The same retinal stimulation can be perceived completely differently, depending on the immediate context, as could be seen on Figure 1.1, while internal representations are too vague when not anchored by a specific stimulus.

People process data from many disparate sources when forming mental representations, which they subsequently apply to structure future inputs based on matching the features of any previously encountered contexts to current input. With regard to language comprehension, it has been argued that a large part of written language processing accumulates with the context available before light reflected from the stimulus reaches the retina. The current thesis investigates the effects of the preceding context over the comprehension of incoming linguistic stimuli be it words of variable frequency in the overall lexicon or subtle misspellings of the expected words. Further, the thesis explores the contributions of each hemisphere to the creation of contextual expectations and their exploitation during word processing.

Bottom-up processing (Section 2.1) reflects a mode of information processing focused on and driven primarily by the external sensory input (light or sound): from external stimulation towards increasingly more complex stages of processing such as meaning comprehension, contextual integration and general discourse. One simplified example would be a child learning to read by focusing on each letter of a word and only then comprehending the entire concept. Evidence indicates that bottom-up processing is executed by feedforward networks in the brain, processing information starting from low-level retinal neurons (in case of written word processing) with increasing complexity through the visual pathways towards high level language, memory or control structures in the brain (Cattinelli et al., 2013; Dehaene et al., 2005; Vinckier et al., 2007).

Conversely, by using prior experience, immediate context, and general linguistic knowledge people are able to generate expectations on what the physical features of the incoming input could be before the input is available to retinal neurons. This process has been referred to as top-down processing. The specifics of expectation generation are under debate (for a review, see Section 1.1): some authors assign top-down processing to neural feedback connections between high level language centers in the brain towards lower level visual processing (Federmeier, 2007), while others believe the facilitation of expected continuations is accumulated during bottom-up processing stages (Kuperberg & Jaeger, 2016).

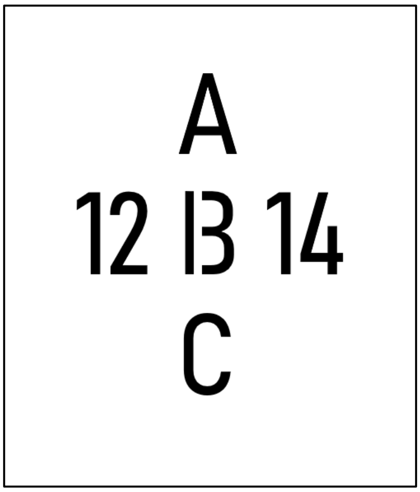

Figure 1.1– Context optical illusion. Depending on the neighboring context, the input in the center can be perceived as the letter B or the number 13, while remaining exactly the same.

Bottom-up and top-down processing do not function in isolation of each other. Accurate language comprehension requires constant interaction between external input and internal representations. Internal representations are usually formed based on external input configurations. In turn, the expectations formed in the process can be used to flesh out, or even override incoming inputs in cases where these inputs are deemed unreliable, such as in noisy environments.

One approach towards understanding the nature of the interactions between bottom-up input and top-down context expectations has been to look into potential differences between bottom-up and top-down processing in each cerebral hemisphere. Previous research indicates that differences in the ways the two hemispheres process language may originate from a top-down vs. bottom-up bias for the left and right hemisphere respectively (Section 3.1). A line of investigation into the hemispheric differences in sentence comprehension specifically indicates that the top-down and bottom-up information pathways may only interact in left hemispheric language structures due to the availability of production feedback networks in the left hemisphere (Federmeier, 2007; Federmeier, Mai, & Kutas, 2005; Wlotko & Federmeier, 2007, 2013). Conversely, while sensitive to both contextual and input-related factors, right hemispheric processing mechanisms have no access to the production feedback networks and thus rely largely on bottom-up processing to comprehend the input.

The potential top-down vs bottom-up distinction in hemispheric processing opens an interesting venue of investigation into the effect such biases can have on sentence processing. Specifically, how does each hemisphere affect the formation of expectations based on previous context and how those expectations interact with the potential facilitation obtained from I the bottom-up features of critical inputs.

1.1 Prediction: definitions, mechanisms and interactions

One prevailing account argues that prediction is crucial for timely language comprehension (Federmeier, 2007; Pickering & Garrod, 2007, 2013), even though some researchers point out it can be costly or unnecessary (Huettig & Mani, 2016; Jackendoff, 2002). In natural settings, while reading words are rarely encountered in isolation. Even when single words are communicated, they are preceded by relevant context, can often be accompanied by supporting gestures, or any forms of emotional, cultural, socio-hierarchical signals. Even outside of language comprehension, correctly appraising context can be considered an adaptive mechanism: recognizing edible plants in specific terrains, judging social group attitudes in unknown situations, catching and throwing projectiles etc. Recognizing and utilizing any previously available context facilitates pattern recognition and has been argued to be a crucial part of any cognitive system (Bansal, Ford, & Spering, 2018; Clark, 2013). It therefore follows, that word processing should not be different and if prediction is indeed easy to utilize and benefit from, there should be ample evidence to point to it being employed in natural reading.

Predictive processing in language comprehension is a well-established instance of top-down comprehension. Being able to anticipate incoming signals before they are completely available, when they cannot be completely available, or simply because it’s less time consuming and more convenient than processing each incoming stimulus can provide a compelling explanation of the efficiency and speed of human communication (Federmeier, 2007; Pickering & Garrod, 2013). Namely, humans seem to apply their stored knowledge of linguistic context, meaning, and structure to extend and support bottom-up processing.

While supportive contexts of any relevant type have been shown to lead to a decrease in processing time or resources required for incoming information (Federmeier, 2007; Pickering & Garrod, 2013), the concrete processing mechanisms which lead to predictive facilitation are still unclear (Huettig & Mani, 2016; Kuperberg & Jaeger, 2016). One of the crucial issues of predictive processing research is establishing a clear timeline of effects in order to demonstrate whether language users anticipate incoming information and what specific features of the input are they able to preactivate. As will be laid out in the rest of this chapter, getting evidence in support of prediction can be done using several methods of experimentation, looking into various stages of processing affected by various previous supporting contexts.

Language processing takes advantage of multiple levels of preceding contextual information from phonemes in auditory contexts and letter shapes in visual ones through single words, illustrations, or entire scripts and discourses. Some of the most often employed experimental methods to investigate the effects of context over each level are reading or reaction times (e.g. Van Berkum, Brown, Zwitserlood, Kooijman, & Hagoort, 2005), eye-tracking (e.g. Pickering & Garrod, 2007), electroencephalography, EEG (e.g. Wang, Zhu, & Bastiaansen, 2012), event-related potentials, ERP (e.g. Kutas, DeLong, & Smith, 2010), magnetoencephalography, MEG (e.g. Halgren et al., 2002; Pulvermüller, Shtyrov, Hasting, & Carlyon, 2008), or functional magnetic resonance imaging, fMRI (Carter, Foster, Muncy, & Luke, 2019; Lau, Weber, Gramfort, Hämäläinen, & Kuperberg, 2016), etc. Additionally, efforts have been made to model the results of such experiments using computational modelling (Brouwer, Crocker, Venhuizen, & Hoeks, 2017; Elman & McClelland, 1984; Kuperberg & Jaeger, 2016; McClelland & Rumelhart, 1981; Rabovsky, Hansen, & McClelland, 2018).

Behavioral measures

Behavioral experimental measures like reaction times and, to a lesser extent, eye movements reflect differences in actions several stages downstream of the target processes in the brain. Reaction and reading times are measured at the point of completion of a certain task that most often requires a certain level of contextual comprehension, so as to be used as evidence for predictive facilitation. Timing in such tasks - like the press of a button, eye-movement/fixation or speech onset - is measured *following* the onset of a critical stimulus. Processing costs are most often registered against a baseline condition, such that response times faster than baseline represent facilitative effects and response times slower than baseline, inhibitory effects. Predictive contexts as an example of a factor influenced by top-down processing, reliably shorten reaction times compared to baseline, even when readers have no specific task to execute or are focused on other aspects of the context (Smith & Levy, 2013; Staub, Grant, Astheimer, & Cohen, 2015; Van Berkum et al., 2005). Moreover, other properties of the critical stimuli that influence bottom-up processing, such as word status (pseudowords or unpronounceable non-words), lexical frequency, or length can also affect response times. Legal words are responded to faster than pseudowords, as are more frequent and shorter words (Balota & Spieler, 1999). Conversely, differences in eye-movements such as fixation times over critical stimuli, saccade length, skipping rate, etc. can also reflect processing costs. Critical words supported by previous contexts are fixated less and skipped more often than unsupported words (Staub, 2015), as are high frequency words, short words, and legal words vs. pseudowords (Rayner, 1998).

When broken down to their neural origins, behavioral measures like these reflect a compound processing time which includes linguistic processing (top-down and/or bottom-up), decision making (depending on the presence of a task), action planning and execution (button-press or a saccade). While it is intuitively clear that ease of processing leads to faster reaction time overall, the aggregate nature of such measures makes it difficult to distinguish which particular stage of processing is affected by experimental manipulation. Moreover, since each of the above processes requires time, effects can only be measured hundreds of milliseconds downstream of critical stimulus presentation, leading to difficulties in making concrete conclusions about the precise processing changes reflected in the results. Lastly, in order to tap into different lexical, semantic or syntactic levels of processing separate tasks and procedures need to be introduced, leading to additional experimental load (e.g. Balota & Spieler, 1999; Van Berkum et al., 2005).

ERP measures

Apart from response and fixation times, another method frequently employed in language processing investigations has been EEG and more specifically, ERP components. ERPs are the sum of electrophysiological activity generated by pyramidal postsynaptic action potentials measured non-invasively on the scalp surface over a certain area of electrode sites and over a certain time span following stimulus presentation. They are commonly characterized by their polarity (negativity = N; positivity = P) and timing in milliseconds as measured after the onset of a critical stimulus (Luck, 2014).

For example, the N400 component (which is employed in this thesis and will be discussed in detail in Chapter 2) is a negative-going wave, usually averaged across centro-posterior electrode sites at 300-500 ms after stimulus onset peaking at approximately 400ms. Other ERP components like the mismatch negativity or MMN are characterized by the eliciting conditions, in this case the effect elicited by odd-ball paradigms where a small percentage of the presented stimuli doesn’t match a specific pattern. Still other components, like the post-N400 positivity (PNP), also known as anterior late positivity, are qualified by their presence following other more prominent and fixed in time components, or by the areas of the scalp over which they exhibit largest modulations.

Differently from reaction time measures, ERPs require no specific task in order to discern different levels of processing. ERPs measure the automatic, involuntary changes in the summed surface electric activity on the scalp (Luck, 2014) reflecting electrophysiological differences between conditions as they unfold with a millisecond precision. There is a certain consensus in the literature as to which levels of processing are indexed by particular ERP components (Swaab et al., 2014) allowing researchers to focus on multiple levels of language comprehension with a single experiment: from early sensory and perceptual, through lexical, semantic, and message-level processing stages (not necessarily sequential or in that order, Pulvermüller, Shtyrov, & Hauk, 2009).

The high temporal resolution of the EEG signal allows researchers to investigate the exact timeline of word processing in sentential contexts. In order to do so some assumptions need to be made about the type of processing reflected in each time window. The psycholinguistic literature on each of the phases of word processing is rich and multifaceted. There are various terms used for each of these phases, just as there are various theories about which time points of word processing they occupy. For instance, the earliest phases of processing following phonological access which will be of chief focus in this thesis have been referred to as word recognition (Gernsbacher, 1984; Olaf Hauk & Pulvermüller, 2004), lexical access (Pulvermüller et al., 2009), or lexico-syntactic access (Friederici, 2002) among others, and have been linked to multiple ERP components peaking in the first 250 ms after stimulus onset including, but not limited to, the P2, the N2, and the MMN. A large part of research on predictive processing also focuses on the N400 ERP component which peaks at a later time-window (300-500 ms), but has been reported to also reflect lexical access (Barber, Vergara, & Carreiras, 2004), as well as lexical retrieval (Brouwer et al., 2017; Brouwer, Fitz, & Hoeks, 2012), semantic integration (Brown & Hagoort, 1993), or semantic access (Kutas & Federmeier, 2011). Following these stages, positivities after the N400 such as the anterior PNP and the posterior P600 have been linked to either semantic integration (Brouwer et al., 2017; Brouwer & Hoeks, 2013), or post-access or meta-processing mechanisms such as syntactic reanalysis (Van Petten, 1993), monitoring (van de Meerendonk et al., 2009), error detection (Thornhill & Van Petten, 2012), or predicted input inhibition (Levy & Anderson, 2002).

A separate work can be written (and several have been) to test the veracity and validity of each of these terms. This is not a goal of the current work. Here the goal is to investigate how lexical and context information are incrementally coordinated during the processing of individual words within the sentential context. Therefore, the introductory chapters will note the use of the terms as preferred by each author, but in the discussions of the current experiments these processing phases will be referred to as word recognition, semantic access, and message-level integration.

As to the timing of those stages, it is still an open question whether processing runs in serial or parallel manner; namely, do early stages of processing like phonological, lexical or semantic access need to each be complete for the next, more complex process to be initiated, or are they cascaded. Relatedly, during word comprehension in context, which of these stages is the first one to be affected by top-down influences, such as context predictability? Do comprehenders need to have accessed a word's form and meaning in order to confirm their expectations as set by a previous context, or do they only need to confirm specific expectations via a rough resemblance by letter shape even before they have completed lexical access? For the purposes of clarity, previous literature will be discussed starting with the most prominent and reliable effects of expectation over the ERP, namely the N400, even though it does not always reflect the earliest instance of sentence predictability affecting word processing. We will then move on to studies reporting predictability effects over earlier stages of word processing and discuss them in the context of earlier N400 research.

In order to measure ERP modulations as a result of top-down expectations or predictions one needs to quantify people's expectations of incoming words based on their exposure to a previous context. These expectations are most often operationalized by using cloze probability paradigms (Taylor, 1953). Those are typically offline or pen-and-paper tests which present readers (or less often listeners) with parts of sentences, full sentences, or small discourses with a crucial word missing. Participants are instructed to complete the phrases using one to (at most) three words. The cloze probability of the provided continuation is then measured as the percentage of people in the sample who suggested that each continuation of the sentence. For example, if 90% of the people surveyed suggested "sugar" as the ending of the sentence "He takes his coffee with cream and _____", then "sugar" has a cloze value of 0.9. The word "honey" might have a lower cloze value, as it might be generated by a smaller percentage of readers, while the word "socks" would have a cloze value of 0 as it would probably never be generated in that context. Conversely, in the sentence "She wore her sandals today so she didn't need ____", the continuation "socks" might have a high cloze value, while "sugar" might have a cloze value of 0. Additionally, the preceding context sentence can be manipulated to widen or narrow down the options for continuation. Consider a sentence such as "She went to the store to buy ____" and compare it to the previous example. Since many words can be used to complete the latter and potentially lower consensus can be reached by readers, none of the potential continuations would have a high cloze value. Factors manipulating the type of continuations presented after the context are referred to as cloze probability, predictability, or expectancy (see for example: DeLong & Kutas, 2016; Federmeier, Wlotko, De Ochoa-Dewald, & Kutas, 2007; Wlotko & Federmeier, 2012).

Semantic access as measured by the N400

One of the ERP components that most strongly correlates with cloze probability is the N400. Since its discovery in the 1980s (Kutas & Hillyard, 1980; Kutas & Hillyard, 1983) it has been extensively studied (Marta Kutas & Federmeier, 2011; Lau, Phillips, & Poeppel, 2008) and is by now widely used as an indicator of successful use of context as measured on the critical continuation. The size in µV of the N400 modulation[1] correlates negatively with the cloze probability of the critical continuation ("socks" elicits larger N400 amplitudes than "sugar" in the context of "She takes her coffee with cream and ____"). N400 modulations have also been elicited in minimal two-word contexts in priming paradigms (Holcomb, 1993), for meaningful acronyms and letter sequences (Laszlo & Federmeier, 2007a), for pictures in auditory contexts (Wicha, Bates, Moreno, & Kutas, 2003), or for signed words in context (Gunter & Bach, 2004; Marta Kutas, Neville, & Holcomb, 1987). Despite some debate (Brouwer & Hoeks, 2013; Pulvermüller et al., 2009; S. Sereno, 2003), the general understanding in the literature is that the N400 effect reflects the final stages of semantic processing (semantic access or semantic integration), where the meaning of target words (or letter strings, or pictures) has become available to the comprehenders as a function of the target's fit in the comprehenders' understanding of the available context.

Based on co-registration studies of the N400 with high spatial resolution imaging techniques such as functional magnetic resonance imaging (fMRI)[2], intracranial electrode

---

[1] ERP effects, similarly to RT effects, are measured as the difference in amplitude magnitude (µV) or modulation of a grand average of ERPs to a baseline condition, which usually requires the least amount of comprehension effort or processing resources, and a condition of interest which manipulates a critical processing aspect.

[2] Functional magnetic resonance imaging is a high-spatial resolution method of non-invasive brain imaging which measures levels of hemodynamic activity in the brain to make conclusions of the underlying neural activation and processing.

recordings[3], event-related optical signal (EROS)[4] or lesion data from the same areas of interest researchers have been able to narrow down the neural generators of the N400 to the left temporal lobe: left superior/middle temporal gyri, anterior medial temporal regions, inferior temporal areas and prefrontal areas (Kutas & Federmeier, 2011; Tse et al., 2007; Van Petten & Luka, 2006). Related activity in the homologue right regions has also been recorded (Just et al., 1996). More specifically, it has been hypothesized that the N400 reflects a combination of semantic activation from the supporting context of "drink", "coffee", and "cream" and the lexical input (see Chapter 2 for discussion on input properties) of the word form "sugar" (Kutas & Federmeier, 2000). In all, N400 activity is not generated at a single time-point by a single brain region, but rather reflects a "wave of activity" (Kutas & Federmeier, 2011) over left temporal and frontal regions starting ~250 ms and spreading until ~500 ms. In fact, the incremental activation over time of a larger neural system fits with the varied types of stimuli and contexts that elicit the N400 effect and allows for the now well-accepted assumption that the N400 effect reflects facilitated access to lexical forms and concepts based on a combination of regions involved both in bottom-up input integration and top-down prediction generation (Kutas & Federmeier, 2011; Lau et al., 2008). In all, N400 scholars argue that the component may hold many answers in the investigation of top-down contextual facilitation over bottom-up input.

The N400 has been used as a reliable measure of semantic activation as a function of the incremental buildup of contextual expectations. It linearly correlates with how expected a word is in a sentential context (Wlotko & Federmeier, 2012), reflects a sensitivity to relatively small "contexts", such as semantic priming paradigms (Holcomb, 1993; Rugg, 1985), single sentences (Davenport & Coulson, 2011; DeLong, Urbach & Kutas, 2005; Federmeier, 2007, among many others), for expected pictures (Wicha et al., 2003) or

---

[3] Intracranial EEG or electrocorticography (ECoG) is a high temporal, high spatial resolution invasive brain imaging technique which is usually performed secondary to necessary neurological interventions to treat epilepsy. It involves placing an electrode grid directly over the surface of the brain, usually in order to localize epileptogenic areas before surgery. The obtained EEG data can also be used for non-clinical purposes: in this case the localization of the N400.

[4] Event-related optical signal imaging is a high temporal, high spatial resolution non-invasive imaging technique, which uses infrared light through optical fibers to measure neural activity in the cerebral cortex.

videos in context (Reid & Striano, 2008), for unexpected panels in comic strip sequences (Manfredi, Cohn, & Kutas, 2017), or locally unexpected words that fit the larger discourse (Metusalem et al., 2012).

To sum up, the N400 may reflect processing at the intersection between lexical (bottom-up) and semantic (top-down) information, providing a very useful tool for the current investigation of the potential interactions between the two.

Late posterior (P600) and anterior (PNP) positivities and the costs of prediction

Differently from the N400, which is elicited by plausible inputs, modulations to implausible inputs are usually marked by a positive deflection over posterior electrode sites, around 500-900 ms after stimulus presentation called the P600 (Kuperberg, 2007). The P600 was originally thought to only reflect syntactic reanalysis or recovery attempts for items such as "was" in plausible, but unexpected garden path structures like "The broker persuaded to sell the stock was sent to jail." (Osterhout & Holcomb, 1992). Later research indicated that P600 modulations could be obtained for implausible, but syntactically valid, semantic anomalies such as "For breakfast the eggs will eat…" or "The meal was devouring…" (Kim & Osterhout, 2005; Kuperberg, Sitnikova, Caplan, & Holcomb, 2003). P600 have also been recorded in cases of bottom-up anomalies, such as misspellings, or pseudoword[5] variations of the expected input (Kim & Lai, 2012; van de Meerendonk, Indefrey, Chwilla, & Kolk, 2011; Vissers, Chwilla, & Kolk, 2006).

In all, the P600 is still under heavy investigation, but generally it has been considered to reflect the downstream contributions of a combinatorial mechanism that works in parallel with semantic memory processing (as indexed by the N400), which is responsible for the analysis and comprehension of sentence constituents and any attempts to revise and

---

[5] Pseudowords are usually strings of letters such as *marf* that are not part of the English (or a certain tested language) lexicon, but can easily be pronounced. They will be addressed in more detail in Section 2.2.

reintegrate the incongruent stimulus in the overall message of the sentence (Kuperberg, 2007; Van Petten & Luka, 2012).

While the P600 modulations seem to reflect a sensitivity to anomalies of semantic or syntactic nature, it still doesn't seem to fully address the potential downsides of prediction and their timeline. Comprehenders are often presented with straightforward sentences with unexpected, but syntactically and semantically completely plausible continuations such as "He bought her a pearl necklace for her *collection*." (Federmeier et al., 2007). While the P600 eliciting examples above are typically not be preceded by an N400 modulation, indicating that they require reanalysis at a different level than semantic access, the continuation "collection" here would elicit difficulties with semantic access (N400 effect) if compared to the more expected "birthday". Following the N400 modulation, Federmeier and colleagues (2007) recorded a positive-going modulation over anterior electrode sites: the post-N400 positivity (PNP). Differently from the posterior P600, which is sensitive to semantic or syntactic incongruities, the anterior PNP has been reported in cases of plausible lexical incongruities between the expected and the perceived inputs (Van Petten & Luka, 2012). The specific mechanisms behind the PNP are still under heavy debate, but current conclusions about what the component may be linked to include: processing costs related to misprediction (Brothers, Swaab, & Traxler, 2015), inhibition of the expected input (Kutas, 1993; Levy & Anderson, 2002), or a similar to the P600 process of monitoring and error detection (Kuperberg & Jaeger, 2016; van de Meerendonk, Kolk, Chwilla, & Vissers, 2009).

Predictability effects over the first 250 ms of stimulus processing (P130, N170, MMN, P2)

An additional strand of research looks into the potential influences of contextual predictability over word processing in its earliest stages, before the effects of semantic access over the N400 become apparent. Data from research using eye-tracking and EEG has been used to argue that 300 ms (the usual onset of an N400 effect) is too late for semantic access to begin (S. Sereno, 2003) since eye-tracking indicates that within 250 ms a word is usually processed and a saccade is usually initiated, meaning that sufficient information has been gathered for the choice of the next fixation target.

Moreover, even though the N400 has been taken to reflect top-down expectation effects over word processing, there are indications that predictability affects the ERP signal earlier than 250 ms post stimulus onset, during earlier processing stages. Supportive contexts have been found to modulate expectations of the specific word form (Kim & Lai, 2012). When context strongly constrained towards a specific continuation ("She measured the flour so she could bake a *cake*"), but a different input was presented "ceke" (pseudoword, with a medial letter replaced with a similar-looking one), readers distinguished between the two as early as 130 ms after onset (P130). In contrast, pseudowords that did not look similar to the expected input like "tont" were distinguishable from "cake" 170 ms after presentation (N170). Both effects indicated that interactions between bottom-up word form processing mechanisms and top-down contextual expectations occurred within the first 130-170 ms of processing, leading to a more interactive account of word processing in context. Sereno, Brewer & O'Donnell (2003) report context effects over ambiguous high and low frequency words in a similar time-window of processing (130-190 ms). Processing for low frequency ambiguous words was facilitated in biasing contexts. In line with Kim & Lai, Sereno and colleagues made conclusions about the early interactivity of top-down predictability and bottom-up frequency during word processing.

Pulvermüller and colleagues also report several ERP studies showing early influences of predictability over word form/lexical factors (for a review, see Pulvermüller et al., 2009). Similarly to Sereno and colleagues, Penolazzi, Hauk, & Pulvermüller (2006) manipulated cloze probability, word frequency and length and found that cloze probability interacted with word length as early as 110-130 ms after stimulus onset. Further work from that group focuses on the mismatch negativity (MMN) to look into other influences of top-down factors during the initial 100-250 ms of word processing (Pulvermüller & Shtyrov, 2006; Pulvermüller et al., 2008; Shtyrov, Hauk, & Pulvermüller, 2004). The MMN is usually sensitive to semantic, syntactic and other types of expectancy violations in long rows of familiar stimuli (odd-ball paradigm, usually used in auditory word processing).

Crucially to this dissertation, Dambacher et al. (2012) directly manipulated cloze probability and lexical frequency using the Potsdam Sentence Corpus (also applied in Experiments 1 and 2 of this thesis). Their findings provide support for very early interaction between cloze and frequency 145 ms after stimulus onset at stimulus onset asynchronies (SOAs) close to normal reading speeds: 280 ms. Dambacher and colleagues looked into 3 different levels of SOA (700, 490, 280) and concluded that accelerated SOAs facilitated accelerated interactions between top-down cloze probability and bottom-up word frequency.

In all, the literature shows that not only does predictability affect word processing over multiple time windows, but also it often facilitates bottom-up processing of word form, length, or frequency as people read or listen to language. The intersection of the top-down processing of sentential context predictability and the bottom-up processing of the incoming words will be the focus investigation of the current thesis. More specifically, we ask whether context predictability is utilized by readers in order to narrow down future continuations, which vary in bottom-up processing difficulty, what is the contribution of each cerebral hemisphere during bottom-up input processing in varying contextual support and how do top-down and bottom-up processing interact over a larger temporal span of processing from word recognition, through semantic access to message-level integration.

1.2 Structure of the thesis

Four event-related potential (ERP) experiments were designed to answer our research questions. The high temporal sensitivity of the EEG method was of crucial importance to the aim of indexing neurophysiological activity at different processing stages. Experiments 1 and 2 focus on the interaction between expectations formed as a result of sentential context predictability and the overall word form frequency of the subsequent input, while

Experiments 3 and 4 test how such context-formed expectations affect pseudoword processing and facilitate the recovery from misspelled inputs.

In order to build our arguments, we summarize two broader directions of investigation in the two following chapters. Chapter 2 is divided in 4 subparts and will start with a brief overview of the neural mechanisms of perception and the initial stages of visual processing in the retina and the brain. Then it continues with a review of the literature on visual word recognition and several psycholinguistic models of the proposed stages of bottom-up processing that readers go through, which end with word recognition. The third part focuses specifically on lexical frequency effects as an example of a bottom-up effect and an index of successful word recognition. Finally, the last part of Chapter 2 focuses on how predictability (operationalized as cloze probability) as an instance of top-down processing interacts with bottom-up processing. The two processes are also referred to as prediction and integration respectively, which is subject to a brief discussion at the end of the chapter.

Chapter 3 continues the predictability research review with a brief introduction to the visual system and its division into two visual fields, explaining how information coming through one visual field gets processed in the contralateral brain hemisphere, and what differences there are in the processes within each brain hemisphere during word reading in sentential context. The chapter discusses in depth three crucial models of hemispheric specialization, two of which focus on single word recognition (visual and auditory) and one of which focuses exclusively on top-down predictability and bottom-up integration. Chapter 3 concludes with an overview of our four novel studies that address the raised research questions, the hypotheses we formulate based on the presented literature, the expected results and the potential contributions to the field.

Chapter 4 through0 describe each of the four experiments. Each consists of a short introduction, a detailed description of the methods, comprehension question accuracy and ERP results, divided in windows that correspond to the three processing stages of interest (word recognition, semantic access and message-level integration). Each chapter ends with a short summary of the corresponding experiment’s findings.

Chapter 4 describes Experiment 1, a central presentation study which seeks to replicate existing findings demonstrating that context-based word predictability and overall lexicon-based word frequency interact very early on in reading. The findings of Experiment 1, which utilized a faster presentation rate than the original study, do not fully replicate the previously published results: predictability and frequency did not interact before 300 ms of presentation, but context predictability facilitated later low frequency semantic access, as well as overall message-level integration (regardless of input frequency).

0 describes Experiment 2, which builds upon Experiment 1 and employs the same stimuli, presenting the critical target word exclusively to the left or right hemisphere so that hemisphere receives precedence in processing. The findings of Experiment 2 suggest that context predictability and word frequency interact for words presented to the left hemisphere, while their influence remains additive for right hemisphere presented words. The results of Experiments 1 and 2 indicate that the left hemisphere is more sensitive to the interactions between context expectations and bottom-up input (in the case of Experiment 2: lexical frequency), while the two factors exert an additive influence over the right hemisphere. Based on the findings of Experiment 2 and previous theories of hemispheric asymmetries in sentence comprehension (Federmeier, 2007) and semantic activation (Jung-Beeman, 2005) a unifying Spotlight Theory is proposed. According to the Spotlight Theory, processing of potential continuations is restricted in the LH based on their predictability in the preceding context, much like a spotlight over the entire set of plausible continuations. Only the words which fall within this contextually-driven LH spotlight are eligible for further facilitation from frequency information. Words outside the spotlight are equally difficult regardless of their frequency. We argue that the LH spotlight affords very efficient top-down processing of the expected input, since only highly predictable inputs receive additional facilitation based on the frequency of their current word form. However, similar to the fine/coarse coding theory (Jung-Beeman, 2005), the lack of an alternative RH spotlight mechanism allows for a flexibility of processing where inputs receive facilitation based on their predictability in context as well as their overall frequency.

Using the conclusions reached by Experiments 1 and 2, in Chapter 6 and Experiment 3 we considered an alternative bottom-up manipulation in order to gain a clearer picture regarding the effect of context on unreliable stimulus perception. We transformed the original target words by replacing a medial letter to create similar-looking misspellings of the original word. Thus, we could further examine how heavily readers might rely on context to recover from irregularities in the visual input.

Experiment 4 (0) then tested the Spotlight Theory using the same stimuli, presented laterally to each hemisphere and looked into whether the LH spotlight also extends to inputs that resemble highly predictable words. We also investigated the second implication of the Spotlight Theory, looking at whether the lack of a harsh spotlight focus on expected continuations for the RH might actually allow for more adequate recognition of irregular inputs and their potential reanalysis. The results of the central presentation Experiment 3 show that comprehenders are sensitive to the violations in bottom-up input during semantic access time-windows, but that does not stop them from using context to construct the larger message of the sentence and to reconstruct the original word from the input violation (misspelling). The data from Experiment 4 allow us to refine the Spotlight Theory and conclude that in the case of input violations, supporting contexts can be used to recover the semantic form of the intended input when it is presented to both LH and RH, but context is preferentially relied on for RH-presented inputs to construct the larger sentential message at later processing stages.

Chapter 8 is divided in five sections and provides a discussion of the findings of the thesis. The first two parts discuss the implications of Experiments 1 & 2 and 3 & 4 respectively, positioning the current findings in the broader context set out in the literature review in the introduction. The third part of Chapter 8 is an attempt to unify the findings of the two strands of experiments in this work and a proposal of an updated hemispheric specialization model that incorporates our results into previous models and extends their theories. The fourth part of Chapter 8 extends the hypotheses of the unifying model and proposes potential future lines of research. The thesis then concludes with an overall summary of the findings and larger impact of the thesis.

Chapter 2

Bottom-up processing in sentential context

As sketched out in the previous chapter, prediction is considered to be a fundamental concept in psycholinguistic theories of reading. However, the specific mechanisms of how context predictability as an indicator of predictive processing shapes reading, whether and how it interacts with other factors fundamental to comprehension, and at what potential timeline are still under debate. Before we introduce the relevant findings, however, we'll start Section 2.1 with a short introduction of the neurobiology of visual perception and some relevant methods and mechanisms. These are crucial to understanding what is meant by bottom-up processing in this work and how plausible are the potential connections between higher-level structures that are relevant to predictive processing and bottom-up processing structures.

Then in Section 2.2 we will turn to neurobiology-informed computational and psycholinguistic models to describe the potential processing stages of bottom-up single word recognition, which will be the focus of the experiments presented later in the thesis. Section 2.3 will discuss the final stage of word recognition and how lexical frequency and its effect on word processing has traditionally been used as an indicator of the timing of successful word recognition and the latest point bottom-up processing may still be influencing word comprehension.

Finally, the chapter ends with a detailed review of crucial studies of the interactions between predictability and bottom-up processing as measured by word frequency effects and pseudoword processing. Special attention will be allocated to ERP investigations of these interactions, their timing and what that signifies to our current understanding of word processing.

2.1 The neural basis of word perception

Bottom-up processing involves processing that appears starting at the time information from the input hits the retina of a reader (or auditory receptors, finger tactile receptors, etc[6]). Retinal receptors from both eyes (~2° visual angle around the fovea: or the most detailed and in-focus input) send information to the brain via the optical nerve, through the optic chiasm and lateral geniculate nuclei of the thalamus, to reach the striate cortex of the occipital lobe (Wixted & Serences, 2018 and Figure 2.1). Qualities of the optical input are processed at each of these steps (including the retina) and increasingly more complex output is sent towards the next processing step. Information from the retinal photoreceptors[7]

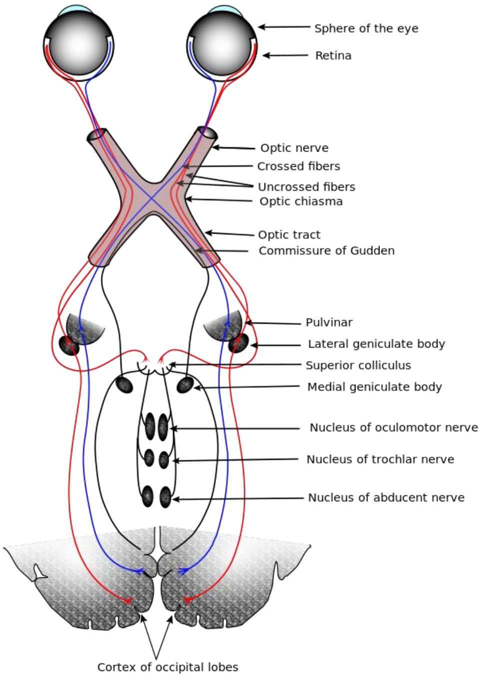

Figure 2.1– Schematic drawing of the visual pathways and the major connections of the optic nerves.

---

[6] For the purposes of this thesis the introduction focuses on visual perception, as all the experiments conducted investigate reading comprehension.

[7] There are two kinds of photoreceptors: cones, which transmit information about color, and rods, which are used in dim light and facilitate black-and-white vision.

is further processed in the retina by bipolar and ganglion cells, which use circular on and off receptive fields to form the basis of edge detection in the visual system. The optical pathways from the left and the right nasal retina cross at the optic chiasm. This way information from the same visual field from both eyes is sent to the contralateral part of the visual cortex, facilitating stereoscopic vision[8]. From the optic chiasm, information goes to the left and right lateral geniculate nuclei (LGN) in the thalamus. LGN neurons are the first on the optical pathway to be influenced by information processed in the visual cortex. The LGN neurons compute bottom-up information such as temporal and spatial correlations, three-dimensional visual processing, velocity perception, direction of movement, etc. Top-down calculations of the LGN facilitate visual attention focus and direct attention to crucial parts of space.

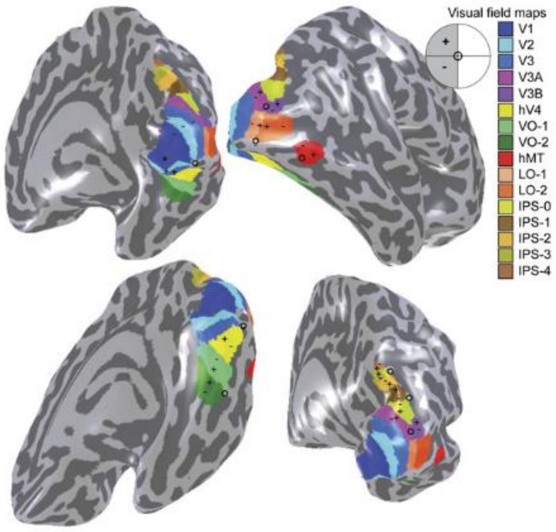

Figure 2.2– Representation of visual processing areas in the occipital cortex. Reprinted from (Wandell, Dumoulin, & Brewer, 2007).

After the LGN optical information reaches the cortex at area V1 (Brodmann Area 17, occipital striate cortex) which detects edges, corners, as well as basic color and motion

---

[8] For a more detailed description of retinal acuity and visual hemifield processing, see Chapter 3.

information. Further, information is distributed rostrally for processing with increasing complexity to areas V2-5 of the extrastriate cortex (Wandell et al., 2007 and Figure 2.2).

Following initial processing in the visual cortex, processing splits along two major streams: the dorsal stream ("where pathway") and the ventral stream ("what pathway"). With regard to visual processing, the dorsal stream is composed of zones responsible for spatial location processing, while in auditory processing, the dorsal areas process speech repetition. Relevant to this thesis is the ventral pathway, which leads to the medial temporal lobe (see 1.1 for a discussion of the connection between the medial temporal lobe and semantic memory) and is linked to object recognition and form representation.

Linking these optic pathways to reading, we can recognize several factors that are affected by the output of the visual cortex and are crucial for successful word comprehension. The bottom-up visual input may introduce unexpected noise and irregularities such as spelling mistakes, badly printed or unreadable text, faulty autocorrect, which could lead comprehenders to focus on the top-down context to infer the intended form and meaning of a specific word. However, while context can constrain readers' expectations towards a certain semantic field[9], to fully comprehend the input, they need to focus on and distinguish between multiple word forms with same general meaning (e.g., bike, bicycle, fixie), before attempting to integrate them in the larger discourse. Variation of the first type is measured by investigating the processing of pronounceable and non-pronounceable pseudowords or misspellings and will be discussed in Section 2.2. Variation of the second type is measured by the lexical frequency of the specific word input and has been argued to mark the turning point of word recognition and conversely the highest reach of bottom-up processing (Hauk & Pulvermüller, 2004) and will be discussed in Section 2.3.

---

[9] We refer to semantic field as a group of related meanings and their corresponding lexical manifestations in the mental lexicon. The members of a semantic field don't need to be synonyms, or the same parts of speech, but they do need to have associated meanings. A loose example of a semantic field would be "ball, doll, play, kite, jump-rope, tree house, etc.".

2.2 Visual word recognition

One successful way to gain a deeper understanding into the progression of information through the brain from character strokes through letters to words (without having to resort to operating on cats)[10] has been by building computational models of word recognition. Modelling has utilized neuroscientific findings to investigate processing mechanisms at each level of word comprehension under both top-down and bottom-up influences (Norris, 2013).

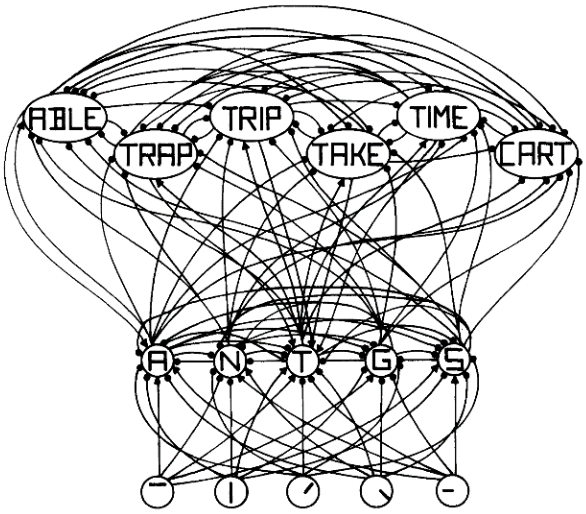

Figure 2.3–Two-layer neural network model. Nodes represent input features at each level of growing complexity, with excitatory (arrows) and inhibitory (dots) connections within and between levels. McClelland & Rumelhart (1981)

Most influential models of visual word comprehension apply neutrally-inspired architectures, with levels of processing similar to the neural pathways in the brain, starting from small clusters of neurons (or even single neurons) to larger hierarchical systems. One of the prominent early examples of computational modelling of word comprehension are interactive activation models (pioneered by McClelland & Rumelhart, 1981; Rumelhart & McClelland, 1982), which model the spreading activation between several processing

---

[10] The original Nobel prize-winning experiments by David Hubel and Torsten Wiesel (Hubel & Wiesel, 1965) discovered the nature of visual perception by presenting visual stimuli to cats' immobilized retinas.

layers (typically 3, most often more), similarly to visual processing in the brain. Each layer consists of nodes or units, not unlike real groups of neurons, and represents a single level of processing such as but not limited to features of letters, letters, or words (see Figure 2.3). Each node has a numeric activity level that represents neural activation and can change depending on its input. Nodes within and between each layer can spread excitatory or inhibitory activation, thus enforcing the rules of a language (certain letters never/always appear together) allowing for successful simulation of both the hierarchical buildup of information in bottom-up word-recognition and for the top-down influences of rules, frequency of use, etc. More specifically, neural network models explain possible mechanisms of spreading activation and priming for similar word forms (TOP and STOP) as well as similar pseudoword forms (JUDGE and JUGDE) and simulate how comprehenders recover meaning from words with missing letters (for a review, see Norris, 2013). As noted in that review, variations in the computational architectures lead to different predictions about visual word recognition and to testable hypotheses about the different levels of processing and the nature of the connections between them.

One shortcoming of computational models is the fact that they typically ignore time. Cerebral processing usually generates weaker activation over a larger number of neurons, over time. Computational models use simplified rules, over smaller number of nodes with larger computational power. Combining ERP findings (with high temporal sensitivity) with the hypotheses generated by computational models paints a much more refined picture of the timeline and nature of visual word recognition (Barber & Kutas, 2007).

One finding to stem from computational modelling findings and be subsequently confirmed by ERP data are word superiority effects as well as acronym superiority effects (e.g. Laszlo & Federmeier, 2007b; Martin, Nazir, Thierry, Paulignan, & Démonet, 2006). Additionally, once a supportive context is available, readers take advantage of it to recover from imperfect inputs, like pseudowords created by replacing a medial letter of expected words (Kim & Lai, 2012). Not only is it easier for readers to access an expected words' form and meaning from misspelled inputs in supporting contexts, but also misspelled inputs that resemble expected words require less resources to correct and reintegrate into the general sentential context (van de Meerendonk et al., 2009; 2011).

In all, both computational models as well as ERP findings indicate that early perceptual processing is immensely aided by preexisting knowledge of both legal strings in the lexicon (word superiority effect) and expectations based on previous context. As reported in the previous section, the visual processing system can be influenced by higher level structures even before words are recognized as such. Research reported in this section further corroborates these results, as both computational models built under the assumption of bi-directional connections between levels of processing and ERP findings of pseudoword processing in context demonstrate that input can easily be amended and inconsistencies ignored as long as the incoming strings fit sufficiently with the preexisting expectations in the processing system.

2.3 Lexical frequency processing in context

Another measure that has been used to look into comprehenders' sensitivity to incoming input form is word frequency. As word frequency is the frequency of an exact word form in a written text corpus (usually measured in number of occurrences per million in magazine or newspaper corpora) a reliable frequency effect can be indicative of the speed of word recognition and has been a focus of linguistic research using both behavioral (eye-tracking) and EEG methods. Low frequency words are recognized slower and fixated longer than high frequency words (Gernsbacher, 1984; Kliegl, Grabner, Rolfs, & Engbert, 2004; Rayner & Duffy, 1986). High frequency words are skipped more often than low frequency words and benefit more from parafoveal preview (Inhoff & Rayner, 1986).

EEG investigations of the word frequency contribution in sentential context indicate that frequency has a complementary role to context predictability. Comprehenders were shown to rely on lexical frequency when there is little contextual information to aid processing. Van Petten & Kutas (1990) reported that N400 amplitudes to low compared to high frequency words were largest at early positions of the sentence, while context predictability N400 effects were largest at later positions. Similar results were reported by Dambacher, Kliegl, Hofmann, & Jacobs (2006) who also manipulated frequency and predictability and found that frequency affected word processing in sentential context during P200 time-windows and interacted with context predictability during N400 time-windows. Low frequency words exhibited larger N400 modulations to predictability than high frequency words. Moreover, Dambacher and colleagues found a similar negative correlation to Van Petten & Kutas between N400 amplitude to word frequency and word position in the sentence.

In a more recent investigation, Dambacher et al. (2012) manipulated both the lexical frequency and contextual predictability of target words in a fully-crossed design (high and low frequency words each appeared in both high and low predictability contexts). Results showed that when words were presented at a speed close to normal reading (280 ms SOA, Exp. 3), predictability interacted with lexical frequency beginning at 135 ms after stimulus onset: high frequency words were reliably distinguishable from low frequency words, but in high predictability conditions only. Based on these results the authors argued that in supporting contexts, frequency and predictability information were used in parallel to narrow down potential sentence continuations, thereby facilitating processing during the word recognition phase.

Lexical frequency and predictability also affect later time-windows during message-level integration. As mentioned in the previous section, message-level integration can be reflected by modulations of the anterior PNP component. These are typically elicited by plausible, but unexpected continuations which are semantically related to the expected continuation (DeLong, Quante, & Kutas, 2014; Van Petten & Luka, 2012; Wlotko & Federmeier, 2012). In addition to plausibility in context, some evidence suggests that PNP amplitudes reflect processing costs related to specific lexical expectations. Thornhill and Van Petten (2012) used a 2x3 design to manipulate sentential constraint (high, low) and the semantic relatedness of target words (high cloze, low cloze but semantically related to the high cloze continuation, low cloze and unrelated to the high cloze continuation). For example, a high constraint sentence like "*He was afraid that doing drugs would* *damage his..., would be continued with either brain/mind/reputation"*. While N400 results showed a graded sensitivity (N400 was smallest for high cloze, largest for unrelated low cloze, and intermediate for related low cloze), anterior PNP results reflect equivalent processing difficulties for both low cloze continuations. In other words, even when participants were presented with a word such as "mind", which is semantically related to the expected continuation "brain", this semantic association did not facilitate message-level integration. The authors suggest that this result may have been driven by participants having specific expectations for lexical form.

In all, in Chapter 2 we discussed results from studies that have manipulated both contextual predictability and lexical frequency suggest that these factors interact during multiple phases of word processing. Bottom-up lexical factors such as word status, or frequency of occurrence in the lexicon have a very tangible effect on word processing in a sentence. Readers draw information from and set their expectations on specific word forms and readily and rapidly shift their focus on bottom-up lexical cues in the absence of reliable top-down contextual support.

This chapter concludes the review of the previous findings of bottom-up and top-down interactions during central presentation of the stimuli, where both hemispheres contribute to the comprehension of incoming inputs. While this allows for a realistic investigation of sentential comprehension, it doesn't allow us to fully investigate the hemispheric contributions to top-down and bottom-up processing. Especially, since some prominent hemispheric differences accounts of reading comprehension specifically focus on differences in context processing. After a short summary of the neurobiology of visual processing and the hemispheric differentiation of visual pathways, the next chapter will focus on the three most prominent models of hemispheric asymmetries in language processing and how these findings inform the setup and goals of the current thesis.

Chapter 3

Hemispheric differences in context

In Chapter 2 we reviewed evidence from multiple sources suggesting that word comprehension relies on an interaction of bottom-up and top-down processing. We discussed how readers rely on constraining contexts to swiftly recognize, access, and integrate incoming information that fits their preexisting mental representations. However, they trade-off top-down efficiency in cases of insufficient contextual information and focus on the bottom-up features of the stimulus in order to facilitate recognition and semantic access, and in some cases even message-level integration.

In this chapter we will introduce the basic neurobiology of the visual pathways, their connections to higher-level processing structures, and how hemispheric asymmetries are built into the visual system. We'll then go on to discuss the three most relevant recent models explaining hemispheric asymmetries in language comprehension, focusing on cytoarchitectural differences, through auditory sampling differences to functional differences of larger cerebral structures. The chapter ends with an overview of the reasoning and setup behind the thesis research and the goals of the experiments to be presented.

As we discussed already in Chapter 1, visual processing is not a one-way street from input perception toward mental representations: feedback (top-down) connections in the brain can start affecting the incoming signal processing even before it reaches the primary visual cortex (at the lateral geniculate nuclei, LGN). Previous research indicates that top-down processing changes how incoming inputs are perceived, and those top-down influences differ based on whether they emerge from the left or the right hemisphere (Hughdahl & Davidson, 2003).

Even though most cortical and subcortical structures in the two hemispheres are duplicated, the manner in which left and right hemispheric structures process information is not identical. One of the first major asymmetries to have been observed as early as 1861 by French neuroscientist Paul Broca is left hemispheric language lateralization: based on his aphasia studies, where patients were left unable to formulate comprehensible language after left hemispheric damage, language production and comprehension were thought to be executed by neural substrates situated only in the left hemisphere (for a review see Martin, 2003). Left hemispheric language comprehension influenced research for over a hundred years afterwards (Démonet, Thierry, & Cardebat, 2005; Price, 2012), leading a lot of researchers to simplistically assume that since the right hemisphere contributed next to nothing for language production, it must therefore not be very involved in language comprehension. However, during the last several decades the distinction between the two hemispheres has become more nuanced and more specific to different levels of comprehension mechanisms (for a comprehensive review, see Friederici, 2011a).

3.1 Hemispheric differences in language comprehension

Even though older models of left-hemispheric language asymmetry are no longer supported by modern findings, there is still evidence that there are subtle differences in how the two brain hemispheres process language. While evidence from DVF and neuroimaging studies indicates that LH structures are heavily involved in most word, sentence and text processing (Démonet et al., 2005; Federmeier et al., 2005; Friederici, 2011b), a lot of evidence points to RH involvement in metaphor and joke comprehension (Davenport & Coulson, 2013; Marinkovic et al., 2011), overall theme and inference processing (Metusalem, Kutas, Urbach, & Elman, 2016; St George, Kutas, Martinez, & Sereno, 1999), and other high-level language comprehension (Lindell, 2006). Moreover, following LH removal during adolescence (usually as part of treatment for epilepsy), patients regain most language abilities (Devlin et al., 2003; Elger, Helmstaedter, & Kurthen, 2004). Adults with LH lesions show increased language processing-related activity in homologue RH areas (Cramer, 2008; Crinion & Price, 2005). Both of these findings indicate that RH structures must be capable of some level of language processing prior to the lesion and that a complete repurposing of RH structures is unlikely.

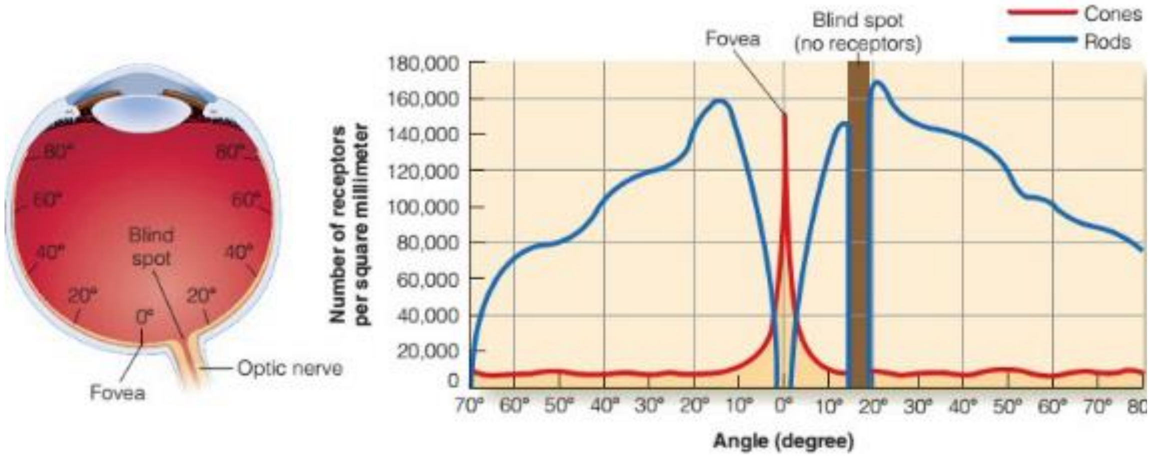

Figure 3.1– Degrees of visual angle representations on the retina and visual acuity curve in number of receptors per degree of visual angle. Highest degree of cones at 3° left and right of fixation indicates area of most acute color perception. Picture reproduced from Goldstein & Brockmole (2015).

In addition to lesion and neuroimaging research, a behavioral paradigm has been developed to non-invasively investigate any differences in processing employed by the two cerebral hemispheres. The divided visual field (DVF) paradigm (Bourne, 2006) allows researchers to take advantage of the structure of the visual pathways to present visual stimuli briefly to the right or left of fixation, thus ensuring that the input is initially processed only by the contralateral-to-presentation hemisphere. Since visual acuity is largest at 5-6° visual angle around the fovea, or 3° degrees left or right of fixation (see Bourne, 2006 and Figure 3.2), words presented to the perifovea for a duration shorter than the time it takes for a saccade to be planned or executed (~250ms according to Sereno, 2003) are initially processed by the hemisphere contralateral of presentation. The time-frame of interhemispheric transfer varies anywhere between 3 and 30 ms based on type of information transferred, corpus callosum thickness, eye-dominance etc. (e.g.

Chaumillon, Blouin, & Guillaume, 2018). One critique of the DVF paradigm points out that hemispheric effects may simply reflect the time of interhemispheric transfer from the less specialized to the more specialized hemisphere to process the input, but methodological investigations of the DVF paradigm indicate that reaction time differences between the hemispheres are too large to reflect simple information transfer without an attempt at processing (e.g. Lavidor & Ellis, 2002). Thus, any processing differences found between words presented to the right visual field/left hemisphere (RVF/LH) versus the left visual field/right hemisphere (LVF/RH) are taken as an indication of asymmetries in hemispheric processing biases.

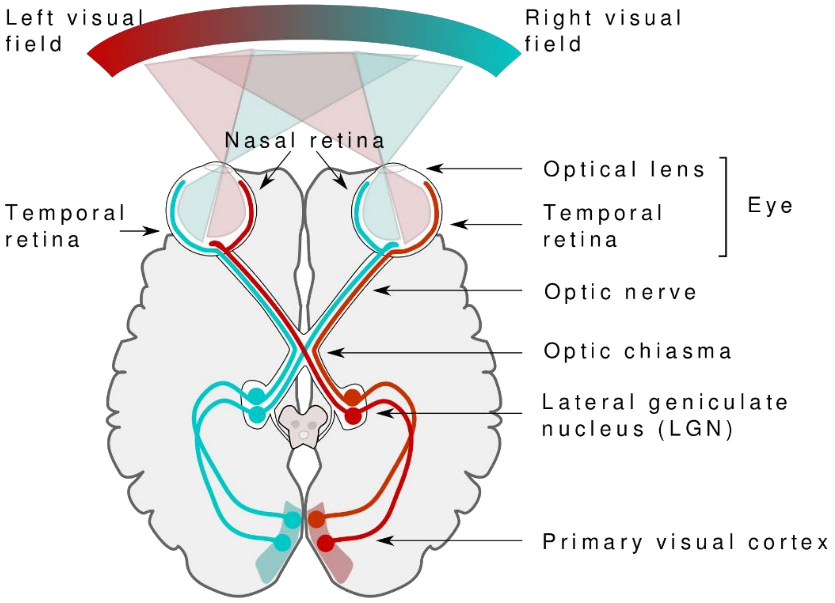

Figure 3.2– Visual field lateralization. Information from each temporal retina is sent to the ipsilateral hemisphere, while information from the nasal retinas, crosses at the optic chiasm to be initially processed by the contralateral hemispheres.

In all, during the last 20 years researchers have started to attribute evidence of hemispheric differences in neurotypical language processing to fundamental physiological and functional differences between the hemispheres, which in turn affect language processing (among other higher-level systems). We will discuss two of the most influential ones (the Fine vs. Coarse Semantic Coding model and the Asymmetric Sampling in Time model) before focusing extensively on a third and latest one (Production Affects Reception in the Left Only model) as well as some recent findings that don't completely fit with these hemispheric processing models (DeLong & Kutas, 2016).

3.2 Fine vs. Coarse Semantic Coding model

The Fine vs. Coarse Semantic Coding model, proposed by Mark Jung-Beeman (Jung-Beeman, 2005), highlights three crucial levels of semantic processing that interact to contribute to successful language comprehension: semantic activation, semantic integration, and semantic selection. Each process corresponds roughly to a fronto-temporal area of the brain: semantic activation, posterior middle/superior temporal gyrus; semantic integration, anterior middle/superior temporal gyrus; and semantic selection, inferior frontal gyrus. The three processes roughly correspond to what we refer to word recognition, semantic access and message-level integration in this research. According to Jung-Beeman, semantic activation reflects the process of "initial access to semantic representations", which could be seen as corresponding to what we refer to as word recognition or early P2 time-windows (Jung-Beeman, 2005, p. 513). Semantic integration is referred to as message-level interpretation or the process of inferring meaning from context (sentence meaning, thematic inference). Even though Jung-Beeman refers to semantic integration as message-level interpretation, based on the cerebral areas involved in it, it appears to correspond to what we refer to as semantic access and N400 time-windows (see for example, Kutas & Federmeier, 2011). Semantic selection is referred to as the process during which irrelevant meanings are inhibited and the relevant ones are selected for conscious execution (response production etc.). Per Jung-Beeman's review of literature, semantic selection-related activity is most prominent in the inferior frontal gyrus the process appears related to what we refer to as message-level integration, as it correlates with frontal activation, related to inhibition of irrelevant information or in our case unpredictable sentential continuations (DeLong & Kutas, 2016; Van Petten & Luka, 2012).

The Fine vs. Coarse Semantic Coding model argues that natural language comprehension requires engagement of these areas from both the left and the right hemisphere. The model postulates that the two hemispheres have similar semantic network structure and similar semantic representations, but differ in the speed and strength of connection between concepts. Crucially to the hypotheses presented later in the current work, Jung-Beeman proposes that the two hemispheres are differently affected by context, which affects the shape of the semantic fields they access, the focus of attention and time-course of processing. The suggested reason for that lies in the dendritic and axonal structure of each hemisphere's neural network system: left hemisphere neurons have a denser neural network, with shorter dendritic connections and smaller density of white matter; right hemisphere neurons are more interconnected, have longer dendritic connections and a greater proportion of white matter. This, according to the model, may lead to differences in language processing such that LH neural networks access, integrate, and select information in a more fine-grained manner, using smaller, more focused semantic fields. Conversely, RH neural networks have a more coarse-grained processing structure, with larger semantic fields. This "division of labor" between the two hemispheres might explain the RH advantage for grasping higher-level context, themes, jokes and metaphors, while LH processing is more efficient processing dominant, literal meanings and very frequent strong semantic connections.

3.3 Asymmetric sampling in time (AST) model

Apart from the dendritic density of each hemisphere's neural networks, another potential source of hemispheric differences can be the different rates of frequency sampling during speech comprehension. Spoken language carries information at different levels of audio temporal resolution, from place of articulation and accent information that require focus on quick changes in the speech signal (usually 25-40 ms), to intonation and prosody that require focus on larger windows of analysis (usually 200-250 ms). The Asymmetric Sampling in Time (AST) model focuses on evidence that the left hemisphere processes information with a temporal resolution of 25-50 ms, while the right hemisphere aggregates data over larger time-windows of 150-250 ms, in line with the general local vs. global distinction (Poeppel, 2003). The AST model rests on the premise that primary speech signal processing is bilaterally represented over temporal structures, indicating that both hemispheres are involved in initial speech perception. Poeppel points out that processing incoming information on the same level in both hemispheres would be redundant and proposes that each hemisphere encodes speech at different temporal resolutions/frequencies. Pointing to neuroimaging evidence, Poeppel reports that the LH has been reported to specialize at processing rapidly changing signals, associated with a power increase in the high frequency gamma band range (40Hz or 25 ms), encoding the speech signal at a small focused sampling window. Conversely, neuroimaging studies indicate larger clusters of RH and not LH neurons parsing information with a large sampling window (5Hz or 200 ms) which can be associated with prosodic information processing. The speech coding perspective of the AST model can actually be used to extend the hypotheses and findings of the Fine vs. Coarse Semantic Coding model. Additionally, the AST model incorporates not only word-level processing, but also accounts for potential hemispheric differences in larger contexts.

3.4 “Production affects reception in left only” (PARLO) framework

One of the more recent models of predictive processing in the two hemispheres, based specifically on ERP research using the DVF paradigm and most central to the current work, is the “Production affects reception in left only” (PARLO) framework proposed by Kara Federmeier (Federmeier, 2007). PARLO is an interactive account of bottom-up and top-down processing in the brain, which is grounded on the assumption that the LH and RH share similar representational structures and bottom-up processing mechanisms during the early phases of word processing (a hypothesis shared by both the Fine vs. Coarse Semantic Coding and AST models) and diverge during later semantic integration phases (>250ms after stimulus presentation) due to differences in hemispheric access to top-down processing structures. According to PARLO and based on preexistent behavioral and neuroimaging findings, language production (bottom-up) and comprehension (top-down) mechanisms interact only in the LH, leaving “an infrastructure” of bottom-up and top-down connections to be exploited in language processing in general. RH structures are not involved in language production, despite being equally well-suited to comprehension. Federmeier argues that specifically the interaction between bottom-up and top-down processing predisposes predictive mechanisms in the LH, while the lack of access to top-down production mechanisms in the RH leads to a bottom-up processing bias. Crucially, according to PARLO, both hemispheres take advantage of sentence-level information and each contributes to comprehension.

Relying on two asymmetric language processing mechanisms in parallel can be seen as more beneficial than relying on one specialized hemisphere (LH). A prediction-oriented system like the LH can lead to fast and accurate language comprehension in a narrow subset of highly familiar and expected contexts, however such a strategy is less useful in the less frequent situations where input is not constraining or unfamiliar. In these situations, a focus on bottom-up processing and a broader, less specific set of contexts/meanings such as RH-processing would prove to be more robust and reliable. Previous behavioral and EEG data support both a top-down, context-oriented processing focus for LH-presented words (Federmeier, 2007; Wlotko & Federmeier, 2007, 2013) and bottom-up, input-oriented focus for RH-presented words (Jung-Beeman, 2005; Poeppel, 2003).

Federmeier and colleagues investigated the premises of PARLO using the divided visual field (DVF) technique over several different manipulations. Wlotko & Federmeier (2007) manipulated two top-down factors independently: word predictability (expected vs. unexpected) and contextual constraint (weakly vs. strongly constraining sentences). Results showed hemispheric asymmetries during the P2 and N400 time-windows. First, contextual constraint modulated processing during the P2 time-window, but only for words presented to the LH: the amplitude of the frontal P2 component was more positive in strongly constraining contexts than in weakly constraining contexts. During the subsequent semantic access phase, N400 amplitudes elicited by LH-presented words reflected a facilitation for expected words regardless of contextual constraint. In contrast, RH-presented words showed a constraint by predictability interaction such that the processing of expected words was only facilitated in strongly supporting contexts. This pattern of hemispheric bias was extended in a follow-up study (Wlotko & Federmeier, 2013) in which the authors analyzed a fuller spectrum of cloze probability as a continuous variable and found that LH-presented sentence endings elicited graded facilitation effects starting at lower levels of contextual constraint than RH-presented ones. Wlotko and Federmeier concluded that RH processing is largely driven by bottom-up information, because facilitation in the RH appeared to require such a high degree of contextual constraint. However, it’s worth noting that the factors manipulated in both studies manipulate top-down sentence processing and any inferences about RH bottom-up focus are made based on a limited effect of predictability, the extent and manner to which bottom-up information truly contributes to these asymmetries remains unclear.

An additional indication of hemispheric asymmetries in predictive processing can be the post-N400 positivity component. Plausible, but unexpected words typically elicit anterior post-N400 positivities (PNPs) in non-DVF studies (Federmeier et al., 2007; Wlotko & Federmeier, 2012) as discussed in Chapter 1. Despite the indications that contextual constraint more robustly facilitates LH processing during the N400 semantic access phase, neither of the above studies showed indications of downstream consequences of misprediction. Wlotko and Federmeier reported no post-N400 positivity modulations during the message-level integration phase when plausible, but unexpected words were presented to either hemisphere (Wlotko & Federmeier, 2007, 2013). This is surprising because as these continuations already elicit difficulties in semantic access, they should also be more difficult to integrate in the overall sentential message, thus eliciting anterior PNP effects for LH-presented plausible, but unexpected continuations. Based on the lack of evidence for anterior PNPs in their hemispheric studies (Wlotko & Federmeier, 2007, 2013), Wlotko and Federmeier concluded that successful message-level integration may require interhemispheric cooperation, which was disrupted by their DVF presentation.

A more recent hemispheric-differences study that also manipulated sentential constraint and word predictability (but not bottom-up information processing) found qualitatively different results (DeLong & Kutas, 2016). First, no hemispheric differences were found during the semantic access phase as measured by the N400 ERP component. Second, later, anterior PNP effects were found for plausible, but unexpected words in strongly constraining contexts, when such words were presented to the LH. DeLong and Kutas speculate that the differences in results between their study and Wlotko and Federmeier (2007, 2013) could potentially be explained by differences in stimulus materials: the stimuli in DeLong and Kutas (2016) contained longer discourse contexts, which they argue may have engendered stronger pre-activations for subsequent input, and consequently led to greater processing costs during the message-level integration phase.

In sum, several DVF studies suggest that important hemispheric asymmetries in the application of contextual predictability during word processing in sentential context may exist, but the timing of these effects is unclear. Some studies find hemispheric effects of predictability during the semantic access phase (N400 time-window) and others find hemispheric effects only during the message-level integration phase (post-N400 positivity time-window). Moreover, these studies address only the hemispheric distribution of top-down contextual predictability, leaving a lot of unanswered questions about the timing and distribution of bottom-up effects and their potential interactions with predictability. Since no bottom-up manipulations were employed, the first question to ask would be is bottom-up information indeed processed similarly in both hemispheres during early word recognition, as assumed by PARLO? Additionally, as stated in sections 2.2 and 2.3 earlier, bottom-up processing encompasses several stages of information processing, such as whether the input is indeed a word in the lexicon (word status) or how frequent the input is in the lexicon (word frequency). One can imagine different ways in which the hemispheres can utilize the immediate sentential context in order to support the resolution to these questions. We can expect that both bottom-up factors affect RH and LH word processing similarly at early time windows, but only interact for LH-presented stimuli during semantic access and/or message-level integration, where the word meaning needs to be accessed from the semantic network and applied to the overall sentential message. Or, it could be the case that top-down and bottom-up information interact rapidly during word recognition phases (as indicated by Dambacher, Rolfs, Göllner, Kliegl, & Jacobs, 2009) for LH-presented words only (in line with the Fine vs. Coarse Semantic Coding model, Jung-Beeman, 2005). The next section will focus in more detail on how these research questions were reflected in the design of our experiments.

3.5 Methods and goals of the current studies

The overarching goal of this thesis is to investigate how top-down expectations based on previous context shape the bottom-up processing of upcoming stimuli in the sentence. Previous findings postulate that the top-down processing of sentential predictability is mostly employed by LH structures, potentially in interaction with bottom-up processing, implying that the RH focuses exclusively on bottom-up processing. However, so far there are no direct investigations of how and which specific bottom-up processing stages are delegated to the RH.

In order to examine the effect of bottom-up processing we focus our manipulations on two separate factors: lexical frequency and word-pseudoword status, as they affect different stages of early word processing. Top-down processing was manipulated in the same way as previous studies, by using word cloze probability as a reflection of its sentential predictability. Each bottom-up factor was investigated together with predictability in a central presentation experiment (Experiments 1 and 3) in order to determine a baseline for the exact timing of the top-down and bottom-up effects and their potential interactions. Hemispheric processing was manipulated for each bottom-up and top-down combination in Experiments 2 and 4 by using the DVF paradigm to present initially to the LH or RH.

These manipulations would thus allow us to determine whether contextual predictability effects are indeed subject to hemispheric bias and whether a larger sensitivity to context in one hemisphere (larger predictability effect over ERP amplitudes) affects what subsequent weight is assigned to bottom-up input processing. More specifically, if RH structures are less involved in critical word anticipation, does this mean word recognition, semantic access, and message-level integration processing stages of irregular inputs (low frequency words or pseudowords) are indistinguishable in high and low predictability contexts? Conversely, if LH structures place larger weights on high predictability contexts, do word recognition, semantic access, or message-level integration stages of low frequency or pseudoword inputs reflect lower processing difficulties than in non-supporting contexts? Namely, is the largest predictability-based facilitation available for high vs. low frequency and word vs. pseudoword inputs?

In order to uncover the interplay of context predictability, word form and hemisphere of initial presentation, we employ ERPs and focus on several word processing time-windows. Hemispheric processing asymmetries are measured by using the DVF paradigm to present exclusively to one hemisphere during initial word processin. This line of investigation is important to language comprehension research as it can corroborate not only previous findings about whether and when readers use context to anticipate incoming inputs, but also whether and how they utilize the two hemispheres to maximize facilitation from both bottom-up frequency or word status and contextual support. As it stands there is very little previous hemispheric research on language comprehension in sentential context and the use of predictability for either hemisphere. Moreover, the existing research presents a homogenous perspective (predictive contexts more efficiently utilized by the LH, according to the PARLO framework), since it only focuses on top-down factors like contextual predictability or contextual constraint. It is unclear what is the hemispheric distribution is for any factors requiring bottom-up processing or what the specific role bottom-up processing plays at each phase of word comprehension in sentential context for each hemisphere and for each predictability condition.

Even though there are no studies so far looking into hemispheric differences in top-down and bottom-up interactions, evidence from previous central presentation research indicates that top-down predictability processing can interact with bottom-up factors such as lexical frequency within the first 200 ms after stimulus onset (Dambacher et al., 2012; Hauk, Coutout, Holden, & Chen, 2012; Kim & Lai, 2012; Penolazzi et al., 2006;

Sereno, 2003), as well as over the subsequent semantic access time-window (Dambacher et al., 2006; Laszlo & Federmeier, 2009; Van Petten & Kutas, 1990). Especially in cases where contextual support is sparse, lexical frequency modulates comprehension processes, such as when target words appear in the early positions of a sentence (Van Petten & Kutas, 1990; Van Petten, 1993) or in low contextual constraint sentences (Dambacher et al., 2006). Subsequently, both lexical and contextual information affect message-level integration. As mentioned in previous sections, anterior PNPs are typically elicited by plausible, but unexpected continuations that are semantically related to the expected continuation (DeLong & Kutas, 2016; DeLong et al., 2014; Federmeier et al., 2007; Van Petten & Luka, 2012; Wlotko & Federmeier, 2012); in addition to plausibility in context, there is also some evidence showing PNP amplitudes to reflect processing costs related to specific lexical expectations (Thornhill & Van Petten, 2012).

Additionally, contextual predictability affects how easily readers recover from inconsistencies in the incoming stimuli, or the bottom-up processing of word form. ERP findings from early time-windows (P130 and N170) indicate that context allows readers to form anticipations of a certain word form and distinguish between pseudowords that resemble the expected word form (essentially misspellings) and pseudowords that don’t (Kim & Lai, 2012). Findings on the N400 time-window initially suggest that such misspelling processing is nearly indistinguishable from supported word processing, due to the hypothetically stronger influence of context over word form during semantic access. Readers’ later P600 modulations, however, reflect that they still attempt to reanalyze and integrate the misspelled stimuli into the sentential context, indicating that bottom-up factor processing of misspellings like lexical frequency might continue to interact with predictability even over later ERP modulations (Kim & Lai, 2012; van de Meerendonk et al., 2011; van de Meerendonk et al., 2009).

While these central presentation findings indicate that contextual predictability and lexical processing interact over multiple phases of word comprehension, the existing models of hemispheric differences in sentence processing (Federmeier, 2007; Wlotko & Federmeier, 2007, 2013) only report significant interactions for semantic access time-windows and only for words presented to the left hemisphere. Additionally, the hemispheric studies that investigate sentence comprehension manipulate several measures related to cloze probability (context predictability/expectedness, sentential constraint), but don’t manipulate, nor extensively control, the bottom-up features of target words (Davenport & Coulson, 2013; DeLong & Kutas, 2016; Metusalem, Kutas, Urbach, & Elman, 2016). A potential shortcoming of this lack of control or explicit manipulation might be that bottom-up factors such as word frequency or word length have a non-negligible contribution above and beyond cloze probability for LH-presented words.

Consider the sentences from Wlotko and Federmeier (2007) as an example: “*He bought her a pearl necklace for her birthday/collection”* or “*He looked worried because he broke his arm/collection.”*. While this is only one sentence pair out of 282, *arm*, *birthday* and *collection* differ significantly in length, frequency, imageability, and abstractness. During the entire experiment, expected target words only appear in weak or strongly constraining conditions, while unexpected continuations appear in both. Overall, one can imagine a scenario where the hemispheric differences measured in the experiment are at least partially due to differences in, for example, length or frequency processing which reflect asymmetries in bottom-up and not top-down processing. Even when only top-down factors related to sentential context are manipulated, the results seem to differ across studies that use different stimuli, but nearly identical designs. The initial findings of effects of hemispheric presentation over N400 time-windows with no further effects over PNP time-windows (Wlotko & Federmeier, 2007, 2013) were not corroborated by later investigations (DeLong & Kutas, 2016) which found identical predictability effects over semantic access windows for both hemispheres and asymmetries in the message-level integration phase.

In an attempt to reconcile both these types of issues: lack of bottom-up manipulation and inconsistent replicability of central presentation findings in lateralization studies, Experiment 1 of this thesis sets out to replicate the original findings of early effects of context predictability over lexical frequency during central presentation. This was also as a way to set a baseline for the hemispheric investigation in Experiment 2. We use an identical stimulus set as the one employed by Dambacher and colleagues (Dambacher et al., 2012a) and we present high and low frequency words in the same high and low predictability contexts, while controlling for other bottom-up factors (see Figure 4.2 and Table 4-1). The goal of Experiment 1 is to investigate the effect of the top-down expectations based on contextual predictability over bottom-up lexical frequency processing during several time-windows and processing phases, using a similar to natural reading times presentation rate. The findings of Experiment 1 allow us to establish clear time-windows of interest for predictability/frequency interactions, informing our subsequent hypotheses on whether context affects bottom-up frequency processing during early word recognition time-windows, or later semantic access ones.

Building on the baseline set by the findings of Experiment 1, in Experiment 2 we investigate the nature of the potential hemispheric contributions to the top-down and bottom-up interactions during the same word processing phases as Experiment 1, using the same materials. We manipulate hemispheric presentation by way of the DVF paradigm where we present the low and high frequency critical words of Experiment 1 to the left or right visual field, allowing for initial processing advantage to the right or left hemisphere respectively. As discussed above, previous theories on the hemispheric asymmetries of prediction and anticipation have stated a difference between how top-down and bottom-up information processing is distributed across hemispheres. What is lacking in previous research is a direct window into top-down and bottom-up interactions, which we bring on by manipulating word frequency and context predictability independently. According to the PARLO framework, we can expect that during semantic access (N400) the RH would focus on bottom-up processing, while the LH is able to benefit from interactions between top-down and bottom-up processing pathways. However, this leaves open the question of potential interactions between predictability and frequency during earlier (word recognition) windows, since no previous hemispheric findings are available, despite central presentation indications of an early interplay. And, as mentioned above, it is unclear whether we can expect a LH specialization in predictability processing during message-level integration as reported by DeLong & Kutas (2016) or equal contributions by both hemispheres as reported by Wlotko & Federmeier (2007, 2013).

One suggestion of the PARLO framework is that the bottom-up focused RH-processing allows for a more veridical approach to the input, i.e. potentially catching and correcting mistakes in the text that a solely top-down focused approach would miss. The goal of Experiments 3 and 4 was, therefore, to extend the investigation of the interplays of hemispheric processing of corrupt input in sentential context of varying predictability and to measure when and to what extend readers are able to perceive and overcome the misspelling. To that end, the high frequency words from the Potsdam Sentence Corpus 3 were altered by replacing a medial letter with a similar looking letter to create a pronounceable illegal word in German that visually resembled the target word (a method similar to the one employed by Kim & Lai (2012).

Experiment 3 was a conceptual replication of the study by Kim & Lai, (2012), with the added cross-manipulation of predictability. We focused specifically on the pronounceable pseudo-word conditions of the study and, unlike Kim & Lai, presented pseudoword targets both in high and low predictability contexts (similarly to Experiment 1). Our aim was to set a reliable baseline for a) the bottom-up processing and recognition of corrupted input as compared to the expected words and b) the timeline of top-down influences on the corrupted input, during recognition, access, and message-level integration.

Presenting readers with erroneous input that still strongly resembles the target words in high or low predictability conditions allows us to assess any potential facilitation that context contributes for them to be able to overcome the unreliable bottom-up signal. It also serves the purpose of pinpointing how early words and misspelled targets can be distinguished in the ERP signal: potentially during N170 time-windows as reported by Kim & Lai, (2012). Additionally, at N400 amplitudes, we can investigate to what extent the context allows some semblance of semantic access for inputs that resemble lexicon entries, but do not, in fact, exist in the mental lexicon. With regard to later phases of processing such as message-level integration we can expect two potential outcomes. If readers treat misspelled words as plausible continuations, we expect to see PNP predictability effects, which can in turn be interpreted to mean that at the message-level integration stage a larger processing weight is placed on overall top-down context coherence. Conversely, if misspelled words are treated as erroneous continuations or flawed bottom-up input that needs to be corrected before it can be integrated in the overall message, we can expect to see P600 differences between words and misspellings, potentially in high predictability conditions, since the reintegration into the preceding context should be easier if the input resembles an expected continuation

Experiment 4 will build on to the findings of Experiment 3 and focus on what each hemisphere's contribution is on how the corrupted bottom-up input is recognized, whether semantic access is even attempted and how it is reintegrated in the previous context. Based on the scant hypotheses in previous literature on how the RH might deal with corrupted input, we expect that during early word recognition stages the RH should be sensitive to the distinction between words and misspelled pseudowords, while the LH should not. Similarly to Experiment 2, during semantic access (N400 amplitudes) we expect that top-down predictability and bottom-up frequency interact for LH, but not RH-presented stimuli. Finally, during message-level integration we expect that top-down predictability would affect LH anterior PNP amplitudes, while potentially the bottom-up distinctions between words and misspellings affect posterior P600 amplitudes for RH-presented stimuli.

The next four chapters will focus in detail on the four experiments conducted for this thesis, their methods and findings. The implications of those findings will be briefly discussed in each experimental chapter, and will then be relayed in detail in Chapter 8.

Chapter 4

Bottom-up frequency and top-down predictability interactions at a rapid presentation rate

We begin the investigation into the effect of contextual support over word frequency by modifying Dambacher and colleagues' study (Dambacher et al., 2012a). The goal of Experiment 1 is to establish a timeline of the interplay between sentence predictability and lexical frequency, thus letting us setup not only a replication but also a direct comparison between central (Experiment 1) and hemispheric (Experiment 2) presentation. Of particular interest in our replication attempt in Experiment 1 aims to replicate the early 90ms interaction between predictability and frequency as observed by Dambacher et al. (2012).

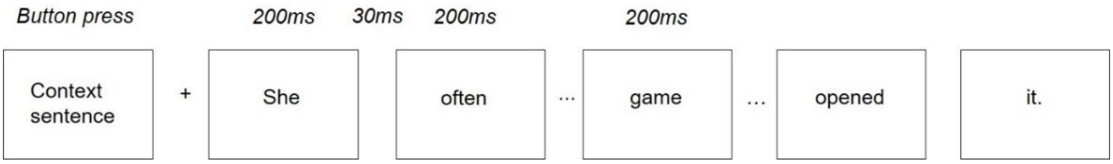

Figure 4.1– Procedure and timings. The context sentence remained on the screen until a button was pressed and was followed by a variable 1000-1500 ms pause. Each word of the target sentence was presented at the center of the screen for 200 ms, interspersed with 30 ms inter-stimulus intervals.

One of the major conclusions of the original investigation was that at a relatively fast-paced presentation rate, similar to reading speeds, sentence comprehenders are forced to draw on both the input's lexical frequency and on the preceding contextual information to be able to most efficiently process incoming words. Our modification focused on lowering the duration of stimulus presentation to 200 ms (compared to 250 ms in Experiment 3 of the original study) to reflect the average time people spend focusing on a word minus the time they might need to start planning and executing an eye-movement to another word (Sereno, 2003). This change in presentation rate was crucial for the replicability of Experiment 1 for the DVF paradigm that will later be used in our Experiment 2.

Caroline liebte es, sich die Zeit mit Schach, Dame oder Mühle zu vertreiben.

Caroline liked to spend her time playing chess or checkers.

Oft holte sie aus dem Regal ein Spiel und öffnete es.

She often took a game from the shelf and opened it.

Caroline liebte es, die Fotos aus ihrer Kindheit anzusehen.

Caroline liked to look at pictures from her childhood.

Oft holte sie aus dem Regal ein **Album** und öffnete es.

She often took an album from the shelf and opened it.

Figure 4.2– Materials. Sample stimulus sentence set illustrating the counterbalancing of frequency and predictability conditions. High and low predictability conditions were established by the initial context sentence, while high and low frequency targets were embedded in the neutral second sentence. Each context sentence acted as high predictability context for one frequency condition and as low predictability context for the other, allowing for a fully counterbalanced design.

Dambacher and colleagues investigated the effect of predictability over what they term lexical access (see Section 1.2 for a discussion of terminology) by finding the first instance of a significant interaction between cloze probability and word form frequency instead of focusing on a specific ERP time-window (a method applied by researchers looking at early word processing effects, e.g. Penolazzi et al., 2006; Pulvermüller, 2007; Pulvermüller et al., 2009). They reported that not only were predictability and frequency interrelated in the processing of upcoming words in context, but also that the two factors interacted at a very early processing stage (eN1 or at about 90 ms post stimulus onset), such that high and low frequency words were only distinguishable in high predictability contexts. This allowed them to conclude that supporting contexts facilitate early lexical access during near-normal reading speeds. Critically, the authors do not report any further instances of interaction between predictability and frequency in their Experiment 3, concluding that top-down influences over bottom-up processing may unfurl extremely rapidly and during very early processing.

The results of Dambacher and colleagues are novel and differ from other ERP studies of sentential context predictability (e.g. Federmeier, 2007; Kutas et al., 2010; Van Petten & Luka, 2012), which indicate that predictability only affects word processing at semantic access stages, namely during the N400 time-window. Replicating Dambacher et al. (2012), Experiment 1 should thus provide additional evidence as to whether rapid presentation requires rapid utilization of contextual support to facilitate early word access before semantic access is achieved. More specifically, we expect to replicate the eN1 interaction between context predictability and word frequency, as well as the main effects of frequency at N1 and P2 time windows and of predictability at the N400 time-window.

4.1 Methods

4.1.1 Participants

Twenty-five right-handed native speakers of German were paid 15 euro for their participation in the study. All participants had normal or corrected-to-normal vision (they were instructed to wear glasses instead of contact lenses to minimize blink artefacts) and none reported a history of neurological disorders. Data of 5 participants were excluded due to excessive artefacts. This left for analysis the data of 20 participants (11 female) with mean age of 23.8 years and age range 19 - 30 years. All participants signed written consent forms, were informed they can cease participation at any point, and reported no knowledge of the purpose of the experiment after participation (all were debriefed).

4.1.2 Materials

	High frequency words		**Low frequency words**	
	High predictability	**Low predictability**	**High predictability**	**Low predictability**
	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
Word form freq.	155.6 (194.6)	155.6 (194.6)	3.8 (2.1)	3.8 (2.1)
Lemma freq.	362.2 (875.3)	362.2 (875.3)	4.9 (2.7)	4.9 (2.7)
Predictability	.84 (.13)	.01 (.02)	.83 (.13)	.01 (.02)
Length	5.36 (1.16)	5.36 (1.16)	5.32 (1.11)	5.32 (1.11)
Word position	6.94 (.76)	6.94 (.76)	6.94 (.76)	6.94 (.76)
Word class	noun pairs: N=92; verb pairs: N=37; adjective pairs: N=15			

Table 4-1 Descriptive statistics per frequency and predictability condition and overall number of targets per word class. Frequency, length and word position were kept the same across predictability condition, as the words were embedded in the same neutral sentences (at the same position) following high or low predictability context sentences.

We used the Potsdam Sentence Corpus 3 (Dambacher, 2010; Dambacher et al., 2012a), which contains 144 German stimulus items (see Figure 4.2). Each item consisted of a target sentence frame, two possible context sentences, and two possible target words that differed in lexical frequency (high, low). Each context sentence acted as the high-predictability context for one target word and the low-predictability context for the other target word, resulting in four conditions per item: high predictability/high frequency, high predictability/low frequency, low predictability/high frequency, low predictability/low frequency. Target sentence frames were neutral such that they did not bias toward either target word. This allowed for the immediate context leading up to target words to be kept identical across conditions, minimizing potential baseline differences for ERPs time-locked to the target word. All target words were sentence-medial, preceded by at least 5 words and followed by at least 2 words. Table 1 summarizes the lexical frequency and cloze probability of target words across conditions as reported in (Dambacher et al., 2012, Table 2, p. 1855). A total of 4 counterbalanced lists were constructed from these materials, such that each participant saw only one item per condition, but no item occurred more than once per list.

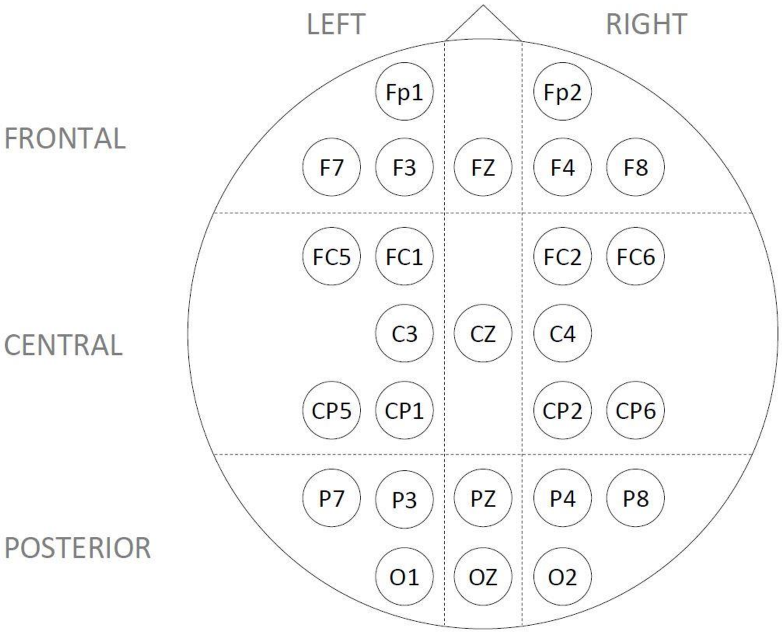

Figure 4.3– Electrode arrangement. Three levels of anteriority (frontal, central, posterior) and two levels of laterality (left, right) were used as topographic factors in statistical analyses.

4.1.3 Procedure

Participants were randomly assigned to a stimulus list and seated 60 cm from a 24” TFT monitor (resolution: 1920 x 1200; refresh rate: 75 Hz) in a sound-attenuated, electrically-shielded chamber. Stimuli were presented in black font on white background in 18 pt

Courier New using E-prime (Schneider, Eschman, & Zuccolotto, 2002) and participants were instructed to read freely for comprehension. Context sentences appeared in their entirety and remained on screen until participants pressed a button to continue. Following a random duration pause (1000-1500 ms), target sentences were presented word-by-word in the center of the screen via rapid serial visual presentation (RSVP): 200 ms per word, 30 ms inter-stimulus interval (Figure 4.1).

Throughout the target sentence participants were instructed to maintain fixation on the word at the center of the screen and to avoid blinking. To confirm that participants were attending to the task, one third of the trials were followed by a Yes/No comprehension question, which did not relate to the target word. Participants responded via button press; the position of Yes/No buttons was counterbalanced across participants. Feedback was provided during a 10-item practice session (not analyzed), but no feedback was given during experimental trials. Upon answering the comprehension question, the next trial was initiated. Items were separated into three blocks, with a short break provided between blocks. Total time on task was approximately 45 minutes.

	% rejected
Low frequency, low predictability	9.58% (SD 8.44%)
Low frequency, high predictability	8.61% (SD 9.90%)
High frequency, low predictability	9.58% (SD 8.72%)
High frequency, high predictability	9.03% (SD 9.04%)

Table 4-2 Artifact rejection. Average percentages of discarded items due to blinks, eye movements, muscle noise or slow sustained electrical activity per condition

4.1.4 EEG Recording

Data were recorded at 26 scalp sites (Figure 3: Fp1/2; F7/3/z/4/8; Fc5/1/2/6; C3/z/4; Cp5/1/2/6; P7/3/z/4/8; O1/z/2) according to the 10-20 system (Klem et al., 1958) using active Ag/AgCl electrodes, embedded in a 32-channel elastic cap (actiCAP, Brain Products

GmbH, Germany). Impedances were kept below 5kΩ. Horizontal eye-movements were monitored by placing electrodes at the outer canthi of each eye. Vertical eye-movements were monitored by placing electrodes above and below the left eye. EEG was recorded continuously at a 500Hz rate with no online filters. Data were then bandpass filtered offline from 0.01 to 30 Hz (slope 24 dB) and re-referenced to the mean of the left and right mastoids. The continuous EEG was divided into epochs from 100 ms before to 1000 ms after target word onset, and epochs were baseline-corrected relative to the 100 ms pre- stimulus window. Epochs contaminated by artefacts were excluded from averages using a semi-automatic procedure available in the Brain Vision Analyser package and confirmed by visual inspection: epochs with amplitudes larger than ±70 Hz were automatically rejected, as were epochs where one or more channels registered slow sustained activity of ±100 Hz for longer than 200 ms. This resulted in a loss of approximately 8% of epochs per participant (Table 2). Remaining epochs were averaged per condition, participant, and electrode. ERPs were analyzed in three main time-windows: P2 (200-260 ms), N400 (300-500 ms), and PNP (500-700 ms). The P2 and N400 time windows were chosen based on the timing and topography in previous central presentation studies utilizing the same stimulus set (Dambacher et al., 2012). PNP time-windows were chosen based on timing and topography in previous central presentation studies (DeLong et al., 2014).

4.2 Results

4.2.1 Comprehension question accuracy

Performance on comprehension questions was near ceiling (mean = 83%; range: 68-94%), confirming that participants were attending to the task.

4.2.2 Event-related potentials

Consistent with prior research (Dambacher et al., 2012a), target words in all conditions elicited early sensory ERP components characteristic of visual stimuli (N1). The visual evoked potentials were followed by a positivity (P2) peaking around 250 ms that was larger (more positive) for low vs. high frequency conditions and larger for high vs. low predictability conditions, and a broadly distributed negativity peaking around 400 ms (N400) that was larger for low- vs. high-predictability conditions. In addition, an anterior late positivity effect which we refer to as post-N400 positivity (PNP) can be seen at anterior channels at approximately 500 - 700 ms for low compared to high predictability target words (see Figure 4.4 for N400 and PNP ERP results).

These effects were quantified using separate repeated-measures analyses of variance (ANOVAs) for each component, comparing mean amplitudes per experimental condition. Within-subject factors included word frequency (high, low), and context predictability (high, low). To assess the topographic distribution of the predictability and frequency effects, electrode locations were divided into three levels of anteriority (frontal, central, posterior) and two levels of laterality (left, right) (Figure 4.3). Where appropriate, Greenhouse-Geisser corrections and corrected p values are reported.

Time window	Factors	*F*-value	*p*-value	*η²*-value
P2	Pred	*F*(1,19) = 4.21	= .05	.022
(200-260 ms)	Pred*Freq*Lat	*F*(1,19) = 6.15	< .05 *	.002
	Pred*Freq*Lat*Ant	*F*(2,38) = 4.75	<.05 *	.001
N400	Pred	*F*(1,19) = 10.38	< .01 **	.066
(300-500 ms)	Pred*Freq	*F*(1,19) = 5.95	< .05 *	.019
	Pred*Ant	*F*(2,38) = 24.02	< .001 ***	.105
PNP	Pred	*F*(1,19) = 8.48	< .01 **	.046
(500-700 ms)	Pred*Freq	*F*(1,19) = 7.16	< .05 *	.007
	Pred*Ant	*F*(2,38) = 25.25	<.001 ***	.084

Table 4-3 ERP results. Repeated measures ANOVA results from P2, N400, and PNP time-windows for VF, predictability (Pred), frequency (Freq), laterality (Lat) and anteriority (Ant) factors. Greenhouse-Geisser corrected p values are reported for comparisons with more than one degree of freedom in the numerator.

4.2.3 P2: 200-260 ms

At the P2 time-window, we recorded a main effect of predictability, a significant three-way interaction between predictability, frequency and laterality and a significant four-way interaction between predictability, frequency, laterality and anteriority (Table 4-3). In order to investigate these higher order interactions, planned follow-up ANOVAs were conducted to analyze frequency and predictability effects within each anteriority and laterality condition.

Comparisons for predictability, frequency and laterality over the 3 anteriority conditions indicated that the predictability effect was significant over central ($F(1,19) = 6.06$, $p<.05$, $\eta^2 = 0.040$) and posterior sites ($F(1,19) = 4.88$, $p<.05$, $\eta^2 = 0.032$), while there was a significant predictability by frequency by hemisphere interaction over central ($F(1,19) = 6.84$, $p<.05$, $\eta^2 = 0.002$) and posterior sites ($F(1,19) = 9.31$, $p<.05$, $\eta^2 = 0.008$). As frontal sites showed no effects or interactions of hemisphere, and central and posterior sites showed very similar effects, further comparisons for each hemisphere condition were conducted over an average of both central and posterior sites. Those comparisons indicated a main effect of predictability over right hemisphere sites ($F(1,19) = 11.80$, $p<.01$, $\eta^2 = 0.076$) and no significant effects or interactions over left hemisphere sites. In all, highly predictable words (M = 1.02 µV) elicited more positive P2 amplitudes than less predictable words (M = 0.95 µV) over right hemisphere centro-posterior electrodes.

4.2.4 N400: 300-500 ms

As shown in Table 4-3, predictability and frequency both affected N400 amplitudes. The two-way interaction between predictability and frequency was significant as was the two-way interaction between predictability and anteriority. The interaction between frequency and predictability was led by a significant difference for low frequency words between high (M = 0.09 µV) and low predictability conditions (M = -1.29 µV). High frequency words did not elicit reliably different N400 amplitudes for high (M = -0.38 µV) and low (M = -0.80 µV) predictability conditions. In addition, the predictability by anteriority interaction indicated that the amplitude difference between high and low predictability conditions was largest over central and posterior sites, in line with the topography of the N400 effect.

4.2.5 Anterior post-N400 positivity (PNP): 500-700 ms

Over anterior sites there was a pronounced positivity for low, compared to high predictability conditions between 500 and 700 ms after stimulus onset as indexed by a predictability by anteriority interaction. Low predictability amplitudes (M = -0.22 µV) were reliably more positive than high predictability ones (M = -0.92 µV).

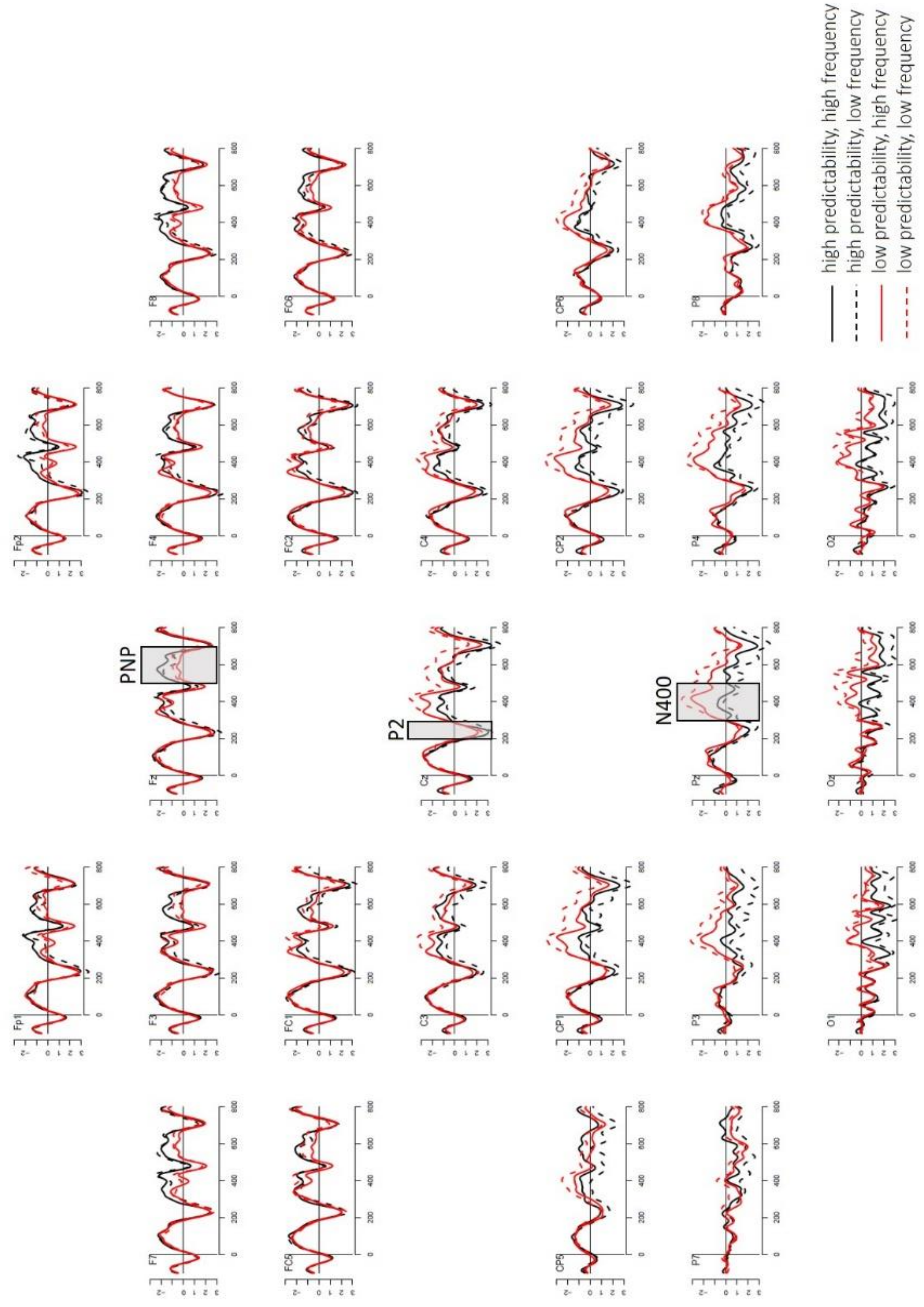

Figure 4.4 – P2, N400, and anterior PNP results. Grand average ERPs by condition for each electrode site. Gray shading indicates significant windows of interest.

4.3 Summary of results

The findings of Experiment 1 indicate that at near-normal reading rates predictability and frequency reliably interact only at N400 time-windows, unlike the results of Dambacher and colleagues (Dambacher et al., 2012a), which we set out to replicate. According to our data, sentential context predictability affected comprehension at word recognition time-windows (P2). Lexical frequency had no discernible effect on comprehension at the P2 time-window.

Frequency only interacted with predictability at N400 time-windows in that the semantic access (as indexed by the N400) of low frequency words was facilitated in high predictability contexts compared to low predictability contexts. The semantic access of high frequency words was equally easy in high and low predictability conditions. In other words, bottom-up processing seemed to affect target comprehension in context around 300-500 ms post stimulus presentation, in line with earlier findings indicating an N400 sensitivity to both bottom-up frequency and top-down predictability (Dambacher et al., 2006; Van Petten & Kutas, 1990b).

Later, at message-level integration (PNP) windows, unexpected continuations elicited larger processing difficulties regardless of their frequency of use in the lexicon. These results confirmed our expectations for the PNP time-window and previous findings indicating that plausible, but unexpected continuations usually elicit frontally distributed positivities (DeLong et al., 2014; Van Petten & Luka, 2012).

In all, participants benefitted from supporting sentential contexts overall and especially so when they had to access the meaning of a word that’s less frequent in the lexicon. Moreover, context predictability clearly affected message-level integration, facilitating plausible continuations’ integration in the overall sentential context when the word fitted previous expectations regardless of its overall frequency. Unfortunately, we found no indication that during time-windows earlier than 300 ms participants processed high and low frequency words differently in high and low predictability contexts. One potential reason for that might be the faster presentation rate we used, which might have put a higher demand on earlier processing windows, only leading to distinguishable effects at later stages.

Chapter 5

Hemispheric differences in frequency and predictability processing

The findings of Experiment 1 confirmed our expectations that high and low frequency words are processed differently depending on the predictability of the sentential context they appear in. Unlike previous findings, context affected word frequency processing only at the point of semantic access (N400 component) and not, as expected, at earlier windows. Results from early word recognition windows (P2 component) only reflected a sensitivity to context predictability. This implies that high and low frequency words were non-distinguishable at word recognition windows. Later N400 amplitudes indicated that participants utilized word frequency information only in situations where context provided insufficient clues as to the meaning of upcoming words. Following successful semantic access per PNP amplitudes, participants benefitted mainly from word predictability to integrate continuations in the overall sentential context.

Importantly, studies like Experiment 1, as well as previous central presentation research that did not investigate hemispheric differences present contradictory findings about the interactions between contextual predictability and lexical frequency information and their specific timing (Dambacher et al., 2012; Kim & Lai, 2012, and see Chapter 2 for further discussion). Such findings suggest that a divided visual field (DVF) study that manipulates lexical frequency could crucially reveal asymmetries in how predictability and frequency are coordinated during both early and later processing time-windows.

Therefore, the goal of Experiment 2 is to investigate how these two major sources of information (top-down predictability and bottom-up frequency) are coordinated in the cerebral hemispheres at the crucial phases of processing: word recognition, semantic access, and message-level integration. Our investigation is motivated by the findings of the PARLO framework (see Chapter 3 for a detailed description), which suggest that the brain may integrate lexical information and context-based expectations via multiple processing strategies, which are distributed differently across the two cerebral hemispheres (Federmeier, 2007; Wlotko & Federmeier, 2007, 2013). Evidence from ERP studies in support of the PARLO model suggests that context-based expectations affect bottom-up processing during the semantic access phase of word processing (N400) differently as a function of hemisphere of presentation: LH processing reflects stronger sensitivity to contextual factors and a top-down preactivation processing strategy, while RH processing shows no indication of a preactivating mechanism and a larger focus on bottom-up processing.

However, as previously discussed (Chapter 3), studies investigating the PARLO hypothesis have focused solely on top-down contextual manipulations, and have not directly manipulated factors related to bottom-up processing. This leaves open the question whether contextual predictability and word frequency interact when critical continuations are presented left or right of fixation, or whether the effects presented by PARLO are a function of hemispheric differences only in the top-down processing of contextual constraint or predictability. Additionally, if top-down predictability and bottom-up word frequency do interact reliably it is unclear at what time window and phase of processing at which these interactions take place. Based on the central presentation findings of Dambacher et al. (2012) we could expect that contextual predictability may affect word frequency processing fairly early. Based on our central presentation findings and PARLO results, however, it seems more likely that predictability and frequency should interact reliably during later semantic access and message-level integration windows of processing. Additionally, as mentioned above, it is unclear how this two-way interaction would unfurl for each hemisphere of presentation.

Experiment 2 seeks to address the following research questions: To what extent is lexical information such as word frequency processed similarly in both hemispheres? At what point during incremental processing does contextual information begin to interact with lexical information as a function of hemispheric presentation? How do these two sources of information influence comprehension during the three phases of interest in word processing?

To investigate these questions, we used the experimental design and materials as Experiment 1 to directly manipulate lexical frequency (high, low) and word predictability (high, low) using the same materials (Chapter 4). Differently from Experiment 1, stimuli were presented visually using the DVF technique, with target words presented to either the RVF/LH or LVF/RH. This resulted in a fully-crossed 2 (frequency) x 2 (predictability) x 2 (visual field) design. As dependent variables, following up from Experiment 1 and based on previous findings we selected the same three well-known ERP components that have been associated with each of the three word-processing phases: word recognition (P2), semantic access (N400), and message-level integration (anterior post-N400 positivity; PNP).

If both cerebral hemispheres initially process lexical information similarly, as assumed by the PARLO hypothesis, then the frequency manipulation should not elicit any hemispheric differences during the word recognition phase: in both hemispheres low frequency words should be harder to process, and therefore elicit smaller P2 amplitudes, than high frequency words (as reported for central presentation by Dambacher et al., 2012). In contrast, if lexical information is processed differently across hemispheres, then we expect to see differences in the P2 frequency effect, potentially indicating easier word recognition for RVF/LH-presented words (more pronounced P2 effect compared to LVF/RH-presented words).

With regard to word predictability both the PARLO model (Federmeier, 2007) and the results from Dambacher et al., (2012) indicate that frequency processing is influenced by word predictability. However, these accounts lead to different predictions as to when such an interaction should occur. According to the PARLO model, the interaction should be observed following RVF/LH presentation during the semantic access phase, as Federmeier and colleagues hypothesize LH top-down processing bias during semantic access or N400 time-windows as well as report no specific hemispheric sensitivity to predictability during earlier time-windows (Wlotko & Federmeier, 2007). Findings from the central presentation Experiment 1 also indicate that context predictability and word frequency interact during N400 time-windows while we found no earlier interactions. The results of Dambacher et al. (2012), however, contradict our findings and hypotheses based on the PARLO framework and indicate that frequency and predictability should interact during very early word recognition stages. Therefore, in Experiment 2, we tested for potential interactions between predictability and frequency processing for RVF/LH presented words during both P2 (word recognition) and N400 (semantic access) time-windows.

For LVF/RH processing, on the other hand, results from Federmeier and colleagues suggest that we should find a main effect of word predictability on N400 amplitudes during the semantic access phase, as RH has been reported to be sensitive to both word predictability in context and sentential constraint (Federmeier, 2007; Federmeier et al., 2005; Wlotko & Federmeier, 2007, 2013). In addition, if lexical frequency is processed similarly across the hemispheres, then we should see main effects of frequency for both RVF/LH and LVF/RH. If, however, the hemispheres process lexical frequency differently during the semantic access phase, we might see a main effect of frequency for LVF/RH only and an interaction between predictability and frequency for RVF/LH (as hypothesized by Federmeier and colleagues).

Finally, during message-level integration if contextual cues continue to bias LH processing as reported by DeLong and Kutas (2016), then we should find that low predictability words presented to the RVF/LH should be more difficult to integrate into the message-level representation than high predictability words. If so, this should result in an anterior PNP effect for low predictability conditions. In addition, the results from Thornhill and Van

Petten (2012) suggest that manipulating lexical processing through frequency may further modulate the anterior PNP predictability effect, such that low frequency words in low predictability conditions may elicit the largest message-level integration difficulties and therefore elicit the greatest PNP modulation.

5.1 Methods

5.1.1 Participants

Fifty-nine right-handed native speakers of German recruited from the Saarland University were compensated 15€ for their participation. All participants had normal or corrected-to-normal vision and reported no history of neurological disorders. Data from 19 participants were excluded due to excessive eye-movement artefacts,[11] leaving 40 participants in the final analysis (35 female; mean age: 23.6 years; range: 18-34).

5.1.2 Materials

As for Experiment 1 (Chapter 4) we used the Potsdam Sentence Corpus 3 (Dambacher et al., 2012a, 2009), which contains 144 German stimulus items (see Figure 4.2). Each item consisted of a target sentence frame, two possible context sentences, and two possible target words that differed in lexical frequency (high, low). Each context sentence acted as the high-predictability context for one target word and the low-predictability context for the other target word, resulting in four conditions per item: high predictability/high frequency, high predictability/low frequency, low predictability/high frequency, low predictability/low frequency. Target sentence frames were neutral such that they did not bias toward either target word. Therefore, the immediate context leading up to target

---

[11] Due to the lateralized presentation of target words, DVF studies tend to elicit more eye-movement artefacts than the standard central-presentation technique typically used in ERP studies, leading to higher rejection rates.

words remained identical across conditions, minimizing potential baseline differences for ERPs time-locked to the target word. All target words were sentence-medial, preceded by at least 5 words and followed by at least 2 words. Table 1 summarizes the lexical frequency and cloze probability of target words across conditions as reported in (Dambacher et al., 2012, Table 2, p. 1855). Because target words were presented to either the LH or RH, a total of 8 counterbalanced lists with 144 trials each were constructed from these materials, such that each participant saw only one item per condition, but no item occurred more than once per list.

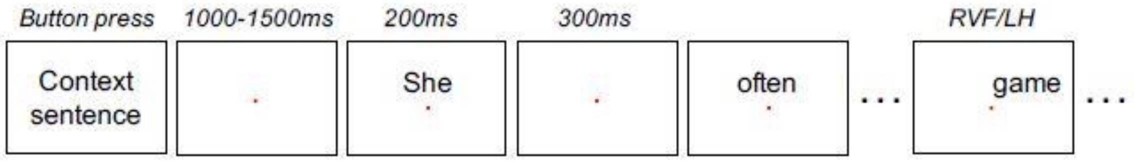

Figure 5.1– Procedure and timings. Context sentence remained on the screen until a button was pressed and was followed by a variable 1000-1500 ms pause. Each word of the target sentence was presented for 200 ms, interspersed with 300 ms inter-stimulus intervals. Target words were presented parafoveally, left or right of fixation and a small red dot was kept constantly in the middle of the screen to aid fixation.

5.1.3 Procedure

Participants were randomly assigned to a stimulus list and seated 60 cm from a 24” TFT monitor (resolution: 1920 x 1200; refresh rate: 75 Hz) in a sound-attenuated, electrically-shielded chamber. Stimuli were presented in black font on white background in 18 pt Courier New using E-prime (Schneider et al., 2002) and participants were instructed to read for comprehension. Context sentences appeared in their entirety and remained on screen until participants pressed a button to continue. Following a random duration pause (1000-1500 ms), target sentences were presented word-by-word in the center of the screen via rapid serial visual presentation (RSVP): 200 ms per word, 300 ms inter-stimulus interval (Figure 2). Fixation during RSVP was aided by a red fixation dot, presented at 0.5° below the center of the screen.

Target words were presented parafoveally, left or right of fixation, spanning no more than 5◦ visual angle and with their inner edge 2° from fixation. To limit anticipatory eye-movements, presentation side was pseudorandomized. Following previous DVF work (Bourne, 2006), target words were presented for only 200 ms in order to ensure that no eye-movements could be attempted during word processing.[12] Participants were instructed to maintain fixation and to avoid blinking throughout the target sentence. To confirm that participants were attending to the task, one third of the trials were followed by a Yes/No comprehension question, which did not relate to the target word. Participants responded via button press; the position of Yes/No buttons was counterbalanced across participants. Feedback was provided during a 10-item practice session (not analyzed), but no feedback was given during experimental trials. Upon answering the comprehension question, the next trial was initiated. Items were separated into three blocks, with a short break provided between blocks. Total time on task was approximately 45 minutes.

5.1.4 EEG recording and processing

Data were recorded at 26 scalp sites (Figure 3: Fp1/2; F7/3/z/4/8; Fc5/1/2/6; C3/z/4; Cp5/1/2/6; P7/3/z/4/8; O1/z/2) according to the 10-20 system (Klem et al., 1958) using active Ag/AgCl electrodes, embedded in a 32-channel elastic cap (actiCAP, Brain Products GmbH, Germany). Impedances were kept below 5kΩ. Horizontal eye-movements were monitored by placing electrodes at the outer canthi of each eye. Vertical eye-movements were monitored by placing electrodes above and below the left eye. EEG was recorded continuously at a 500Hz rate with no online filters. Data were then bandpass filtered offline from 0.01 to 30 Hz (slope 24 dB) and re-referenced to the mean of the left and right mastoids. The continuous EEG was divided into epochs from 100 ms before to 1000

---

[12] This duration is less than the average time required for a saccade (Sereno, 2003).

ms after target word onset, and epochs were baseline-corrected relative to the 100 ms pre- stimulus window. Epochs contaminated by artefacts were excluded from averages using a semi-automatic procedure available in the Brain Vision Analyser package and confirmed by visual inspection: epochs with amplitudes larger than ±70 Hz were automatically rejected, as were epochs where one or more channels registered slow sustained activity of ±100 Hz for longer than 200 ms. This resulted in a loss of approximately 8% of epochs per participant (Table 5-1). Remaining epochs were averaged per condition, participant, and electrode. ERPs were analyzed in three main time-windows: P2 (230-290 ms), N400 (300-500 ms), and PNP (700-1100 ms). The P2 time window was chosen based on the timing and topography of P2 effects in previous central presentation studies utilizing the same stimulus set (Dambacher et al., 2012) and visual inspection. N400 and PNP time-windows were chosen based on the timing and topography for N400 and PNP effects in previous DVF literature (e.g. Wlotko and Federmeier, 2013; DeLong and Kutas, 2016).

	RVF/LH	**LVF/RH**
Low frequency, low predictability	9.58% (SD 8.44%)	5.28% (SD 7.11%)
Low frequency, high predictability	8.61% (SD 9.90%)	8.47% (SD 7.44%)
High frequency, low predictability	9.58% (SD 8.72%)	6.94% (SD 7.83%)
High frequency, high predictability	9.03% (SD 9.04%)	6.94% (SD 8.06%)

Table 5-1 Artifact rejection. Average percentages of discarded items due to blinks, eye movements, muscle noise or slow sustained electrical activity per condition

5.2 Results

5.2.1 Comprehension question accuracy

Performance on comprehension questions was near ceiling (mean = 94%; range: 84-98%), confirming that participants were attending to the task.

5.2.2 Event-related potentials

Consistent with prior DVF studies (Wlotko & Federmeier, 2013), target words in all conditions elicited early sensory ERP components characteristic of visual stimuli (N1) and a sustained parietal negativity (selection negativity), which both appeared larger and earlier over sites contralateral to presentation side (Figure 5.2). The visual evoked potentials were followed by a positivity (P2) peaking around 250 ms and a broadly distributed negativity peaking around 400 ms (N400) that was larger for low- vs. high-frequency conditions, as well as larger for low- vs. high-predictability conditions. In addition, visual inspection indicates a post-N400 positivity (PNP) effect at anterior channels starting at approximately 700 ms for target words presented to RVF/LH (see for N400 and PNP ERP results).

These effects were quantified using separate repeated-measures analyses of variance (ANOVAs) for each component, comparing mean amplitudes per experimental condition. Within-subject factors included word frequency (high, low), predictability (high, low), and VF (left, right). To assess the topographic distribution of the predictability and frequency effects, electrode locations were divided into three levels of anteriority (frontal, central, posterior) and two levels of laterality (left, right) (Figure 4.3). Where appropriate, Greenhouse-Geisser corrections and corrected p and ε values are reported. Only statistical results with p <.05 are reported.

5.2.3 DVF presentation effects

Before analyzing the critical time windows, we first confirmed that the DVF manipulation resulted in initial processing by the contralateral hemisphere. Mean amplitudes of the N1 component (170-230 ms) and the selection negativity (300-1200 ms) were submitted to separate VF (left, right) and hemisphere (left, right) ANOVAs at 10 non-midline posterior channels (LH: CP5, CP1, P3, P7, O1; RH: CP6, CP2, P4, P8, O2) where these DVF effects are the largest. A reliable VF * hemisphere interaction was found for both components [N1: F(1,39)=53.04, p <.001, η2 = .097; selection negativity: F(1,39) = 58.58, p <.001, η2 = .049], indicating that the DVF paradigm successfully shifted the balance of processing to the hemisphere contralateral to the visual-field of presentation (Figure 5.2).

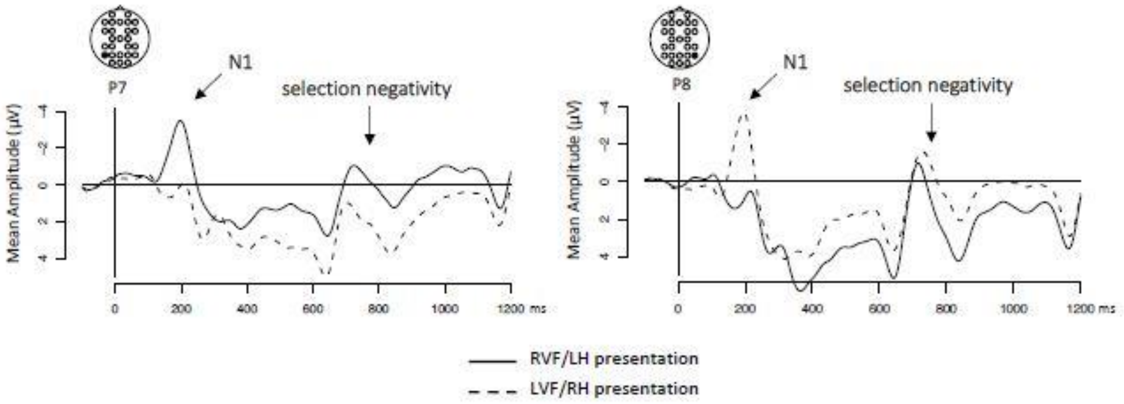

Figure 5.2– Effects of DVF presentation. The N1 component and the selection negativity are both larger over contralateral electrodes, indicating that the DVF paradigm worked as intended to selectively stimulate the contralateral hemisphere.

5.2.4 P2 (230-290 ms)

Repeated-measures ANOVAs in the P2 time-window revealed no significant main effects or interactions.

5.2.5 N400 (300-500 ms)

Figure 5.3 shows that predictability, frequency and the VF of presentation each exerted an influence on ERPs during the N400 time window. This was reflected in multiple three-way interactions (Table 5-2). In order to investigate these higher order interactions, we conducted planned follow-up ANOVAs to analyze frequency and predictability effects within LVF and RVF subsets of the data.

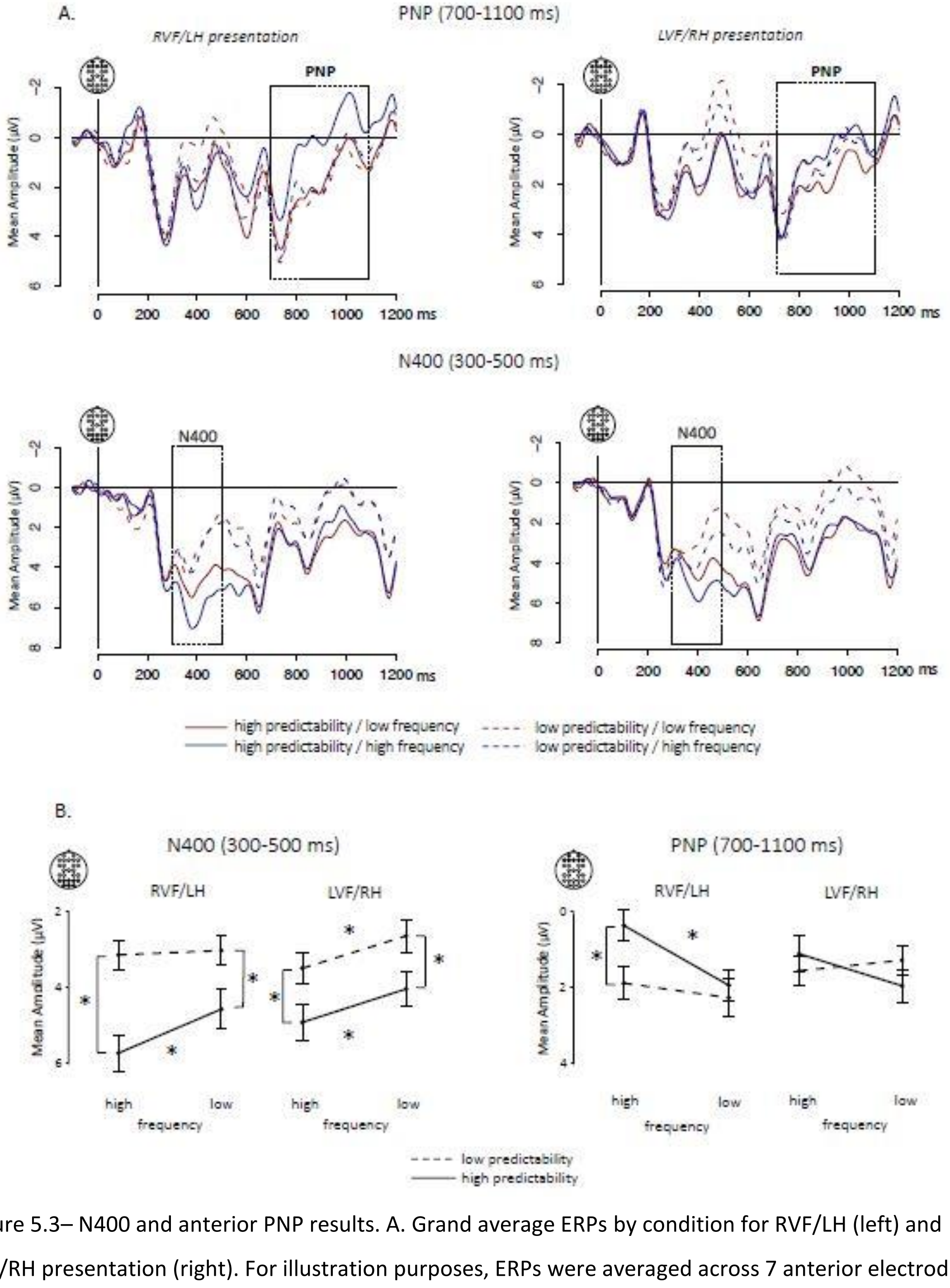

Figure 5.3– N400 and anterior PNP results. A. Grand average ERPs by condition for RVF/LH (left) and LVF/RH presentation (right). For illustration purposes, ERPs were averaged across 7 anterior electrodes (as indicated in black on electrode map) for PNP time windows (upper panel) and averaged across 8 posterior electrodes (indicated in black on electrode map) for N400 time-windows (lower panel). B. Interaction plots for high and low frequency and high and low predictability conditions.

Time window	Factors	*F*-value	*p*-value	η^2-value
N400 (300-500 ms)	Pred	*F*(1,39) = 37.70	< .001 ***	.066
	Freq	*F*(1,39) = 10.61	<.01 **	.011
	Lat	*F*(1,39) = 16.06	<.001 ***	.007
	Ant	*F*(2,78) = 42.05	<.001 ***	.130
	VF*Lat	*F*(1,39) = 6.43	<.05 *	.003
	Pred*Ant	*F*(2,78) = 10.24	<.001 ***	.004
	VF*Pred*Ant	*F*(2,78) = 3.83	<.05 *	.001
	Pred*Freq*Ant	*F*(2,78) = 3.92	<.05 *	.001
	VF*Lat*Ant	*F*(2,78) = 14.03	<.001 ***	.002
	Pred*Lat*Ant	*F*(2,78) = 6.33	<.01 **	< .001
PNP (700-1100 ms)	Pred	*F*(1,39) = 5.10	<.05 *	.005
	Freq	*F*(1,39) = 10.61	<.01 **	.011
	VF*Freq	*F*(1,39) = 4.25	<.05 *	.004
	Pred*Freq	*F*(1,39) = 9.65	<.01 **	.009
	VF*Lat	*F*(1,39) = 45.88	<.001 ***	.009
	Pred*Lat	*F*(1,39) = 6.65	<.05 *	.001
	Pred*Ant	*F*(2,78) = 27.67	<.001 ***	.020
	Freq*Ant	*F*(2,78) = 3.67	.06	.002
	VF*Lat*Ant	*F*(2,78) = 88.04	<.001 ***	.009

Table 5-2 ERP results. Repeated measures ANOVA results from N400 and PNP time-windows for VF, predictability (Pred), frequency (Freq), laterality (Lat) and anteriority (Ant) factors. Greenhouse-Geisser corrected p values are reported for comparisons with more than one degree of freedom in the numerator.

5.2.5.1 N400: RVF/LH presentation

Table 5-3 indicates that for words presented to the RVF/LH, both frequency and predictability exhibited main effects in the expected directions: low frequency words (M = 4.46 µV) elicited more negative N400 amplitudes than high frequency words (M = 5.65

µV) and low predictability words (M = 0.86 µV) were more negative than high predictability words (M = 2.63 µV). However, the difference in amplitude between low and high frequency words was larger in high predictability contexts and larger over right posterior electrode sites, leading to a significant frequency * predictability * anteriority interaction.

5.2.5.2 N400: LVF/RH presentation

Target words presented to the LVF/RH also showed main effects of predictability and frequency in the expected direction: low frequency conditions (M = 1.69 µV) were more negative than high frequency conditions (M = 2.33 µV), and low predictability conditions (M = 1.18 µV) were more negative than high predictability conditions (M = 2.84 µV). However, in contrast to RVF/LH presentation, no interaction between the two factors was found (see Table 5-3 and Figure 5.3)

5.2.6 Post-N400 positivity (700-1100 ms)

Statistical analyses revealed multiple interactions during the PNP time window (Table 5-2). Consistent with the typical scalp distribution and timing of PNP effects, low predictability conditions were more positive over anterior electrode sites (and more negative at posterior sites) than high predictability conditions. In order to investigate the interactions at frontal sites, we conducted planned follow-up ANOVAs to analyze frequency and predictability effects within LVF and RVF subsets of the data, using anterior electrodes only.

Time window	**VF**	**Factors**	***F*-value**	***p*-value**	**η^2-value**
N400 (300-500 ms)	RVF/LH	Pred	*F*(1,39) = 31.86	< .001 ***	.073
LoPred > HiPred		Freq	*F*(1,39) = 12.01	<.01 **	.012
LoFreq > HiFreq		Ant	*F*(2,78) = 31.79	<.001 ***	.124
		Lat	*F*(1,39) = 22.11	<.001 ***	.012
		Pred*Ant	*F*(1,39) = 11.00	<.001 ***	.010
		Ant*Lat	*F*(2,78) = 13.33	<.001 ***	.003
		Freq*Pred*Ant	*F*(2,78) = 6.28	<.05 *	.003
		Pred *Ant*Lat	*F*(2,78) = 2.78	<.05 *	< .001
LoPred > HiPred	LVF/RH	Pred	*F*(1,39) = 21.42	<.001 ***	.059
LoFreq > HiFreq		Freq	*F*(1,39) = 5.08	<.05 *	.009
		Ant	*F*(2,78) = 47.50	<.001 ***	.136
		Ant*Lat	*F*(2,78) = 4.11	<.05 *	.002
PNP (700-1100 ms)	RVF/LH	Pred	*F*(1,39) = 6.11	<.05 *	.027
anterior electrodes		Freq	*F*(1,39) = 9.24	<.01 **	.031
HiPred > LoPred		Pred*Freq	*F*(1,39) = 4.08	.05 *	.012
	LVF/RH		all *F*s < 1	n.s.	

Table 5-3 ERP results by VF. Predictability (Pred), frequency (Freq), anteriority (Ant) and laterality (Lat) effects and interactions within each visual field of presentation for P2, N400, and PNP time windows. LoFreq: low frequency, HiFreq: high frequency, LoPred: low predictability, HiPred: high predictability. Greenhouse-Geisser corrected p values are reported for comparisons with more than one degree of freedom in the numerator.

5.2.6.1 PNP: RVF/LH presentation

Figure 5.3 A shows that for RVF/LH-presented stimuli, words that were both high predictability and high frequency elicited less positive PNP amplitudes (M = 0.31 µV) than the other three conditions, which did not differ from each other (low predictability/high frequency: M = 1.84 µV, high predictability/low frequency M = 1.90 µV, and low predictability/low frequency M = 2.22 µV). This was reflected in a marginal predictability by frequency interaction (p=.05).

5.2.6.2 PNP: LVF/RH presentation

No main effects or interactions were found for LVF/RH-presented words (Table 5-3).

5.3 Summary of results

The findings of Experiment 2 continued to support hypotheses for later interactions between context predictability and word frequency and showed no indication of a P2 sensitivity to either of the factors when words were presented laterally to the LVF or RVF.

Of most relevance to the current work were the findings of the N400 time-window. Words, presented to the LH elicited different N400 amplitudes as a function of both their frequency and the predictability of the context they appeared in. High frequency words benefitted more from contextual support in high predictability conditions than low frequency words did. Alternatively, for words presented to the RH frequency and predictability had independent effects. High frequency words in both predictability conditions had a processing boost, as well as words in supporting contexts regardless of their frequency.

During message-level integration, only PNP components following LH-presented stimuli exhibited a sensitivity to contextual predictability, while RH-presented words did not elicit distinguishable PNP effects. Low predictability continuations elicited larger frontal PNP amplitudes compared to high predictability continuations regardless of their lexical frequency. The fact that frequency did not affect message-level integration was in line with Experiment 1 and previous findings that bottom-up frequency rarely affects processing stages after semantic access (N400). Similarly, our results extend PARLO findings in that contextual predictability only elicited reliable amplitude modulations to continuations presented to the LH, in support of the hypothesis that top-down predictability continues to facilitate LH word comprehension overall and its integration in the overall sentential message.

Results from neither Experiment 1, nor Experiment 2 led to a confirmation of Dambacher et al's (2012) findings of an early interaction between contextual predictability and target word frequency. It appears that even though there are indications of a P2 main effect of predictability following central presentation, the effect did not reach significance when words were presented laterally, indicating that foveation/hemispheric cooperation may be necessary for early perception-related processing. Our findings are, however, in line with PARLO-based expectations: N400 patterns to LH-presented words reflected larger sensitivity to contextual predictability above any facilitation they received from general lexical frequency. N400 patterns of RH-presented words indicated versatile facilitation as a result of both high lexical frequency and high sentential predictability, but no indication of a focus on a specific subset of words, based on previous context in the same way as LH processing patterns. In confirmation of these conclusions, PNP findings also support the theory that LH-presented continuations are not only accessed, but also integrated in the general context based on their predictability, while no such differences were recorded in the PNP time-window for RH-presented words.

Chapter 6

The time-course of (pseudo)word form access and integration

The findings of Experiments 1 and 2 indicated that contextual predictability affects bottom-up word frequency processing both for centrally and laterally presented continuations. The interactions between the two factors were reliably recorded during semantic access over the N400 time-windows. More specifically, using the DVF paradigm, we were able to ascertain that predictability interacts with word frequency for words presented initially to the RVF or the LH: low frequency words received a processing boost in high predictability conditions only. N400 amplitudes to RH-presented words indicated that predictability and frequency have additive influence to RH semantic access.

Additionally, we were able to determine that during central presentation top-down predictability influenced word processing fairly early on, namely during word recognition stages (P2). Lateralized presentation seemed to disrupt this early effect, leading us to the conclusion that participants might show the effect only when words are presented to the fovea.

And finally, message-level integration results indicated that plausible but unexpected continuations led to more difficulties with processing regardless of their frequency. PNP amplitudes to lateralized stimuli reflected that only LH-presented words elicited difficulties with integration in a previous context. This led us to the overall conclusion that even though both hemispheres were sensitive to both top-down and bottom-up manipulations, but only results to LH-presented stimuli reflected a focus on predictive processing as well as a tendency to narrow down the set of potential continuations based on both frequency and predictability.

The next two chapters will focus on extending these conclusions as well as the hypotheses posited by PARLO by manipulating a factor that requires a different focus on bottom-up processing than lexical frequency, namely word status. The distinction between words and pseudowords has been reported to occur earlier than lexical frequency effects for both single item processing (O Hauk, Davis, Ford, Pulvermüller, & Marslen-Wilson, 2006) and in-context processing (Kim & Lai, 2012). ERP investigations of the word status effect usually focus on the N170 as an index of successful distinction (see Section 2.2), while as reported by Experiment 1 and previous investigations (Dambacher et al., 2006; Olaf Hauk & Pulvermüller, 2004; Van Petten & Kutas, 1990a), lexical frequency affects ERP amplitudes at 200 ms after stimulus onset, as measured by the P2 component (see Section 2.3).

In that sense, manipulating word status gives us the opportunity to investigate the effect of context on even lower bottom-up processing levels. Our first two experiments allowed us to conclude that high predictability contexts facilitate access to a specific high frequency word form and, to a lesser extent, to low frequency ones. Would context help participants make sense of word forms that they haven't seen before and can't anticipate? If so, when should the effect of predictability over word status emerge: during word recognition or later during semantic access and message-level integration?

Previous findings (Kim & Lai, 2012) show some indication that context (*She measured the flour so she could bake a*) affects words (*cake*), supported and unsupported pseudowords (*ceke*/*tont*) and unpronounceable nonwords (*srdt*) differently over N400 and P600 time-windows, but not over N170 time-windows. Unfortunately, the authors did not manipulate contextual support orthogonally to word status (all words are contextually supported, pseudowords appear in both supported and unsupported conditions). Other investigations of the effect of context over misspellings (one can treat *ceke* as a misspelling of *cake*) report no N400 interactions, but a P600 interaction, such that misspellings in high predictability contexts elicit larger P600 effects than misspellings in low predictability contexts (van de Meerendonk et al., 2011).

Experiment 3 sets out to extend the findings of our Experiment 1, as well as replicate the results of Kim and Lai and van de Meerendonk and colleagues. We used the high frequency target words from Experiment 1 and modified them to create the pseudoword/misspelling condition. Our goal was to investigate whether sentential context facilitates processing even when the input is not just infrequent in the lexicon, but only resembles existing entries. More specifically, we set out to establish whether our participants relied on context to the point of treating the pseudoword targets as resembling real words which extend the meaning of the sentence, in which case they should elicit an N400 effect during the semantic access time-window, similarly to word targets and in line with the findings of Kim and Lai (2012). If the pseudoword targets are treated as mistakes, participants may not attempt to search for the adjacent words in their lexicons, but might instead try to address the discrepancy as an issue with the overall message-level integration of the pseudoword continuations, resulting in larger P600 effects in line with the findings of van de Meerendonk et al. (2011).

In all, the most important goal of Experiment 3 is to find out how and when top-down predictability facilitates bottom-up word status, extending the interaction findings from Experiment 1 where predictability facilitated the semantic access of low frequency words. We focus on the same three processing stages of interest as in the previous chapters, namely word recognition (here reflected by the N170 component), semantic access (N400), and message-level integration (late positivities, PNP and P600).

6.1 Methods

6.1.1 Participants

Twenty-four right-handed native speakers of German participated in the study and were paid 15 euro. All participants had normal or corrected-to-normal vision (they were instructed to wear glasses instead of contact lenses to minimize blink artefacts) and none reported a history of neurological disorders. Data of 4 participants were excluded due to excessive eye-movement artefacts. This left for analysis the data of 20 participants (15 female) with mean age of 23.2 years and age range 19 - 33 years. All participants signed written consent forms, were informed they can cease participation at any point, and reported no knowledge of the purpose of the experiment after participation (all were debriefed).

	% rejected (SD)
Low predictability word	6.67% (SD 9.94%)
High predictability word	5.28% (SD 8.25%)
Low predictability pseudoword	6.53% (SD 7.87%)
High predictability pseudoword	6.53% (SD 8.37%)

Table 6-1 Artifact rejection. Average percentages of discarded items per condition due to blinks, eye movements, muscle noise or slow sustained electrical activity.

6.1.2 Materials

In order to create the stimuli for our experiment we modified the 144 high frequency target words from the Potsdam Sentence Corpus 3 (Dambacher et al., 2012a, 2009) to create 144 pronounceable pseudowords that resembled the original target words in form. We created the pseudowords by replacing one letter (mostly medial) of the original target word with a visually similar letter, in order to create a pronounceable, orthographically similar to the target, but illegal in German, pseudoword. The pseudoword stimuli were created by a native German speaker who took specific care the stimuli did not resemble common words in other similar languages (e.g. English, Dutch), or dialects of German (especially the local dialect and dialects of nearby regions) and that they could follow morpho-syntactic rules as a member of the same category as the target word (same number, gender, word class type.).

HP: Caroline liked to spend her time playing chess or checkers.

LP: Caroline liked to look at pictures from her childhood.

She often took a ***game/geme*** from the shelf and opened it.

Figure 6.1– Word and pseudoword stimuli. High frequency words from the Potsdam Sentence Corpus 3 were transformed by replacing a medial letter with another visually similar one, to create the pseudoword items.

6.1.3 Procedure

6.1.4 EEG recording and processing

Data recording and processing protocols were the same as Experiment 1. Artefact discarding procedures resulted in a loss of approximately 5% of epochs per participant (Table 6-1). Remaining epochs were averaged per condition, participant, and electrode. ERPs were analyzed in three main time-windows: N170 (160-230 ms), N400 (300-500 ms), and LP (500-900 ms). The N170 analysis was based on the timing and topography of N170 effects in similar pseudoword studies (O Hauk et al., 2012; Kim & Lai, 2012) as well as visual inspection of the N170 effect in the current experiment. N400 time-windows were chosen based on the timing and topography for N400 in previous literature (Kutas & Federmeier, 2011). LP effects were measured over the same frontal (PNP) and posterior (P600) sites as previous studies (DeLong et al., 2014; Van Petten & Luka, 2012), but as the timing of the LP effect seems to vary in previous literature (partially depending on the amplitude and size of the area under any preceding N400 effects), we relied on visual inspection when establishing the frontal and posterior LP time-windows.

6.2 Results

6.2.1 Comprehension question accuracy

Performance on comprehension questions was near ceiling (mean = 96%; range: 79-100%), confirming that participants were attending to the task.

6.2.2 Event-related potentials

The current ERP effects were quantified using separate repeated-measures analyses of variance (ANOVAs) for each time window, comparing mean amplitudes per channel, participant, and experimental condition. Within-subject factors included word status (word, pseudoword) and predictability (high, low). To infer the general distribution of the predictability and words status effects, we arranged electrode locations in two additional factors: anteriority with 3 levels - frontal, central, and posterior and laterality with 2 levels: left and right (in line with the previous experiments in the thesis). Time windows for each component of interest were selected based on previous literature. Where appropriate, Greenhouse-Geisser corrections and corrected p and ε values are reported. Only statistical results with $p < .05$ are reported.

Time window	**Factors**	***F*-value**	***p*-value**	**η^2-value**
N2 (160-230 ms)	Word	*F*(1,19) = 5.49	<.05 *	.009
	Word*Ante	*F*(2,38) = 6.71	<.05 *	.006
N400 (300-500 ms)	Pred	*F*(1,19) = 16.01	< .001 ***	.059
	Word	*F*(1,19) = 10.58	<.01 **	.049
	Word*Lat	*F*(1,19) = 4.55	<.05 *	.004
	Pred*Ant	*F*(2,38) = 29.49	< .001 ***	.048
	Word*Ant	*F*(2,38) = 14.14	< .001 ***	.025
	Pred*Word*Ant	*F*(2,38) = 3.62	.06	.005
PNP (500-900 ms)	Word	*F*(1,19) = 15.17	<.001 ***	.109
	Pred*Lat	*F*(1,19) = 6.70	<.05 *	.002
	Pred*Ant	*F*(2,38) = 21.17	<.001 ***	.030
	Word*Ant	*F*(2,38) = 17.79	<.001 ***	.058

Table 6-2 ERP results. Repeated measures ANOVA results from N170, N400, and PNP time-windows for predictability (Pred), word status (Word), laterality (Lat) and anteriority (Ant) factors. Greenhouse-Geisser corrected p values are reported for comparisons with >1 degree of freedom in the numerator.

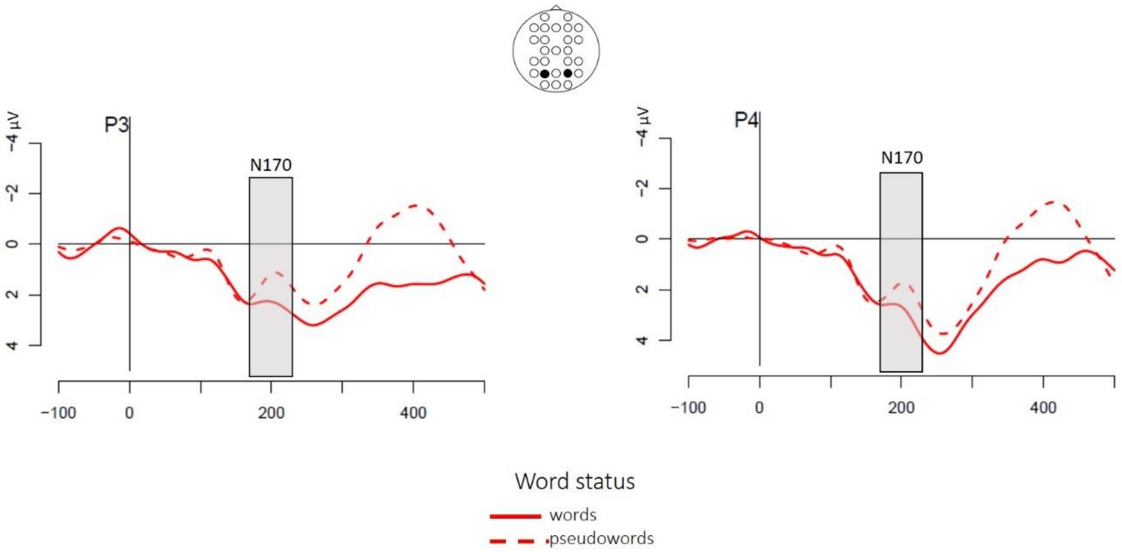

Figure 6.2– Word status effect as reflected by the N170 component. Grand average ERPs by condition over P3 and P4 electrode sites (as indicated in black on the electrode map above). Gray squares indicate time-windows of interest.

6.2.3 N170: 160-230 ms

An ANOVA with predictability (high, low), word status (word, pseudoword), anteriority (frontal, central, posterior), and laterality (left, right) as factors yielded a main effect of word status as well as a significant word status by anteriority interaction. Based on pairwise comparisons for words vs pseudowords within each anteriority condition we concluded that pseudowords (M = 0.93 µV) were reliably more negative than words (M = 1.41 µV) averaged across central and posterior sites, in line with the usual topography of the word status N170 effect (Kim & Lai, 2012).

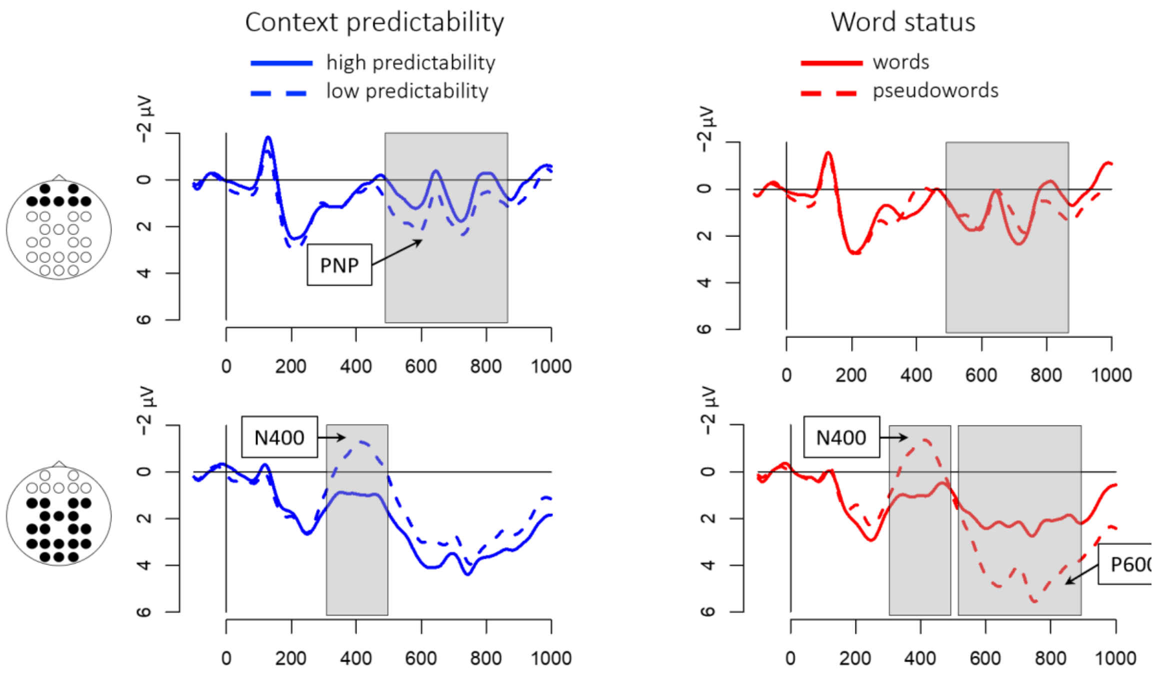

Figure 6.3– N400 and late positivity results. Grand average ERPs by condition for context predictability (left) and word status (right). For illustration purposes ERPs in the upper two panels were averaged across 7 anterior electrodes (as indicated in black on the electrode map) while the lower two panels were averaged across 19 central and posterior electrodes (indicated in black on the electrode map). Gray squares indicate time-windows of interest, while boxes and arrows point out significant effects.

6.2.4 N400: 300-500 ms

As shown by Figure 6.3, predictability and word status both affected N400 amplitudes. To investigate the topography of the word status and predictability effects we performed separate ANOVAs for each level of anteriority, which indicated that the two main effects of predictability and word status were strongest over central and posterior sites. Low predictability conditions (M = -0.72 µV) were more negative than high predictability conditions (M = 1.06 µV) and pseudowords (M = -0.58 µV) were more negative than words (M = 0.91 µV).

6.2.5 Late positivities (LP): 500-900 ms

In the LP time window, we observed a main effect of word status and three two-way interactions: (Table 6-2). The scalp distribution of the late positivities differed over frontal and centro-posterior sites. Over frontal electrodes, there was a main effect of predictability such that low predictability conditions (M = 1.26 µV) exhibited more positive amplitudes than high predictability ones (M = 0.49 µV), in line with the topography of a frontal post-N400 positivity (PNP).

Over central and posterior sites, there was a main effect of word status such that pseudowords elicited more positive amplitudes (M = 4.52 µV) compared to words (M = 2.16 µV) in line with the topography of a posterior P600 positivity.

In addition to the posterior LP (P600) word status effect, posterior amplitudes reflected a prolonged weaker effect of predictability following the preceding N400 effect (see the lower left quadrant of Figure 6.3) where high predictability conditions (M = 3.80 µV) were more positive than low predictability ones (M = 2.89 µV).

6.3 Summary of results

In Experiment 3 we manipulated word status (bottom-up) and predictability (top-down) following Experiment 1 where bottom-up processing was operationalized through word frequency. Unlike Experiment 1, word status and predictability did not interact at either of the levels of processing of interest (word recognition, semantic access or message-level integration). This led us to the conclusion that participants did not require the help of contextual support to recognize or access our pseudowords, nor did they have additional difficulties integrating pseudoword continuations into low predictability sentences as opposed to word continuations.

Still of significance, participants distinguished between words and pseudowords as early as 160 ms after initial presentation, in line with the timing of previous N170 markers of word recognition (O Hauk et al., 2006; Kim & Lai, 2012; Maurer, Brandeis, & McCandliss, 2005). Predictability, however, did not affect word recognition. It’s important to point out that the timing of word recognition shifted at 160 ms for Experiment 3 (N170), as opposed to 200 ms for Experiment 1 and 230 ms for Experiment 3 (P2). We speculate that the shift in timing has to do with the type of processing required to distinguish a word from a pseudoword (or a misspelled variant of a word) vs a high from a low frequency legal word form (see Section Chapter 88.2 for further discussion).

During semantic access, both word status and predictability affected processing, but the two factors did not interact. In line with previous findings, the N400 amplitude was reliably sensitive to both word status (Kim & Lai, 2012; Laszlo & Federmeier, 2007a) as well as predictability (Marta Kutas & Federmeier, 2011). Unlike Experiment 1, predictability did not modify bottom-up word status processing.

However, frontal PNP amplitudes reflected a main effect of top-down predictability, very much in line with our previous results. Low predictability conditions elicited larger positivities over prefrontal and frontal sites following the N400 modulations (500-900 ms). During the same time-window and over posterior electrode sites, we recorded a P600 LP effect of word status, where pseudowords elicited larger positive amplitudes than words.

In all, the results of Experiment 3 indicate that word status and predictability are processed independently over all time-windows of interest. Moreover, during LP message-level integration windows we were able to record a spatial distinction between the bottom-up (posterior P600) and the top-down (anterior PNP) factors, suggesting a distinction between the two types a processing (DeLong & Kutas, 2020; DeLong et al., 2014; Van Petten & Luka, 2012).

Chapter 7

Hemispheric asymmetries in (pseudo)word recognition in context

According to the results of Experiment 3, participants did not need to rely on contextual support to be able to semantically access the expected meaning of sentential continuations even when these continuations did not exist in the lexicon, but strongly resembled existing words. Crucially, they had no issue integrating predictable continuations in the overall sentential message (in line with DeLong et al., 2014), while at the same time reanalyzing and potentially correcting the dissimilarities of the pseudoword continuations (in line with van de Meerendonk et al., 2011). The two processes were separated topographically and reflected by two different late positivity components, an anterior PNP and a posterior P600 respectively.

These results were not in line with the findings of our Experiment 1, which manipulated top-down predictability and bottom-up word frequency and indicated that readers do take benefit from supporting contexts when accessing word forms of different lexical frequency (as evidenced by the predictability by frequency interaction recorded in the N400 time-window). One explanation of the findings can be that the pseudoword stimuli were not so hart to process as to require contextual facilitation for participants to be able to access the intended meaning.

However, another explanation could be that different hemispheres contributed differently to the results. As Experiment 2 and previous literature (Wlotko & Federmeier,

2013) indicated, central presentation results do not always represent an average of the overall processes contributed by each hemisphere. Despite lack of evidence for hemispheric differences in early word recognition stages, the findings of Experiment 2 indicate that during semantic access (N400) for LH-presented stimuli, top-down context predictability interacts with bottom-up lexical frequency. If LH processing benefits from top-down interactions with any kind of bottom-up lexical information, such as frequency or, in the case of the current Experiment, word status, then we should see this reflected in the ERP amplitudes during the same time-windows as Experiment 2 (N400). With regard to RH processing during N400 time-windows, we expect additive effects of word status and contextual predictability.

We have little previous data on which to base our predictions for hemispheric differences during message-level integration. The results of Experiment 3 indicated that even though predictability and word status didn't interact, they affected ERP amplitudes over different electrode sites, such that word status elicited a posterior P600 modulation, while predictability affected anterior PNP amplitudes. To our knowledge, no P600 hemispheric differences with regard to word status or lexical processing have been reported so far. In case of an overall bottom-up focus for RH processing mechanisms, we may expect a RH-lateralized P600 modulation. With regard to anterior PNP modulations, our results from Experiment 2, as well as previous findings (DeLong & Kutas, 2016) indicate that the anterior PNP should be sensitive to predictability for LH-presented words only.

Therefore, the current and last experiment of the thesis will build upon the previous three and address questions so far unanswered by the literature. Namely, what is the contribution of each hemisphere to unreliable input comprehension? Does the LH context-based spotlight strategy apply to corrupted input? Or does the LH spotlight mechanism apply only to semantic access (N400) and integration (PNP) time-windows for high frequency words, while the RH focuses on detecting (N170) and reanalyzing (P600) pseudowords?

7.1 Methods

7.1.1 Participants

Fifty-two right-handed native speakers of German participated in the study and were paid 15€. None of the participants had participated in Experiment 1. All participants had normal or corrected-to-normal vision (they were instructed to wear glasses instead of contact lenses to minimize blink artefacts) and none reported a history of neurological disorders. Data of 12 participants were excluded due to excessive eye-movement artefacts. This left for analysis the data of 40 participants (31 female) with mean age of 24.2 years and age range 18-33 years. All participants signed written consent forms, were informed they can cease participation at any point, and reported no knowledge of the purpose of the experiment after participation (all were debriefed).

7.1.2 Materials

We employed the same stimuli as in Experiment 3.

7.1.3 Procedure

The procedure and presentation rates used were the same as for Experiment 3. Differently from Experiment 1, target words and pseudowords were presented parafoveally, left or right of fixation, spanning no more than 5° visual angle and with their inner edge 2° from fixation. To limit anticipatory eye-movements, presentation side was pseudorandomized. Participants were instructed to maintain fixation and to avoid blinking throughout the target sentence.

7.1.4 EEG Recording and processing

Data recording and processing protocols were the same as Experiment 2. Artefact rejection procedures resulted in the removal of approximately 7% of epochs per participant (Table 7-1). Remaining epochs were averaged per condition, participant, and electrode. ERPs were analyzed in three main time-windows: P2 (200-260 ms), N400 (300-500 ms), and LP (800-1200 ms). The P2 time window was chosen based on the timing and topography of P2 effects in previous hemispheric studies of sentential comprehension (Wlotko & Federmeier, 2007, 2013) and visual inspection. N400 time-windows were chosen based on the timing and topography for N400 effects in the previous literature (DeLong & Kutas, 2016; Kutas & Federmeier, 2011; Wlotko & Federmeier, 2007, 2013). LP amplitudes were measured over the same electrode sites for anterior PNP effects and posterior P600 effects as for Experiment 3. In line with our previous setup, we used visual inspection to determine the exact time window of analysis and kept the time window constant for both anterior PNP and posterior P600 effects.

7.2 Results

7.2.1 Comprehension question accuracy

Performance on comprehension questions was above chance (mean = 93%; range: 53-100%), confirming that participants were attending to the task.

7.2.2 Event-related potentials

ERP effects were quantified using separate repeated-measures analyses of variance (ANOVAs) for each time window, comparing mean amplitudes per channel, participant, and experimental condition. Within-subject factors included word status (word, pseudoword), predictability (high, low), and visual field (VF) of presentation (LVF, RVF). To infer the general distribution of the predictability and words status effects, we arranged electrode locations in two additional factors: anteriority with 3 levels - frontal, central, and posterior and laterality with 2 levels: left and right. Time windows for each component of interest were selected based on previous literature. Where appropriate, Greenhouse-Geisser corrections and corrected p and ε values are reported. Only statistical results with $p < .05$ are reported.

	RVF/LH	**LVF/RH**
Low predictability words	9.31% (SD 9.94%)	6.67% (SD 7.25%)
High predictability words	7.08% (SD 8.05%)	5.97% (SD 8.66%)
Low predictability pseudowords	7.08% (SD 7.23%)	6.81% (SD 7.60%)
High predictability pseudowords	8.61% (SD 10.96%)	7.64% (SD 9.56%)

Table 7-1 Artifact rejection. Average percentages of discarded items due to blinks, eye movements, muscle noise or slow sustained electrical activity per condition

7.2.3 DVF presentation effects

As in Experiment 2, we confirmed that the DVF manipulation resulted in initial processing by the contralateral hemisphere. Mean amplitudes of the N1 component (100-200 ms) and the selection negativity (300-1200 ms) were submitted to separate VF (left, right) and hemisphere (left, right) ANOVAs at 10 non-midline posterior channels (LH: CP5, CP1, P3, P7, O1; RH: CP6, CP2, P4, P8, O2) where these DVF effects are the largest (Figure). A reliable VF * hemisphere interaction was found for both components [N1: $F(1,39)=88.99$, $p < .001$, $\eta^2 = .131$; selection negativity: $F(1,39) = 101.07$, $p < .001$, $\eta^2 = .058$]. LVF amplitudes were more negative over right hemisphere sites, while RVF amplitudes were more negative over left hemisphere sites, indicating that the DVF paradigm successfully shifted the balance of processing to the hemisphere contralateral to the visual-field of presentation.

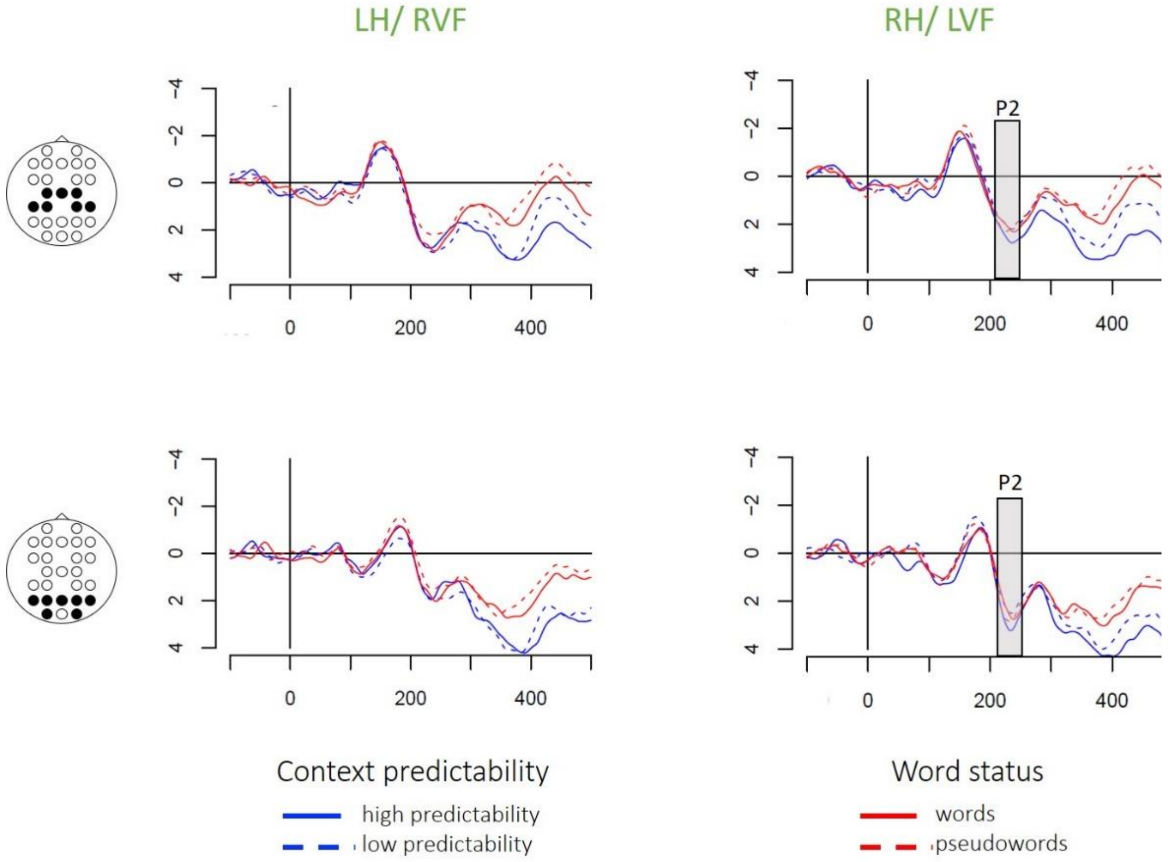

Figure 7.1– Word status effect as reflected by the P2 component. Grand average ERPs by condition over P3 and P4 electrode sites (as indicated in black on the electrode map above). Gray squares indicate time-windows of interest.

Time window	**Factors**	***F*-value**	***p*-value**	**η^2-value**
P2 (200-260 ms)	VF*Lat	*F*(1,39) = 5.58	< .05 *	.003
	VF*Ant	*F*(2,78) = 13.31	< .001 ***	.010
	VF*Pred*Word	*F*(1,39) = 4.49	< .05 *	.003
	Pred*Word*Lat	*F*(1,39) = 5.15	< .05 *	.001
N400 (300-500 ms)	Pred	*F*(1,39) = 42.29	< .001 ***	.034
	Word	*F*(1,39) = 16.76	<.001 ***	.007
	VF*Lat	*F*(1,39) = 7.96	<.01 **	.004
	Pred*Lat	*F*(1,39) = 6.05	<.05 *	.001
	Pred*Ant	*F*(2,78) = 31.77	<.001 ***	.022
	VF*Word*Lat	*F*(1,39) = 6.76	<.05 *	.001
	Pred*Word*Lat	*F*(1,39) = 6.06	<.05 *	.001
	VF*Lat*Ant	*F*(2,78) = 27.91	<.001 ***	.006
PNP (700-1100 ms)	Pred	*F*(1,39) = 25.18	<.001 ***	.020
	VF*Lat	*F*(1,39) = 40.04	<.001 ***	.008
	Pred*Ant	*F*(2,78) = 19.10	<.001 ***	.020
	VF*Lat*Ant	*F*(2,78) = 88.04	<.001 ***	.009
	VF*Pred*Word*Ant	*F*(2,78) = 3.28	.07	.002

Table 7-2 ERP results. Repeated measures ANOVA results from P2, N400, and PNP time-windows for VF, predictability (Pred), word status (Word), laterality (Lat) and anteriority (Ant) factors. Greenhouse-Geisser corrected p values are reported for comparisons with more than one degree of freedom in the numerator.

7.2.4 P2: 200-260 ms

P2 amplitudes showed two significant two-way interactions (Table 7-2): VF and laterality and VF and anteriority. There were also two significant three-way interactions between predictability, word status and VF and predictability, word status and laterality. Further comparisons for each VF condition indicated a significant interaction between predictability and word status for LVF-presented stimuli only (*F*(1,39) = 4.67, *p*<.05, η^2 =

0.008): in high predictability contexts words (M = 1.83 µV) elicited more positive P2 amplitudes than pseudowords (M = 1.39 µV).

7.2.5 N400: 300-500 ms

As shown by Table 7-2, there were two main effects of predictability and word status as well as several significant two- and three-way interactions. Planned follow-up ANOVAS looking into the interaction between predictability word status and laterality indicate two main effects and an interaction over right electrode sites such that pseudowords elicited a smaller but still significant N400 predictability effect (M_{low} = 0.83 µV and M_{high} = 1.50 µV) than words (M_{low} = 1.03 µV and M_{high} = 2.09 µV). Over left electrode sites there were only two main effects: pseudowords (M = 0.88 µV) elicited more negative N400 amplitudes than words (M = 1.30 µV) and low predictability conditions (M = 0.73 µV) elicited more negative N400 amplitudes than high predictability conditions (M = 1.44 µV).

Moreover, planned ANOVAS looking into the interaction between VF word status and laterality indicate that a main effect of word status over right electrode sites such that pseudowords (M = 1.45 µV) elicited more negative N400 amplitudes than words (M = 1.83 µV). Over left electrode sites there was a main effect of word status such that pseudowords (M = 0.88 µV) elicited more negative N400 amplitudes than words (M = 1.30 µV) and a main effect of visual field such that RVF conditions (M = 0.87 µV) elicited more negative N400 amplitudes than LVF conditions (M = 1.30 µV).

In all, follow-up comparisons over the N400 time-window indicate that there were no meaningful differences between the N400 effects for both word status and contextual predictability for stimuli presented to the LVF or RVF.

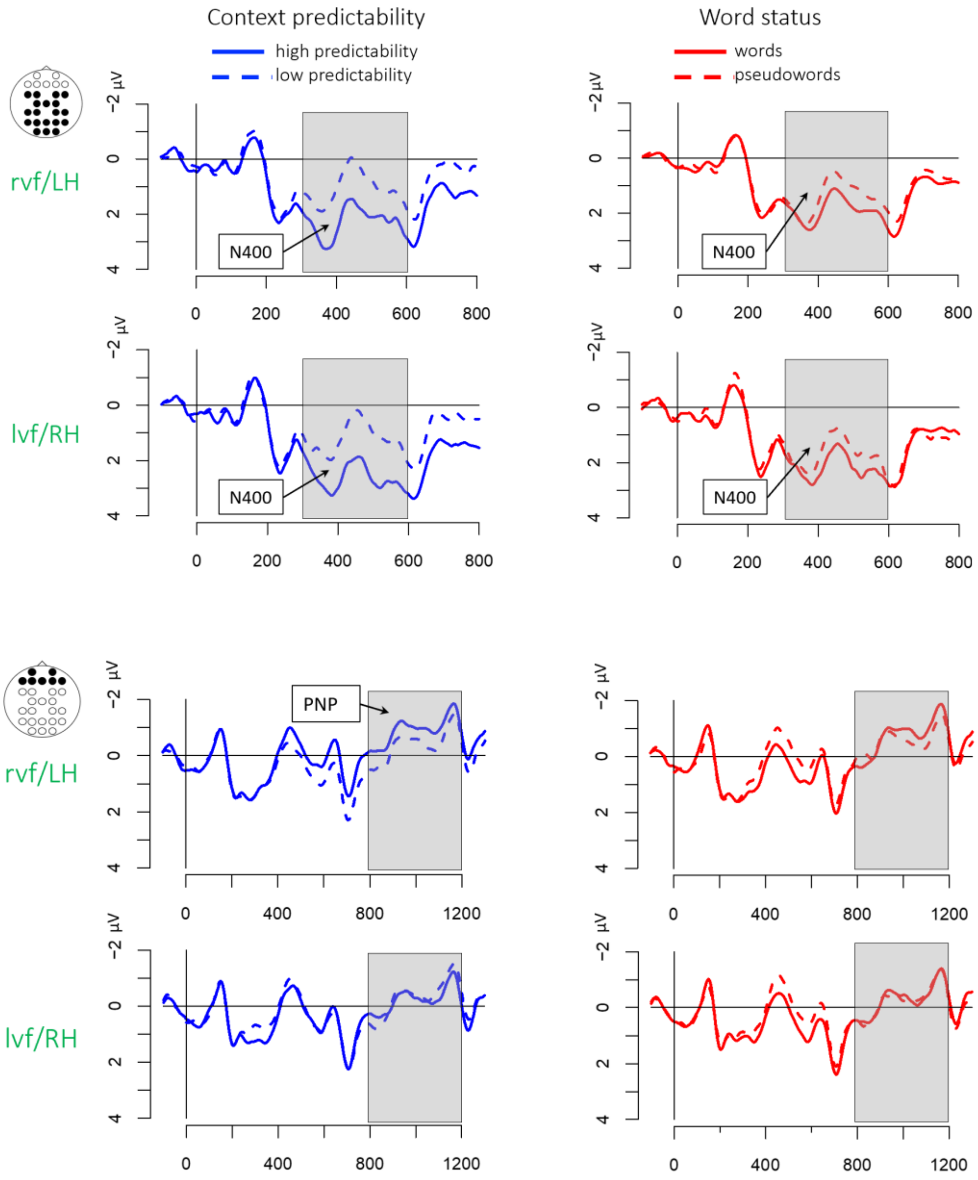

Figure 7.2– N400 and PNP results per visual field. Grand average ERPs by condition for context predictability (left) and word status (right). For illustration purposes ERPs in the upper two panels were averaged across 19 centro-posterior and 7 anterior electrodes (indicated in black on the electrode map). Gray squares indicate time-window of interest, while boxes and arrows point out significant effects.

7.2.6 Late positivities: anterior PNP (800-1200 ms)

As shown on Table 7-2 the four-way interaction between predictability, word status, VF, and anteriority was marginally significant. While central and posterior sites exhibited similar effects to the N400 time-window, planned comparisons for each VF condition over anterior electrodes indicate that predictability had a marginally significant effect for RVF-presented stimuli regardless of word status such that low predictability conditions (M = -0.39 μV) elicited more positive PNP amplitudes than high predictability conditions (M = -0.97 μV).

Stimuli presented to the LVF elicited no significant main effects or interactions.

7.2.7 Late positivities: posterior P600 (800-1200 ms)

Unlike the results from Experiment 3, no posterior P600 peaks or differences in amplitude were found for stimuli presented to either VF.

7.3 Summary of results

The goal of Experiment 4 was to investigate whether top-down predictability affects word status processing differently following initial lateralized presentation and at what level of processing. We hypothesized that the additive effects of contextual predictability and word status we recorded from central presentation of the stimuli in Experiment 3 may reflect an average of two different foci of processing, in line with previous theories of how hemispheric presentation results relate to central presentation results (Federmeier, 2007; Wlotko & Federmeier, 2007).

Starting with word recognition, we expected to see no hemispheric differences in the main effect of word status we recorded in Experiment 3. More importantly, since our Experiment 2 indicated that top-down and bottom-up processing interact only following LH-presentation, we hypothesized that if we are to find an interaction between top-down predictability and bottom-up word status, it should be for LH-presented stimuli, potentially during N400 semantic access windows.

We also expected that the topographic difference in the LP effects of predictability and word status we recorded in Experiment 3 was contributed by the LH and RH respectively, as a reflection of a top-down vs. bottom-up focus of message level integration processing.

The results of Experiment 4 did not completely follow our hypotheses. First, the earliest effects of predictability and word status were measured during the P2 time-window, in line with Experiments 1 and 2, but unlike the expected word status N170 effect of Experiment 3. Since to our knowledge there are no reports of hemispheric studies investigating word vs. pseudoword processing, it is unclear whether the N170 effect requires foveation in order to be properly measured. The P2 findings indicated that participants differentiated between words and pseudowords as early as 200 ms after stimulus onset, but only in high predictability contexts and only for RH-presented continuations.

The N400 results were identical to the findings of Experiment 3: we found additive effects for predictability and word status. Semantic access was easier for all high predictability continuations and words were generally accessed easier than pseudowords (pseudowords did not exist in the lexicon, so could not in fact be “accessed” as such). Our hypothesis that central presentation semantic access reflects different contributions from each hemisphere was refuted.

During message-level integration we were again able to replicate our findings from all three previous experiments, in that top-down contextual predictability affected anterior PNP amplitudes regardless of word status and for LH-presented stimuli only. Unfortunately, our hypothesis that the posterior P600 word status effect from Experiment 3 could be due to an RH bottom-up focus could not be confirmed. Similarly, to the N170 effect, to our knowledge no hemispheric investigations of word status or general P600 studies exist that shed light on the lateralization of the posterior late positivity. For now, we can conclude that word status reanalysis requires central presentation and neither hemisphere seems to have a larger “say” in it, unlike the anterior PNP which reflects earlier “commitment” to a certain expected continuation.

Chapter 8

General discussion

This chapter will discuss separately the results of the first two experiments which investigated the nature of the interaction between contextual predictability and lexical frequency for words presented centrally or to each hemisphere (Section 8.1) and the last two experiments which investigated the beneficial effect of context for the integration and reanalysis of centrally and laterally presented word and pseudoword inputs (Section 8.2). We will then discuss the implications of these findings in light of existing models of hemispheric processing of sentential context and in light of general models of hemispheric asymmetry (Section 8.3) and present a unifying theory of hemispheric processing in sentential context, the Spotlight Theory.

8.1 Facilitation without limitations: high frequency words in context

Experiment 1 and 2 set out to investigate the nature of the potential interaction between bottom-up mechanisms (carrying lexical information) and top-down mechanisms (carrying sentence-level information) during several phases of online language comprehension (word recognition, semantic access and message-level integration). Both bottom-up and top-down processing were manipulated in order to better understand the importance and sensitivity of the two hemispheres together and separately to these two qualitatively different information sources. Bottom-up mechanisms were investigated via target word frequency (high, low), a key determinant of lexical processing. Top-down mechanisms were investigated via word predictability (high, low) by embedding target words into small discourse contexts that either strongly constrained expectations to the target word or to another word.

The findings of Experiment 1 indicated that at near normal reading rates context predictability did indeed affect word processing even before lexical frequency, but later than indicated by the findings of the studies we replicated (Dambacher et al., 2012, 2009). The effect of predictability began at P2 amplitudes, and continued in the same direction over N400 time-windows. The two factors interacted over N400 time-windows. During semantic access (N400 effect) in supporting contexts the lexical frequency of the input brought no additional facilitation as the context set by the previous sentence was enough to activate the input meaning. When the presented word did not match the previous sentential context, its frequency provided an additional boost to semantic processing, leaving unexpected low frequency words with the highest level of processing difficulties. These results supported earlier findings that lexical frequency takes a secondary role in sentence processing only when context is scarce (Dambacher et al., 2006; Van Petten & Kutas, 1990). Finally, during message-level integration predictability was still found to play a role, further facilitating the integration of both high and low frequency expected continuations in the general context, while low predictability continuations were harder to integrate due to their unexpectedness based on context.

Experiment 2 shed further light on the nature of the interaction between contextual constraint and frequency during semantic access (N400). The interaction between frequency and predictability was present for left-hemisphere-presented stimuli only, while right-hemisphere-presented words only elicited two main effects, but no interaction between the two. For right hemispheric presentation, frequency and predictability elicited additive effects over the N400 semantic access amplitudes. It appeared that for RH-presented stimuli any facilitative information was beneficial, regardless of its source. On the other hand, for left hemispheric presentation, the semantic access benefits for high frequency words occurred only in high predictability contexts. LH-presented high frequency words did not facilitate semantic processing if context did not support them. We interpreted this as evidence that the LH uses context to restrict the domain of semantic access to a subset of words that are highly expected by preceding content. As a consequence, only the words, which fall within this contextually-driven “spotlight”, appear to be eligible for further facilitation by frequency information while words outside the spotlight are equally difficult regardless of their frequency. The benefits of this spotlight effect continue to play a role in LH processing during the message-level integration phase but are not observed in the RH.

These findings and their potential implications are discussed in more detail below.

Word recognition (P2)

For centrally presented words (Experiment 1), context affected P2 amplitudes regardless of the target word frequency. Differently from Dambacher et al. (2012), this was the first instance predictability affected the ERP signal we recorded. Also, differently from Dambacher and colleagues’ findings, frequency did not affect the P2 amplitude. The topography and direction of the P2 effect matches the results of Dambacher et al. (2012). Following lateralized presentation of the same stimuli (Experiment 2), however, we recorded no reliable predictability effect during P2 time-windows.

The current findings indicate that during central presentation at near natural reading rates readers rely on context information acquired prior to exposure to the stimulus to facilitate the earliest stages of word processing. However, it appears that lateralized presentation delays the first instance of contextual effect over the ERP.

Semantic access (N400)

N400 amplitudes for centrally presented words (Experiment 1) reflected an interaction between context predictability and word frequency. In line with previous central presentation findings, (Dambacher et al., 2012, 2006; Van Petten & Kutas, 1990a), readers only benefitted from high frequency words when they could not rely on context to narrow down the meaning of a potential continuation. For high predictability contexts the ease of semantic access of high and low frequency words did not differ. Differently from Dambacher and colleagues (Dambacher et al., 2012), this was the first instance of an interaction between context predictability and word frequency, which might question their findings that bottom-up and top-down processing pathways interact as early as 135 ms after stimulus presentation and indicate that even though participants had started to form expectations and narrow down potential continuations at 200 ms, word form frequency only interacted with these expectations during semantic access.

Lateralized presentation results (Experiment 2) for semantic access were consistent with previous PARLO studies (Wlotko & Federmeier, 2007, 2013). The predictability of target words affected semantic processing regardless of whether words were initially presented to the LH or RH. However, the hemispheres differed in the degree to which contextual information modulated the effect of word frequency. For target words presented to the LVF/RH, the effects of predictability and frequency on the N400 amplitude were strictly additive. Semantic access was facilitated for both high frequency and high predictability target words, relative to their low frequency and low predictability counterparts, but the factors did not interact. This finding suggests that contextual processing does not take precedence over bottom-up mechanisms in the RH as hypothesized by Federmeier (2007).

In contrast, frequency and predictability interacted for words presented to the RVF/LH. Differently from the results of Experiment 1, high frequency words received an additional boost in facilitation when appearing in high predictability contexts, whereas in low predictability contexts frequency did not modulate processing. These results suggest that following lateralized presentation LH processing only brings frequency information to bear on a subset of potential continuations that are consistent with the preceding sentential context.

Figuratively speaking, it is as if context is used in the LH to shine a spotlight into the mental lexicon, considering only words that are likely to be mentioned next. Only words falling within this spotlight benefit from frequency information. Conversely, if the incoming word is not within the spotlight (i.e. does not match contextual expectations), frequency provides no additional facilitation to semantic access. For RH presentation, predictability facilitated semantic access, but there was no indication that predictability was used to narrow down potential continuations: semantic access for high frequency words was facilitated regardless of whether they appeared in supportive contexts or not.

While this pattern of results is consistent with the PARLO hypothesis (see Section 3.4), the findings are nevertheless novel: previous hemispheric differences work in support of PARLO (Wlotko & Federmeier, 2007, 2013) has not directly tested the effect of top-down contextual expectations on bottom-up word frequency processing. Moreover, contrary to previous work that reports no hemispheric differences in the processing of contextual predictability during semantic access (DeLong & Kutas, 2016), results from Experiment 2 provide further evidence that top-down mechanisms take priority over bottom-up mechanisms in the LH, such that predictability drives word processing during the semantic access phase.

Message-level integration (anterior PNP)

During the message-level integration phase, anterior positivity results for centrally presented targets reflected an overall difficulty to integrate unexpected, but plausible low predictability stimuli in the previous sentential context. This effect was present regardless of the lexical frequency of the input. This meant that even though high frequency facilitated semantic access for words in unexpected conditions, it did not seem to facilitate their further integration into an already low predictability context.

For laterally presented stimuli top-down contextual information continued to take priority in the LH. An interaction between contextual predictability and word frequency indicated that the same high predictability/high frequency continuations that received a boost in facilitation during the semantic access phase were also the easiest to process during message-level integration, leading to attenuated anterior PNP amplitudes relative to all other conditions.

In contrast, no differences across conditions were found for words presented to LVF/RH. We speculate that this may be because the RH does not prioritize contextual information during the earlier semantic access phase and is therefore unable to take advantage of contextual predictability to facilitate processing during message-level integration.

Contrary to some previous findings (Wlotko & Federmeier, 2007, 2013), this pattern of results indicates that the DVF technique does not necessarily disrupt message-level integration processes. Rather, our results extend other findings showing larger PNP effects in the LH (DeLong & Kutas, 2016). However, while the previous results suggest that predictability is the only factor that determines PNP amplitudes for words presented to the RVF/LH, the findings from Experiment 2 indicate that facilitation from frequency information can carry over into the message-level integration phase. Put differently, if the incoming word confirms expectations based on context and has a high frequency in the mental lexicon, only minimal further effort would be required to integrate that word into the overall message-level representation of the sentential context.

8.2 Right hemisphere can walk and chew gum at the same time: pseudoword processing in context

The goal of Experiments 3 and 4 was to extend the investigation of the effect context predictability exerts over bottom-up processing by presenting participants with corrupt input and measuring when and to what extend were they able to perceive and overcome the misspelling. To that end the high frequency words from the Potsdam Sentence Corpus 3 were altered by replacing a medial letter with a similar looking letter to create a pronounceable illegal word in German that visually resembled the target word (a method similar to the one employed by Kim & Lai (2012).

The results of the central experiment closely followed previous findings (Kim & Lai, 2012). Participants' ERP modulations indicated that they distinguished between words and misspellings as early as 170 ms after stimulus presentation (N170) regardless of context predictability. This finding indicates that compared to lexical frequency (Experiment 1), word status does elicit an early independent effect on word processing even in supporting contexts. During semantic access processing phases, context predictability and lexical frequency exerted additive influences over the N400 amplitudes. It appears that while it was impossible to access the non-existent meaning of misspelled word forms, the incorrect input did not significantly hinder processing when presented in supporting contexts. The independence of word status and context predictability processing prevailed during late positivity phases, with added spatial distinctions of the effects over the scalp: while low predictability conditions elicited larger anterior PNP modulations, word status affected posterior P600 amplitudes. Participants seemed to both seamlessly access and integrate misspellings of expected stimuli as if they were the actual expected words as well as to simultaneously recruit resources to reanalyze the misspellings.

Experiment 4 hypothesized that the parallel processing findings of Experiment 3 might be due to hemispheric cooperation similar to the findings of Experiment 2: while LH-presented stimuli are processed based on their predictability or fit in the preceding context (since the stimuli were all of high frequency), RH-presented stimuli should exhibit a larger effect of word status and a potential focus on correcting the bottom-up signal to fit the overall sentential message. The findings of Experiment 4 do show an early sensitivity of RH-presented stimuli to bottom-up word status (P2), which was not present for LH-presented targets and was interpreted as early initial bottom-up focus for the RH. During semantic access context predictability and word status did not interact for either hemisphere, indicating that the hypothesis that central presentation findings represent different contributions from the hemispheres was wrong. Instead, the two hemispheres appeared to benefit from both contextual support and word status.

Early N170 word status and P2 predictability effects

One methodological particularity of our early time-window findings that needs to be addressed before we consider the implications of the early bottom-up focus of the RH is the exact timing of the first significant ERP modulations. The timing and nature of the early effects for Experiments 3 and 4 differed, similarly to Experiments 1 and 2. Since the only difference between Experiment 3 and 4 was the lateralized presentation of the stimuli, we concluded that parafoveal processing of the stimuli affects the early perceptual ERP amplitudes differently than foveal presentation. While in Experiment 3 participants' N170 amplitudes indicated an early distinction between words and misspellings, lateralized stimuli could only be reliably distinguished based on their word status in high predictability contexts at P2 amplitudes. Extending the word recognition findings of Experiment 2, P2 amplitudes in Experiment 4 indicated that participants distinguished between words and pseudowords presented to the RH when these stimuli appeared in supportive contexts. This finding not only supports our hypothesis that bottom-up processing is in the focus of RH structures, but also that it interacts with contextual support as early as 200 ms after stimulus presentation, which was not evident in either previous findings or when lexical frequency was the bottom-up factor of focus (Experiment 2).

While the N170 is reported to be sensitive to word status regardless of context (Kim & Lai, 2012) and our results match previous findings in topography and timing, the context predictability P2 effect appears slightly more posterior. One explanation for the posterior topography and direction of the P2 could be its' proximity to the N400 effect. The results might indicate an early semantic access (N400) effect of context over RH bottom-up processing of word status, instead of early word recognition for the RH. This would not, however, explain the earlier timing of the context predictability effect in the RH, compared to the LH, or the fact that no such early sensitivity to predictability was recorded for the high frequency words in Experiment 2. One potential explanation for the early RH sensitivity to context predictability might be an overall difficulty of processing due to the overall presence of unreliable input in the experiment (50% of the stimuli were misspelled) leading to a larger focus allocation to context.

Semantic access (N400)

The findings of Experiments 3 and 4 for the semantic access phase did not differ. Unlike the results from Experiments 1 and 2, central presentation N400 modulations corresponded to the activation patterns in each hemisphere. This led to the conclusion that participants had no difficulties using previous context to form expectations of the meaning of a certain continuation, while still recognizing that the input doesn't fully match an existing word in the lexicon. It might have been the case that the pseudoword manipulation was too subtle and too similar to the target words, leading to similar semantic access processing patterns. Following that logic, one would expect that a spotlight mechanism would not need to be engaged, as all stimuli in Experiment 4 were either high frequency (already in the LH spotlight as hypothesized in Experiment 2) or very similar to a high frequency word.

Message-level integration (PNP) and reanalysis (P600)

The clear distinction between context predictability and word status remained during late positivity processing phases for Experiment 3 and 4. Following central presentation, participants continued to exhibit indications that misspelled targets are treated as plausible continuations indistinguishable from legal words over anterior PNP amplitudes (in line with DeLong et al., 2014; Van Petten & Luka, 2012). During the same time-window, misspellings elicited larger posterior P600 amplitudes, which indicated that participants were sparing resources to potentially identify the sources of the irregularity of the bottom-up input before integrating it back into the larger context (in line with van de Meerendonk et al., 2011).

Anterior PNP results for laterally presented targets extended the high frequency word findings of Experiment 2, such that only LH-presented low predictability contexts elicited message level integration difficulties. Differently from Experiment 2 these difficulties were indistinguishable for words and misspellings, potentially due to the abovementioned subtle distinction between the two. With regard to the posterior P600 findings of Experiment 3, no such modulations were apparent for lateralized presentation to either hemisphere, leading to another unexpected results. Similarly to the conclusions made by Wlotko & Federmeier (2007), speculations can be made that such a task-specific positivity may not be apparent when the presentation style (DVF) is exerting and requires a lot of conscious control over instinctive eye-movements.

In all, the findings of Experiment 4 do not seem to fully confirm the hypotheses set out by us as a result of PARLO: RH-presented stimuli exhibited an early sensitivity to context predictability that wasn't apparent for LH-presented targets, while the two hemispheres exhibited identical semantic access patterns of activation. The one result that seemed to carry over from previous findings (DeLong & Kutas, 2016) and Experiments 2 and 4 was the fact that message-level integration as indexed by the anterior PNP was only evident for targets presented to the LH, leading to a conclusion that higher level contextual processing like judging a continuation's plausibility might be LH-specific.

The following section will attempt to apply these surprising findings extend and combine the available models of hemispheric processing.

8.3 Spotlight theory of hemispheric asymmetries in context

The current results indicate that the cerebral hemispheres coordinate lexical and context-based information differently during the various phases of word processing. When given a processing head start via the DVF paradigm, the LH appears to prioritize contextual information, whereas the role of the RH appears to shift based on the global context of the task as well as the specific bottom-up features of the input. We speculate that these different processing "strategies" may also operate during more typical language comprehension situations, when the hemispheres must work in conjunction with each other, and could therefore provide important benefits to comprehension processes in general. To flesh out this proposal let’s return to the example stimuli in Figure 4.2.

When the stimuli presented to the readers vary as a function of their frequency in the overall lexicon (Experiment 2) for the RH, a high frequency word like “game” is facilitated during both word recognition and semantic access phases of processing, regardless of whether the prior context increases the expectations for “game” (e.g., Caroline liked to spend her time playing chess or checkers.) or not (e.g., Caroline liked to look at pictures from her childhood.), This bottom-up focus may be particularly useful in situations where incoming words are not highly predictable or contexts can’t be fully relied upon, such as when one is learning new vocabulary, or when figurative language is used (e.g., metaphor, irony, jokes, poetry, novel domains). In fact, previous work has suggested that the RH may play an important role in the processing of figurative language (Coulson and Williams, 2005; Davenport and Coulson, 2013). This does not mean, however, that the RH cannot make use of contextual support. Following the appropriate context (e.g., Caroline liked to look at pictures from her childhood.), a low frequency word like “album” is also facilitated, but only during the later semantic access phase of processing, and only in combination with frequency information. Thus, while the RH appears to prioritize bottom-up lexical information, it is not strictly limited by it.

The ability of the RH to benefit from both bottom-up and top-down information becomes even more apparent when the bottom-up lexical information readers receive is unreliable, but not so much so as to be unrecognizable. When some of the presented inputs were slightly modified misspellings of expected targets (Experiment 4) RH processing not only did not exhibit difficulties recovering from the misspellings, but also seemed to shift focus towards an early reliance on contextual support. Together the findings of Experiments 2 and 4 paint a picture of a much more flexible RH processing, which might even take into consideration meta-level factors like overall misspelling frequency in the entire experiment and general DVF processing difficulties. The current RH results reflect a processing pattern more similar to that proposed by Jung-Beeman (2005) or even

McGilchrist (2019) of a more coarse and global vigilance that can nevertheless be aimed towards the contextual support of a larger discourse.

With regard to LH processing, according to the findings of Experiment 2, the LH appears to prioritize contextual information using a fine-grained, acutely-focused, spotlight-like strategy. For example, the context Caroline liked to spend her time playing chess or checkers. highlights related words such as “game”, “dice”, and “chessboard”, which facilitates semantic access if the expected word is then encountered in the input. Contextual processing focus like this would be perfectly suited for everyday communication, which typically contains many linguistic regularities and is rich in contextual cues. Consequently, LH processing can be extremely fast and efficient under such circumstances because the contextual spotlight obviates the need for a lexicon-wide search. Crucially, however, frequency alone does not appear to facilitate semantic access in the LH. The same high frequency word, “game” receives no additional facilitation when it is unpredictable (e.g., following the context *Caroline liked to look at pictures from her childhood*).

The Spotlight Theory further appears to be compatible with Jung-Beeman’s fine/coarse semantic coding framework for describing hemispheric differences during language comprehension, which is inspired by cyto-architectural differences in the microcircuitry of language processing areas in the two hemispheres (Jung-Beeman, 2005). A key component of the Jung-Beeman framework is the proposal that semantic processes in the LH may activate narrow and focused meaning associations between single words (i.e., fine coding), while analogous processes in the RH may activate wider and more diffuse semantic associations (i.e., coarse coding).

Future neuroimaging work would be needed to investigate the degree to which such differences in microcircuitry might contribute to the sentential context processing differences reported in the current thesis, not just single word processing and semantic field exploration. Additionally, findings from the development of top-down processing for first- and second-language learners should shed light on whether and how bottom-up processing focus shifts as top-down information is insufficient and unreliable. While language learners are sufficiently successful in their use of bottom-up information, it is still unclear to what extent they benefit from sentential predictability (Rabagliati, Gambi, & Pickering, 2016). Hemispheric asymmetries research can contribute to a clearer understanding of the development of top-down contextual information focus.

In sum, we speculate that the hemispheric differences identified in the current study may serve important and complementary functions during normal language comprehension. In typical situations, incoming information is largely predictable. Thus, the comprehension system can rely primarily on LH processing during most everyday communicative situations, as it is fast and efficient due to the LH focus on contextual information. On the other hand, when the input is less predictable or less reliable – or when prediction fails outright – the RH may play an indispensable role because it places a greater emphasis on the bottom-up lexical properties of the input. In combination, these complementary processing strategies may provide the comprehension system with the robustness and efficiency required for successful bilateral processing during any array of bottom-up and top-down inputs for any type of visual language processing.

Chapter 9 Conclusion

The findings of this thesis replicate and extend the current state of the art of the hemispheric processing literature. We coupled the high temporal resolution of ERPs with the DVF paradigm to directly investigate when and how bottom-up information and top-down contextual support are coordinated during sentence processing in each hemisphere. We focused on a wide array of processing time-windows in order to gain a larger perspective on how reading unfurls from word recognition, through semantic access and to message-level comprehension.

We made sure to tether our hemispheric differences hypotheses by first replicating central presentation findings, which gave us the opportunity to not only create a baseline for discussing our hemispheric differences findings, but also to double-check the reliability of critical effects in previous literature (something which we weren't always able to confirm). The significant bottom-up and top-down interaction findings we reported over several time-windows for each hemisphere were able to add meaningful discussion points to previous hemispheric asymmetries models of word and sentence processing, which never explicitly manipulated or considered how bottom-up and top-down factors interplay.

Based on the four experiments presented in this thesis, we were able to propose a novel Spotlight Theory of hemispheric processing. The left hemispheric spotlight applies top-down predictability to boost the activation of lexical exemplars, which are highly likely in a current context, whose bottom-up properties like lexical frequency or even lexical intactness (misspellings) are of secondary consideration only insofar as they fall into the predictive spotlight. Even though LH processing was not reliably recorded during word recognition windows, semantic access and message-level integration time-windows painted the picture of a very efficient top-down short-listing of only the most probable exemplars to be processed. Alternatively, RH processing did keep a critical bottom-up focus starting as early as word recognition when the incoming stimuli were unreliable, but still resembled expected inputs enough for the RH to actually benefit from the top-down context they appeared in. This finding was the first of its kind to our knowledge and potentially may have supported the successful later semantic access and message-level integration of irregular inputs for both hemispheres.

In all, our findings were able to present a more comprehensive picture of the hemispheric interplay between the properties of the incoming stimuli and the internal mental representations based on sentential context, as well as provide several lines of potential hypotheses for future research.

Bibliography

Balota, D. A., & Spieler, D. H. (1999). Word frequency, repetition, and lexicality effects in word recognition tasks: Beyond measures of central tendency. *Journal of Experimental Psychology: General*, *128*(1), 32–55. https://doi.org/10.1037/0096-3445.128.1.32

Bansal, S., Ford, J. M., & Spering, M. (2018). The function and failure of sensory predictions. *Annals of the New York Academy of Sciences*, *1426*(1), 199–220. https://doi.org/10.1111/nyas.13686

Barber, H. a., & Kutas, M. (2007). Interplay between computational models and cognitive electrophysiology in visual word recognition. *Brain Research Reviews*, *53*, 98–123. https://doi.org/10.1016/j.brainresrev.2006.07.002

Bourne, V. J. (2006). The divided visual field paradigm: methodological considerations. *Laterality*, *11*(4), 373–393. https://doi.org/10.1080/13576500600633982

Brothers, T., Swaab, T. Y., & Traxler, M. J. (2015). Effects of prediction and contextual support on lexical processing: prediction takes precedence. *Cognition*, *136*, 135–149. https://doi.org/10.1016/j.cognition.2014.10.017

Brouwer, H., Crocker, M. W., Venhuizen, N. J., & Hoeks, J. C. J. (2017). A Neurocomputational Model of the N400 and the P600 in Language Processing. *Cognitive Science*, *41*, 1318–1352. https://doi.org/10.1111/cogs.12461

Brouwer, H., & Hoeks, J. C. J. (2013). A time and place for language comprehension: mapping the N400 and the P600 to a minimal cortical network. *Frontiers in Human*

Neuroscience, *7*(November), 1–12. https://doi.org/10.3389/fnhum.2013.00758

Carter, B. T., Foster, B., Muncy, N. M., & Luke, S. G. (2019). Linguistic networks associated with lexical, semantic and syntactic predictability in reading: A fixation-related fMRI study. *NeuroImage*, *189* (December 2018), 224–240. https://doi.org/10.1016/j.neuroimage.2019.01.018

Cattinelli, I., Borghese, N. A., Gallucci, M., & Paulesu, E. (2013). Reading the reading brain: A new meta-analysis of functional imaging data on reading. *Journal of Neurolinguistics*, *26*(1), 214–238. https://doi.org/10.1016/j.jneuroling.2012.08.001

Chaumillon, R., Blouin, J., & Guillaume, A. (2018). Interhemispheric transfer time asymmetry of visual information depends on eye dominance: An electrophysiological study. *Frontiers in Neuroscience*, *12*, 1–19. https://doi.org/10.3389/fnins.2018.00072

Clark, A. (2013). Are we predictive engines? Perils, prospects, and the puzzle of the porous perceiver. *Behavioral and Brain Sciences*, *36*(3), 233–253. https://doi.org/10.1017/S0140525X12002440

Cramer, S. C. (2008). Repairing the human brain after stroke: I. Mechanisms of spontaneous recovery. *Annals of Neurology*, *63*(3), 272–287. https://doi.org/10.1002/ana.21393

Crinion, J., & Price, C. J. (2005). Right anterior superior temporal activation predicts auditory sentence comprehension following aphasic stroke. *Brain*, *128*(12), 2858–2871. https://doi.org/10.1093/brain/awh659

Dambacher, M. (2010). *Bottom-up and top-down processes in reading*.

Dambacher, M., Dimigen, O., Braun, M., Wille, K., Jacobs, A. M., & Kliegl, R. (2012a). Stimulus onset asynchrony and the timeline of word recognition: Event-related potentials during sentence reading. *Neuropsychologia*, *50*(8), 1852–1870.

https://doi.org/10.1016/j.neuropsychologia.2012.04.011

Dambacher, M., Dimigen, O., Braun, M., Wille, K., Jacobs, A. M., & Kliegl, R. (2012b). Stimulus onset asynchrony and the timeline of word recognition: Event-related potentials during sentence reading. *Neuropsychologia*, *50*(8), 1852–1870. https://doi.org/10.1016/j.neuropsychologia.2012.04.011

Dambacher, M., Kliegl, R., Hofmann, M., & Jacobs, A. M. (2006). Frequency and predictability effects on event-related potentials during reading. *Brain Research*, *1084*(1), 89–103. https://doi.org/10.1016/j.brainres.2006.02.010

Dambacher, M., Rolfs, M., Göllner, K., Kliegl, R., & Jacobs, A. M. (2009). Event-related potentials reveal rapid verification of predicted visual input. *PloS One*, *4*(3), e5047. https://doi.org/10.1371/journal.pone.0005047

Davenport, T., & Coulson, S. (2011). Predictability and novelty in literal language comprehension: an ERP study. *Brain Research*, *1418*, 70–82. https://doi.org/10.1016/j.brainres.2011.07.039

Davenport, T., & Coulson, S. (2013). Hemispheric asymmetry in interpreting novel literal language: an event-related potential study. *Neuropsychologia*, *51*(5), 907–921. https://doi.org/10.1016/j.neuropsychologia.2013.01.018

Dehaene, S., Cohen, L., Sigman, M., & Vinckier, F. (2005). The neural code for written words: a proposal. *Trends in Cognitive Sciences*, *9*(7), 335–341. https://doi.org/10.1016/j.tics.2005.05.004

DeLong, K. A., & Kutas, M. (2016). Hemispheric differences and similarities in comprehending more and less predictable sentences. *Neuropsychologia*, *91*, 380–393. https://doi.org/10.1016/j.neuropsychologia.2016.09.004

DeLong, K. A., & Kutas, M. (2020). Comprehending surprising sentences: sensitivity of post-N400 positivities to contextual congruity and semantic relatedness. *Language,* *Cognition and Neuroscience*, *3798*. https://doi.org/10.1080/23273798.2019.1708960

DeLong, K. A., Quante, L., & Kutas, M. (2014). Predictability, plausibility, and two late ERP positivities during written sentence comprehension. *Neuropsychologia*, *61*, 150–162. https://doi.org/10.1016/j.neuropsychologia.2014.06.016

DeLong, K., Urbach, T., & Kutas, M. (2005). Probabilistic word pre-activation during language comprehension inferred from electrical brain activity. *Nature Neuroscience*, *8*(8), 1117–1121. https://doi.org/10.1038/nn1504

Démonet, J. F., Thierry, G., & Cardebat, D. (2005). Renewal of the neurophysiology of language: Functional neuroimaging. *Physiological Reviews*, *85*(1), 49–95. https://doi.org/10.1152/physrev.00049.2003

Devlin, A. M., Cross, J. H., Harkness, W., Chong, W. K., Harding, B., Vargha-Khadem, F., & Neville, B. G. R. (2003). Clinical outcomes of hemispherectomy for epilepsy in childhood and adolescence. *Brain*, *126*(3), 556–566. https://doi.org/10.1093/brain/awg052

Elger, C. E., Helmstaedter, C., & Kurthen, M. (2004). Chronic epilepsy and cognition. *Lancet Neurology*, *3*(11), 663–672. https://doi.org/10.1016/S1474-4422(04)00906-8

Elman, J. L., & McClelland, J. L. (1984). Speech perception as a cognitive process: The interactive activation model. *Speech and Language*, *10*, 337–374.

Federmeier, K. D. (2007). Thinking ahead: The role and roots of prediction in language comprehension. *Psychophysiology*, *44*(4), 491–505. https://doi.org/10.1111/j.1469-8986.2007.00531.x

Federmeier, K. D., Mai, H., & Kutas, M. (2005). Both sides get the point: hemispheric sensitivities to sentential constraint. *Memory & Cognition*, *33*(5), 871–886.

Federmeier, K. D., Wlotko, E. W., De Ochoa-Dewald, E., & Kutas, M. (2007). Multiple effects of sentential constraint on word processing. *Brain Research*, *1146*(1), 75–84. https://doi.org/10.1016/j.brainres.2006.06.101

Friederici, A. D. (2011a). The brain basis of language processing: from structure to function. *Physiological Reviews*, *91*(4), 1357–1392. https://doi.org/10.1152/physrev.00006.2011

Friederici, A. D. (2011b). The brain basis of language processing: From structure to function. *Physiological Reviews*, *91*(4), 1357–1392. https://doi.org/10.1152/physrev.00006.2011

Gernsbacher, M. A. (1984). Resolving 20 years of inconsistent interactions between lexical familiarity and orthography, concreteness, and polysemy. *Journal of Experimental Psychology: General*, *113*(2), 256–281. https://doi.org/10.1037/0096-3445.113.2.256

Goldstein, E. B., & Brockmole, J. R. (2015). *Sensation and Perception* (10th ed.). Cengage Learning.

Gunter, T. C., & Bach, P. (2004). Communicating hands: ERPs elicited by meaningful symbolic hand postures. *Neuroscience Letters*, *372*(1–2), 52–56. https://doi.org/10.1016/j.neulet.2004.09.011

Halgren, E., Dhond, R. P., Christensen, N., Van Petten, C., Marinkovic, K., Lewine, J. D., & Dale, A. M. (2002). N400-like magnetoencephalography responses modulated by semantic context, word frequency, and lexical class in sentences. *NeuroImage*, *17*(3), 1101–1116. https://doi.org/10.1006/nimg.2002.1268

Hauk, O, Coutout, C., Holden, A., & Chen, Y. (2012). The time-course of single-word reading: evidence from fast behavioral and brain responses. *NeuroImage*, *60*(2), 1462–1477. https://doi.org/10.1016/j.neuroimage.2012.01.061

Hauk, O, Davis, M. H., Ford, M., Pulvermüller, F., & Marslen-Wilson, W. D. (2006). The time course of visual word recognition as revealed by linear regression analysis of ERP data. *NeuroImage*, *30*(4), 1383–1400. https://doi.org/10.1016/j.neuroimage.2005.11.048

Hauk, Olaf, & Pulvermüller, F. (2004). Effects of word length and frequency on the human event-related potential. *Clinical Neurophysiology*, *115*(5), 1090–1103. https://doi.org/10.1016/j.clinph.2003.12.020

Holcomb, P. J. (1993). Semantic priming and stimulus degradation: Implications for the role of the N400 in language processing. *Psychophysiology*. https://doi.org/10.1111/j.1469-8986.1993.tb03204.x

Hubel, D., & Wiesel, T. (1965). Receptive fields and functional architectures in two nonstriate visual areas (18 and 19) of the cat. *Journal of Neurophysiology*, *28*(2), 229–289.

Huettig, F., & Mani, N. (2016). Is prediction necessary to understand language? Probably not. *Language, Cognition and Neuroscience*, *31*(1), 19–31. https://doi.org/10.1080/23273798.2015.1072223

Hughdahl, K., & Davidson, R. J. (2003). *The Asymmetrical Brain*. (K. Hughdahl & R. J. Davidson, Eds.). Cambridge, Massachusetts; London, England: The MIT Press.

Inhoff, A. W., & Rayner, K. (1986). Parafoveal word processing during eye fixations in reading: Effects of word frequency. *Perception & Psychophysics*, *4*(6), 431–439. https://doi.org/10.3758/BF03208203

Jackendoff, R. (2002). *Foundations of Language: Brain, Meaning, Grammar, Evolution*. Oxford: Oxford University Press. https://doi.org/10.1215/00267929-4-1-96

Jung-Beeman, M. (2005). Bilateral brain processes for comprehending natural language. *Trends in Cognitive Sciences*, *9*(11), 512–518. https://doi.org/10.1016/j.tics.2005.09.009

Just, M. A., Carpenter, P. A., Keller, T. A., Eddy, W. F., Thulborn, K. R., & Just, M. A. (1996). Brain Activation Modulated by Sentence Comprehension. *Science*, *274*(5284), 114–116.

Kim, A., & Lai, V. (2012). Rapid interactions between lexical semantic and word form analysis during word recognition in context: evidence from ERPs. *Journal of Cognitive Neuroscience*, *24*(5), 1104–1112. https://doi.org/10.1162/jocn_a_00148

Kim, A., & Osterhout, L. (2005). The independence of combinatory semantic processing: Evidence from event-related potentials. *Journal of Memory and Language*, *52*(2), 205–225. https://doi.org/10.1016/j.jml.2004.10.002

Kliegl, R., Grabner, E., Rolfs, M., & Engbert, R. (2004). Length, frequency, and predictability effects of words on eye movements in reading. *European Journal of Cognitive Psychology*, *16*(1–2), 262–284. https://doi.org/10.1080/09541440340000213

Kuperberg, G. R. (2007). Neural mechanisms of language comprehension : Challenges to syntax. *Brain Research*, *1146*, 23–49. https://doi.org/10.1016/j.brainres.2006.12.063

Kuperberg, G. R., & Jaeger, T. F. (2016). What do we mean by prediction in language comprehension? *Language, Cognition and Neuroscience*, *31*(1), 32–59. https://doi.org/10.1080/23273798.2015.1102299

Kuperberg, G. R., Sitnikova, T., Caplan, D., & Holcomb, P. J. (2003). Electrophysiological distinctions in processing conceptual relationships within simple sentences. *Cognitive Brain Research*, *17*(1), 117–129. https://doi.org/10.1016/S0926-6410(03)00086-7

Kutas, M, & Federmeier, K. D. (2000). Electropsysiology reveals semantic memory use in language comprehension. *Trends in Cognitive Science*, *12*(12), 463–470.

Kutas, M, & Hillyard, S. (1980). Reading senseless sentences: brain potentials reflect semantic incongruity. *Science (New York, N.Y.)*. https://doi.org/10.1126/science.7350657

Kutas, Marta. (1993). In the company of other words: Electrophysiological evidence for single-word and sentence context effects. *Language and Cognitive Processes*, *8*(4), 533–572. https://doi.org/10.1080/01690969308407587

Kutas, Marta, DeLong, K. A., & Smith, N. J. (2010). A Look around at What Lies Ahead : Prediction and Predictability in Language Processing. In M. Bar (Ed.), *Predictions in the brain: Using our past to generate a future* (pp. 190–207). Oxford University Press.

Kutas, Marta, & Federmeier, K. D. (2011). Thirty years and counting: finding meaning in the N400 component of the event-related brain potential (ERP). *Annual Review of Psychology*, *62*, 621–647. https://doi.org/10.1146/annurev.psych.093008.131123

Kutas, Marta, & Hillyard, S. A. (1983). Event-related brain potentials to grammatical errors and semantic anomalies. *Memory & Cognition*, *11*(5), 539–550.

Kutas, Marta, Neville, H., & Holcomb, P. J. (1987). A preliminary comparison of the N400 response to semantic anomalies during reading, listening and signing. *Electroencephalography and Clinical Neurophysiology Supplement*, *39*, 352–330.

Laszlo, S., & Federmeier, K. D. (2007a). Better the DVL you know: Acronyms reveal the contribution of familiarity to single-word reading. *Psychological Science*, *18*(2), 122–126. https://doi.org/10.1111/j.1467-9280.2007.01859.x

Laszlo, S., & Federmeier, K. D. (2007b). The acronym superiority effect. *Psychonomic Bulletin & Review*, *14*(6), 1158–1163. https://doi.org/10.3758/BF03193106

Laszlo, S., & Federmeier, K. D. (2009). A beautiful day in the neighborhood: An event-related potential study of lexical relationships and prediction in context. *Journal of*

Memory and Language, *61*(3), 326–338. https://doi.org/10.1016/j.jml.2009.06.004

Lau, E. F., Phillips, C., & Poeppel, D. (2008). A cortical network for semantics: (de)constructing the N400. *Nature Reviews. Neuroscience*, *9*(12), 920–933. https://doi.org/10.1038/nrn2532

Lau, E. F., Weber, K., Gramfort, A., Hämäläinen, M. S., & Kuperberg, G. R. (2016). Spatiotemporal Signatures of Lexical-Semantic Prediction. *Cerebral Cortex*, *26*(4), 1377–1387. https://doi.org/10.1093/cercor/bhu219

Lavidor, M., & Ellis, A. W. (2002). Orthographic Neighborhood Effects in the Right but Not in the Left Cerebral Hemisphere. *Brain and Language*, *80*(1), 63–76. https://doi.org/10.1006/brln.2001.2570

Levy, B. J., & Anderson, M. C. (2002). Inhibitory processes and the control of memory retrieval. *TRENDS in Cognitive Sciences*, *6*(7), 299–305.

Lindell, A. K. (2006). In your right mind: Right hemisphere contributions to language processing and production. *Neuropsychology Review*, *16*, 131–148. https://doi.org/10.1007/s11065-006-9011-9

Luck, S. J. (2014). *An introduction to the event-related potential technique* (Second). Cambridge, Massachusetts; London, England: MIT Press.

Manfredi, M., Cohn, N., & Kutas, M. (2017). When a hit sounds like a kiss: An electrophysiological exploration of semantic processing in visual narrative. *Brain and Language*, *169*, 28–38. https://doi.org/10.1016/j.bandl.2017.02.001

Marinkovic, K., Baldwin, S., Courtney, M. G., Witzel, T., Dale, A. M., & Halgren, E. (2011). Right hemisphere has the last laugh: neural dynamics of joke appreciation. *Cognitive, Affective & Behavioral Neuroscience*, *11*(1), 113–130. https://doi.org/10.3758/s13415-010-0017-7

Martin, C. D., Nazir, T., Thierry, G., Paulignan, Y., & Démonet, J. F. (2006). Perceptual and lexical effects in letter identification: An event-related potential study of the word superiority effect. *Brain Research*, *1098*(1), 153–160. https://doi.org/10.1016/j.brainres.2006.04.097

Martin, R. C. (2003). Language processing: Functional organization and neuroanatomical basis. *Annual Review of Psychology*, *54*, 55–89. https://doi.org/10.1146/annurev.psych.54.101601.145201

Maurer, U., Brandeis, D., & McCandliss, B. D. (2005). Fast, visual specialization for reading in English revealed by the topography of the N170 ERP response. *Behavioral and Brain Functions*, *1*, 1–12. https://doi.org/10.1186/1744-9081-1-13

McClelland, J. L., & Rumelhart, D. E. (1981). An interactive activation model of context effects in letter perception: Part 1. An account of basic findings. *Psychological Review*, *88*(5), 375–407. https://doi.org/10.1037/0033-295X.88.5.375

McGilchrist, I. (2019). *The master and his emissary: The divided brain and the making of the Western world*. Yale University Press.

Metusalem, R., Kutas, M., Urbach, T. P., & Elman, J. L. (2016). Hemispheric asymmetry in event knowledge activation during incremental language comprehension: A visual half-field ERP study. *Neuropsychologia*, *84*, 252–271. https://doi.org/10.1016/j.neuropsychologia.2016.02.004

Metusalem, R., Kutas, M., Urbach, T. P., Hare, M., McRae, K., & Elman, J. L. (2012). Generalized event knowledge activation during online sentence comprehension. *Journal of Memory and Language*, *66*(4), 545–567. https://doi.org/10.1016/j.jml.2012.01.001

Norris, D. (2013). Models of visual word recognition. *Trends in Cognitive Sciences*, *17*(10), 517–524. https://doi.org/10.1016/j.tics.2013.08.003

Osterhout, L., & Holcomb, P. J. (1992). Event-Related Brain Potentials Elicited by

Syntactic Anomaly. *Journal of Memory and Language*, *31*, 785–806.

Penolazzi, B., Hauk, O., & Pulvermüller, F. (2006). Early semantic context integration and lexical access as revealed by event-related brain potentials. *Biological Psychology*, *74*(3), 374–388. https://doi.org/10.1016/j.biopsycho.2006.09.008

Pickering, M. J., & Garrod, S. (2007). Do people use language production to make predictions during comprehension? *Trends in Cognitive Sciences*, *11*(3), 105–110. https://doi.org/10.1016/j.tics.2006.12.002

Pickering, M. J., & Garrod, S. (2013). An integrated theory of language production and comprehension. *Behavioral and Brain Science*, *36*(4), 1–64. https://doi.org/10.1017/S0140525X12001495

Poeppel, D. (2003). The analysis of speech in different temporal integration windows: Cerebral lateralization as “asymmetric sampling in time.” *Speech Communication*, *41*, 245–255. https://doi.org/10.1016/S0167-6393(02)00107-3

Price, C. J. (2012). NeuroImage A review and synthesis of the fi rst 20 years of PET and fMRI studies of heard speech , spoken language and reading. *NeuroImage*, *62*(2), 816–847. https://doi.org/10.1016/j.neuroimage.2012.04.062

Pulvermüller, F., & Shtyrov, Y. (2006). Language outside the focus of attention: the mismatch negativity as a tool for studying higher cognitive processes. *Progress in Neurobiology*, *79*(1), 49–71. https://doi.org/10.1016/j.pneurobio.2006.04.004

Pulvermüller, F., Shtyrov, Y., Hasting, A. S., & Carlyon, R. P. (2008). Syntax as a reflex: neurophysiological evidence for early automaticity of grammatical processing. *Brain and Language*, *104*(3), 244–253. https://doi.org/10.1016/j.bandl.2007.05.002

Pulvermüller, F., Shtyrov, Y., & Hauk, O. (2009). Understanding in an instant: neurophysiological evidence for mechanistic language circuits in the brain. *Brain and Language*, *110*(2), 81–94. https://doi.org/10.1016/j.bandl.2008.12.001

Rabagliati, H., Gambi, C., & Pickering, M. J. (2016). Learning to predict or predicting to learn? *Language, Cognition and Neuroscience*, *31*(1), 94–105. https://doi.org/10.1080/23273798.2015.1077979

Rabovsky, M., Hansen, S. S., & McClelland, J. L. (2018). Modelling the N400 brain potential as change in a probabilistic representation of meaning. *Nature Human Behaviour*, *2*(9), 693–705. https://doi.org/10.1038/s41562-018-0406-4

Rayner, K. (1998). Eye Movements in Reading and Information Processing : 20 Years of Research. *Psychological Bulletin*, *124*(3), 372–422.

Rayner, K., & Duffy, S. A. (1986). Lexical complexity and fixation times in reading: Effects of word frequency, verb complexity, and lexical ambiguity. *Memory & Cognition*, *14*(3), 191–201. https://doi.org/10.3758/BF03197692

Reid, V. M., & Striano, T. (2008). N400 involvement in the processing of action sequences. *Neuroscience Letters*, *433*(2), 93–97. https://doi.org/10.1016/j.neulet.2007.12.066

Rugg, M. D. (1985). The effects of semantic priming and word repitition on event-related potentials. *Psychophysiology*, *22*(6), 642–647.

Rumelhart, D. E., & McClelland, J. L. (1982). An interactive activation model of context effects in letter perception: II. The contextual enhancement effect and some tests and extensions of the model. *Psychological Review*. US: American Psychological Association. https://doi.org/10.1037/0033-295X.89.1.60

Schneider, W., Eschman, A., & Zuccolotto, A. (2002). *E-Prime user's guide*. Pittsburgh: Psychology Software Tools Inc.

Serences, J. T., & Wixted, J. T. (Eds.). (2018). *Steven's handbook of experimental psychology and cognitive science. Volume 2: Sensation, Perception & Attention* (4th ed.). Hoboken, NJ: John Wiley & Sons, Inc.

Sereno, S. (2003). Measuring word recognition in reading: eye movements and event-related potentials. *Trends in Cognitive Sciences*, *7*(11), 489–493. https://doi.org/10.1016/j.tics.2003.09.010

Sereno, S. C., Brewer, C. C., & O'Donnell, P. J. (2003). Context effects in word recognition: evidence for early interactive processing. *Psychological Science*, *14*(4), 328–333.

Shtyrov, Y., Hauk, O., & Pulvermüller, F. (2004). Distributed neuronal networks for encoding category-specific semantic information: The mismatch negativity to action words. *European Journal of Neuroscience*, *19*, 1083–1092. https://doi.org/10.1111/j.1460-9568.2004.03126.x

Smith, N. J., & Levy, R. (2013). The effect of word predictability on reading time is logarithmic. *Cognition*, *128*(3), 302–319. https://doi.org/10.1016/j.cognition.2013.02.013

St George, M., Kutas, M., Martinez, A., & Sereno, M. I. (1999). Semantic integration in reading: Engagement of the right hemisphere during discourse processing. *Brain*, *122*(7), 1317–1325. https://doi.org/10.1093/brain/122.7.1317

Staub, A. (2015). The Effect of Lexical Predictability on Eye Movements in Reading: Critical Review and Theoretical Interpretation. *Linguistics and Language Compass*. https://doi.org/10.1111/lnc3.12151

Staub, A., Grant, M., Astheimer, L., & Cohen, A. (2015). The influence of cloze probability and item constraint on cloze task response time. *Journal of Memory and Language*, *82*, 1–17. https://doi.org/10.1016/j.jml.2015.02.004

Swaab, T. Y., Ledoux, K., Camblin, C. C., Boudewyn, M. a., Caffarra, S., Pesciarelli, F., … Yaxley, R. H. (2014). Language-Related ERP Components. In U. of C. at D. Traxler, Matthew J (Department of Psychology & M. A. (University of W. Gernsbacher (Eds.), *Oxford Handbook of Psycholinguistics* (3rd ed., pp. 1–49). Oxford: Elsevier Inc.

https://doi.org/10.1016/j.neuropsychologia.2013.01.018

Taylor, W. L. (1953). “Cloze Procedure”: A New Tool for Measuring Readability. *Journalism Bulletin*, *30*(4), 415–433. https://doi.org/10.1177/107769905303000401

Thornhill, D. E., & Van Petten, C. (2012). Lexical versus conceptual anticipation during sentence processing: frontal positivity and N400 ERP components. *International Journal of Psychophysiology : Official Journal of the International Organization of Psychophysiology*, *83*(3), 382–392. https://doi.org/10.1016/j.ijpsycho.2011.12.007

Tse, C.-Y., Lee, C.-L., Sullivan, J., Garnsey, S. M., Dell, G. S., Fabiani, M., & Gratton, G. (2007). Imaging cortical dynamics of language processing with the event-related optical signal. *Proceedings of the National Academy of Sciences*, *104*(43), 17157–17162. https://doi.org/10.1073/pnas.0707901104

Van Berkum, J. J. A., Brown, C. M., Zwitserlood, P., Kooijman, V., & Hagoort, P. (2005). Anticipating upcoming words in discourse: Evidence from ERPs and reading times. *Journal of Experimental Psychology. Learning, Memory, and Cognition*, *31*(3), 443–467. https://doi.org/10.1037/0278-7393.31.3.443

van de Meerendonk, N., Indefrey, P., Chwilla, D. J., & Kolk, H. H. J. (2011). Monitoring in language perception: Electrophysiological and hemodynamic responses to spelling violations. *NeuroImage*, *54*(3), 2350–2363. https://doi.org/10.1016/j.neuroimage.2010.10.022

van de Meerendonk, N., Kolk, H. H. J., Chwilla, D. J., & Vissers, C. T. W. M. (2009). Monitoring in language perception. *Linguistics and Language Compass*, *3*(5), 1211–1224. https://doi.org/10.1111/j.1749-818X.2009.00163.x

Van Petten, C. (1993). A comparison of lexical and sentence-level context effects in event-related potentials. *Language and Cognitive Processes*, *8*(4), 485–531. https://doi.org/10.1080/01690969308407586

Van Petten, C., & Kutas, M. (1990a). Interactions between sentence context and word frequency in event-related brain potentials. *Memory & Cognition*, *18*(4), 380–393. https://doi.org/10.3758/BF03197127

Van Petten, C., & Kutas, M. (1990b). Interactions between sentence context and word frequencyinevent-related brainpotentials. *Memory & Cognition*, *18*(4), 380–393. https://doi.org/10.3758/BF03197127

Van Petten, C., & Luka, B. J. (2006). Neural localization of semantic context effects in electromagnetic and hemodynamic studies. *Brain and Language*, *97*(3), 279–293. https://doi.org/10.1016/j.bandl.2005.11.003

Van Petten, C., & Luka, B. J. (2012). Prediction during language comprehension: Benefits, costs, and ERP components. *International Journal of Psychophysiology*, *83*(2), 176–190. https://doi.org/10.1016/j.ijpsycho.2011.09.015

Vinckier, F., Dehaene, S., Jobert, A., Dubus, J. P., Sigman, M., & Cohen, L. (2007). Hierarchical Coding of Letter Strings in the Ventral Stream: Dissecting the Inner Organization of the Visual Word-Form System. *Neuron*, *55*(1), 143–156. https://doi.org/10.1016/j.neuron.2007.05.031

Vissers, C. T. W. M., Chwilla, D. J., & Kolk, H. H. J. (2006). Monitoring in language perception: The effect of misspellings of words in highly constrained sentences. *Brain Research*, *1106*(1), 150–163. https://doi.org/10.1016/j.brainres.2006.05.012

Wandell, B. A., Dumoulin, S. O., & Brewer, A. A. (2007). Visual field maps in human cortex. *Neuron*, *56*(2), 366–383. https://doi.org/10.1016/j.neuron.2007.10.012

Wang, L., Zhu, Z., & Bastiaansen, M. (2012). Integration or Predictability? A Further Specification of the Functional Role of Gamma Oscillations in Language Comprehension. *Frontiers in Psychology*, *3*(June), 187. https://doi.org/10.3389/fpsyg.2012.00187

Wicha, N. Y. Y., Bates, E. a., Moreno, E. M., & Kutas, M. (2003). Potato not Pope: human brain potentials to gender expectation and agreement in Spanish spoken sentences. *Neuroscience Letters*, *346*(3), 165–168. https://doi.org/10.1016/S0304-3940(03)00599-8

Wlotko, E. W., & Federmeier, K. D. (2007). Finding the right word: Hemispheric asymmetries in the use of sentence context information. *Neuropsychologia*, *45*(13), 3001–3014. https://doi.org/10.1016/j.neuropsychologia.2007.05.013

Wlotko, E. W., & Federmeier, K. D. (2012). So that's what you meant! Event-related potentials reveal multiple aspects of context use during construction of message-level meaning. *NeuroImage*, *62*(1), 356–366. https://doi.org/10.1016/j.neuroimage.2012.04.054

Wlotko, E. W., & Federmeier, K. D. (2013). Two sides of meaning: the scalp-recorded n400 reflects distinct contributions from the cerebral hemispheres. *Frontiers in Psychology*, *4*, 181. https://doi.org/10.3389/fpsyg.2013.00181

Potsdam Sentence Corpus 3

The stimuli used for Experiments 1 and 2 consist of 144 German items created by Michael Dambacher and colleagues for the Potsdam Sentence Corpus 3 (Dambacher, 2010). Each item consists of two context sentences (c1/c2) that manipulate contextual predictability (high vs. low) and one neutral sentence (ns) that is identical across conditions, where target words of low and high frequency are embedded. The two factors are fully counterbalanced such that each target word appears in the same target sentence, preceded by each context sentence. Context sentences were either high or low predictability depending on the target word.

Target words (italics) here are presented in the neutral sentence as high frequency/low frequency. Context 1 (c1) represents a high predictability condition for the the high frequency target, and low predictability condition for the low predictability target. Context 2 (c2) represents a high predictability condition for the the low frequency target, and low predictability condition for the high predictability target.

1. c1: Gustav sah keinen Ausweg mehr aus seiner Lage und ging zu einem Priester.
   c2: Gustav war nun schon seit vier Wochen arbeitslos und ging zum Arbeitsamt.
   ns: Er hoffte, dort endlich einen guten *Rat/Job* zu bekommen.
2. c1: Uwe war so konzentriert, dass er die Zeit vergaß und überrascht war, als die Pausensirene hupte.
   c2: Uwe hatte keine Ahnung mehr, warum er gerade das große Beil aus der

Garage geholt hatte.

ns: Verwundert blickte er auf die *Uhr/Axt* in seiner Hand.

3. c1: Ingo erkannte, dass seine Strategie nicht wie geplant aufgehen würde.

   c2: Ingo erkannte, dass er den Baum mit seiner kleinen Feile niemals fällen könnte.

   ns: Er brauchte dringend eine gute *Idee/Säge* für sein Unterfangen.

4. c1: Die Mutter sah, dass sie viel zu viel Teig für einen kleinen Kuchen gemacht hatte.

   c2: Die Mutter freute sich sehr über den riesigen Blumenstrauß zu ihrem Geburtstag.

   ns: Geschwind holte sie die große *Form/Vase* aus dem Schrank.

5. c1: Yuri wollte später unbedingt Komponist werden.

   c2: Yuri wollte später unbedingt Zauberer werden.

   ns: Nichts faszinierte ihn mehr als die *Musik/Magie* seiner Vorbilder.

6. 6. c1: Frauke fand ihre Waden und Schenkel trotz des vielen Laufens zu dick.

   c2: Frauke zog das Pflaster von der Stelle ihres Fußes, wo der Schuh immer drückt.

   ns: Mit finsterer Miene betrachtete sie ihre *Beine/Blase* im Spiegel.

7. c1: Bis es zum Streit kam, war der Heerführer Flint ein guter Freund des Landes.

   c2: Im ganzen Land kannte man den Seeräuber Flint, der viele Schätze erobert hatte.

   ns: Mittlerweile galt er als der schlimmste *Feind/Pirat* aller Zeiten.

8. c1: Keinesfalls konnte der Mechaniker die Werkstatt alleine putzen.

   c2: Allein mit Wasser bekam der Mechaniker die Schmiere nicht von den Fingern.

   ns: Er brauchte dringend ein bisschen *Hilfe/Seife* und viel Geduld.

9. c1: Beim Joggen fiel Simon ein, was er sich zu Weihnachten schenken lassen könnte.

   c2: Beim Joggen schmerzte Simons Wade plötzlich und die Muskeln verspannten sich.

ns: Tatsächlich hatte er einen ungewöhnlichen *Wunsch/Krampf* und er strauchelte.

10. c1: Johannes hörte in einiger Entfernung ein riesiges Flugzeug kommen.
    c2: Bevor Johannes durch den Berg ging, wollte er sicher sein, dass ihm kein Zug entgegenkam.
    ns: Er blickte angestrengt in den *Himmel/Tunnel* und lauschte aufmerksam.
11. c1: Anita hatte den vierten Raum ihrer Wohnung früher nur für Klamotten genutzt.
    c2: In der Abstellkammer fand Anita die Karnevalsverkleidung, die sie früher selber trug.
    ns: Dieses Jahr vermietete sie das *Zimmer/Kostüm* zum ersten Mal.
12. c1: Sabine hatte eine ausführliche Beschreibung des Tathergangs verfasst.
    c2: Bei der Personenkontrolle fragte der Beamte Sabine nach ihren Papieren.
    ns: Etwas zögerlich überreichte sie nun ihren *Bericht/Ausweis* dem Polizisten.
13. c1: Pablo hatte das Konzept gut vorbereitet und sein Vorhaben genau durchdacht.
    c2: Pablo konnte das Netz kaum an Bord ziehen, so voller Fische war es.
    ns: Er war sehr zufrieden mit seinem *Plan/Fang* und grinste.
14. c1: Markus saß in seinem Auto im Halteverbot, als plötzlich ein Polizist an seine Scheibe klopfte.
    c2: Markus fuhr mit seinem geschlossenen Kabrio durch den Regen, als plötzlich die Sonne hervorkam.
    ns: Markus lächelte und öffnete das *Fenster/Verdeck* in beachtlicher Geschwindigkeit.
15. c1: Besorgt betrachtet Tobi sein blau angelaufenes Handgelenk.
    c2: Besorgt betrachtet Tobi seinen blau angelaufenen Fußnagel.
    ns: Gestern stieß er sich äußerst schmerzhaft seinen *Arm/Zeh* am Schrank.

16. c1: Manche Industriezweige erzielen wirklich unglaublich hohe Gewinne.
    c2: Manche Industriezweige produzieren wirklich unglaublich viel Abfall.
    ns: Man fragt sich, was sie mit ihrem *Geld/Müll* machen wollen.
17. c1: Martina wurde von ihrem Freund gefragt, was sie da gerade lese.
    c2: Martina sah, wie ihr Freund ungeschickt versuchte, mit dem Boot am Steg anzulegen.
    ns: Kurzerhand warf sie ihm das dicke *Buch/Seil* zu und lachte.
18. c1: Florian tat alles dafür, um das Medizinstudium zu schaffen.
    c2: Florian tat alles dafür, um groß raus zu kommen.
    ns: Er wollte später unbedingt ein berühmter *Arzt/Star* in Amerika werden.
19. c1: In Nordamerika sind Gewalt und Kriminalität ein großes Problem.
    c2: In Nordamerika ist das Fischen ein beliebter Zeitvertreib.
    ns: In jedem Haushalt findet man dort eine *Waffe/Angel* im Schrank.
20. c1: Bettina mochte den Hausmeister sehr und beschloss, ihm ein paar nette Zeilen zu schreiben.
    c2: Bettina ärgerte den Hausmeister immer, wenn er den Hof kehren wollte.
    ns: Voll heimlicher Freude versteckte sie den *Brief/Besen* in der Kammer.
21. c1: Gestern waren am Flussufer plötzlich alle Felder mit Jauche gedüngt.
    c2: Gestern waren am Flussufer plötzlich alle Bäume abgenagt.
    ns: Die Verantwortung dafür trägt wohl ein *Bauer/Biber* aus der Umgebung.
22. c1: Nach der langen Krankheit war Nico sehr schwach.
    c2: Seit der Pause hatte Nico nichts mehr getrunken.
    ns: Langsam aber sicher bekam er wieder *Kraft/Durst* und stand auf.
23. c1: Heute sollten die Kinder in der Schule geometrische Figuren malen.
    c2: Heute sollten die Kinder in der Schule heimische Insekten malen.
    ns: Als erstes zeichneten viele Schüler einen dicken *Kreis/Käfer* mit Bleistift.
24. c1: Frederike erzählte oft Geschichten und die anderen umringten sie.
    c2: Frederike kam richtig ins Schwitzen, als der Bademeister den Aufguss machte.
    ns: Sie saß gerne in der *Mitte/Sauna* und genoss das Gefühl.

Potsdam Sentence Corpus 3

25. c1: Schemenhaft erkannte Philipp zwischen den Bäumen eine weiße, leuchtende Gestalt.
    c2: Schemenhaft erkannte Philipp zwischen den Bäumen eine kleine, bärtige Gestalt.
    ns: Bei dem Gedanken, es könnte ein *Geist/Zwerg* sein, erschrak Philipp.
26. c1: Im Krankenhaus ist Kilian am liebsten allein und will keinen Menschen sehen.
    c2: Im Krankenhaus ist Kilian im Moment der einzige Epileptiker.
    ns: Gerade gestern bekam er einen unerfreulichen *Besuch/Anfall* in seinem Zimmer.
27. c1: Carsten sah ein, dass er den neuen Schrank nicht ohne Hilfe montieren konnte.
    c2: Carsten sah ein, dass das Loch in der Wand für die dicke Schraube zu klein war.
    ns: Also holte er seinen großen *Bruder/Bohrer* aus dem anderen Zimmer.
28. c1: Als nach zehn Minuten noch niemand da war, hofften die Schüler, der Unterricht würde ausfallen.
    c2: Die Schüler sahen den hellen Blitz am Himmel und hielten gespannt den Atem an.
    ns: Dann hörten sie draußen den grummelnden *Lehrer/Donner* und sie erschraken.
29. c1: Seine Haltung war stramm, seine Stiefel glänzten und sein Gewehr hing gerade.
    c2: Sein Iglu war makellos, sein Mantel aus feinstem Robbenfell und seine Jagdkünste beispielhaft.
    ns: Knud war ein vorbildlicher und beliebter *Soldat/Eskimo* und wurde bewundert.
30. c1: Friedrich übernahm immer schnell das Kommando und die Menschen folgten und vertrauten ihm.

c2: Friedrich erzählte immer haarsträubende Geschichten, von denen natürlich keine stimmte.
ns: Er war wirklich ein geborener *Führer/Lügner* und wollte Politiker werden.

31. c1: Es stellte sich heraus, dass die zwei Mädchen Halbschwestern waren.
c2: Die zwei Mädchen präsentierten sich ihre neuen Haarschnitte und erschraken.
ns: Sie hatten beide die gleiche *Mutter/Frisur* und sie waren schockiert.
32. c1: Peter hatte ein Ölbild gemalt und wollte es nun gerne einfassen.
c2: Peter wollte ein Ölbild malen und hatte bereits Farbe und eine Leinwand.
ns: Ihm fehlte aber noch ein geeigneter *Rahmen/Pinsel* und etwas Platz.
33. c1: Beim Kochen dachte die Mutter nach und fragte sich, ob ihren Kindern etwas zugestoßen war.
c2: Der Mutter fiel plötzlich ein, dass seit drei Tagen der Fisch im Kofferraum lag, und sie öffnete ihn.
ns: Geradezu unerträglich war dieser entsetzliche *Gedanke/Gestank* und ihr wurde schlecht.
34. c1: Schon als Kind war Lucas immer der beste in Mathe, Deutsch und Biologie.
c2: Schon als Kind erreichte Lucas im Wasser Tiefen von dreißig Metern.
ns: Er war ein ganz hervorragender *Schüler/Taucher* und wollte Meeresforscher werden.
35. c1: Von den anderen Studenten wurde Chris oft für seine leserlichen Notizen gelobt.
c2: Mit den anderen Studenten saß Chris gern am Lagerfeuer und zupfte ein paar Akkorde.
ns: Er hatte eine sehr schöne *Schrift/Gitarre* von seiner Mutter geerbt.
36. c1: Als Fotomodel war Marianne sehr beliebt und vor allem ihr Antlitz war oft in Zeitschriften zu sehen.
c2: Wenn ihre Eltern kamen, deckte Marianne den Tisch immer mit den goldenen

Messern und Gabeln.

ns: Sie hatte wirklich ein schönes *Gesicht/Besteck* und pflegte es gut.

37. c1: Obwohl Lukas es eilig hatte, half er der gebrechlichen Dame über die gefährliche Straße.

    c2: Gestern erschien Lukas ein kleines, elfenähnliches Wesen, das ihm drei freie Wünsche anbot.

    ns: Dies war zweifellos eine gute *Tat/Fee* gerade zum rechten Zeitpunkt.

38. c1: Herr Betz kann sich drei Äpfel gleichzeitig zwischen die Backen stecken.

    c2: Herr Betz hat noch nie etwas gespendet oder verschenkt.

    ns: Er ist stadtbekannt für seinen enormen *Mund/Geiz* und leidet darunter.

39. c1: Nach Feierabend verabschiedete sich der Lehrling höflich beim Bäckermeister.

    c2: Der Lehrling fragte den Bäckermeister nach einem Treibmittel für den Teig.

    ns: Der Meister reichte ihm lächelnd die *Hand/Hefe* und ging hinaus.

40. c1: Einige fragten sich, warum der Fremde Toilettenpapier mit sich herumtrug.

    c2: Einige dachten, der schwarz gekleidete Fremde sei der Tod höchstpersönlich.

    ns: In seiner Hand schwenkte er eine *Rolle/Sense* und schaute finster.

41. c1: Pedro drehte sich zu der Frau um, die ihn aus feurigen Augen wutentbrannt anstarrte.

    c2: Pedro stand in der Arena, schwenkte lässig sein rotes Tuch und ließ sich als Torero feiern.

    ns: Da erst bemerkte er den zornigen *Blick/Stier* und er erschrak.

42. c1: Eigentlich wollte Theo heute am Strand in den Schatten, aber alle Schirme waren besetzt.

    c2: Der einst vornehme und wohlhabende Theo verlor alles und endete schließlich als Penner.

    ns: Nun lag er jammernd in der *Sonne/Gosse* und war verzweifelt.

43. c1: Dem Piloten war es nur in seiner Freizeit gestattet Alkohol zu trinken, jedoch nicht jetzt.

c2: Der Frau des Piloten wurde gesagt, dass ihr Mann in wenigen Minuten landen würde.

ns: Er befand sich momentan im *Dienst/Anflug* und musste sich konzentrieren.

44. c1: Die Polizei war ihnen dicht auf den Fersen, bevor sie das Land verließen.

    c2: Sie konnten die Wasserlache nicht umgehen, deswegen mussten sie springen.

    ns: Sie schafften es gerade noch, über die *Grenze/Pfütze* zu gelangen.

45. c1: Der Bankräuber sah, dass es sieben Uhr war, und um acht wollte die Polizei die Bank stürmen.

    c2: Der Bankräuber hatte mittlerweile sieben von den acht Bankangestellten freigelassen.

    ns: Er hatte jetzt nur noch eine *Stunde/Geisel* und beschloss aufzugeben.

46. c1: Heidi mochte es, wenn ihr Krankengymnast italienisch mit ihr redete.

    c2: Heidi entspannte sich, als ihr italienischer Krankengymnast ihren Rücken durchknetete.

    ns: Sie war sehr angetan von seiner *Sprache/Massage* und seufzte leise.

47. c1: Michael hatte bereits dreimal geklingelt, doch niemand öffnete ihm.

    c2: Während des Rennens schafften es die Mechaniker nicht, Michaels Reifen zu wechseln.

    ns: Er stand schon seit Minuten an der *Tür/Box* und wurde ärgerlich.

48. c1: Das Ende von Kapitän Ahab war gleichsam traurig und grausam.

    c2: Durch alle Weltmeere segelte Kapitän Ahab auf der Suche nach Moby Dick.

    ns: Zusammen mit seiner Mannschaft fand er den *Tod/Wal* im indischen Ozean.

49. c1: Alle drängten Frank, endlich ein Foto seiner neuen Freundin zu zeigen.

    c2: Durch den Wind waren Franks Haare ganz zerzaust, was er gar nicht leiden konnte.

    ns: In seiner Tasche kramte er nach einem *Bild/Kamm* und wurde fündig.

50. c1: Für ihren Garten hatten die Kunzes einen Lastwagen voller Humus kommen lassen.

    c2: Anscheinend hatten alle Obstbäume im Garten der Kunzes gleichzeitig ihre

Blätter verloren.

ns: Vor ihrem Haus lag ein riesiger Haufen *Erde/Laub* mitten im Weg.

51. c1: Thomas schlenderte gestern ganz langsam und gemütlich durch den Park.

    c2: Gestern im Casino verlor Thomas jedes Spiel und sehr viel Geld.

    ns: An diesem Abend hatte er richtig viel *Zeit/Pech* und er grübelte.

52. c1: Nach der langen Fahrt war Pascal völlig erschöpft und nicht mehr fähig zu denken.

    c2: Nach der langen Fahrt durch die Wüste hatte Pascal keinen Tropfen Benzin mehr.

    ns: Gähnende Leere herrschte in seinem *Kopf/Tank* und er brauchte eine Pause.

53. c1: Der Lehrer hatte gesagt, das Prinzip des Bumerangs sei ziemlich einfach.

    c2: Als sie zurückkamen, war das Lagerfeuer heruntergebrannt und schimmerte noch rötlich.

    ns: Marco warf das gebogene Holz in die *Luft/Glut* und wartete ab.

54. c1: Während der Fahrt hatte sich Dieter geschworen, das Büro seines Chefs heute nicht zu betreten.

    c2: Dieter dachte, er käme pünktlich ins Büro, denn zunächst war wenig Verkehr auf der Autobahn.

    ns: Wenig später stand er aber mitten im *Raum/Stau* und er fluchte.

55. c1: Caroline liebte es, sich die Zeit mit Schach, Dame oder Mühle zu vertreiben.

    c2: Caroline liebte es, die Fotos aus ihrer Kindheit anzusehen.

    ns: Oft holte sie aus dem Regal ein *Spiel/Album* und öffnete es.

56. c1: Bei dem Hochwasser war das etwas höher gelegene Rom das einzige trockene Land.

    c2: In der Bibel steht, dass es während der Sintflut vierzig Tage und Nächte lang regnete.

    ns: Viele Tiere flüchteten damals in die *Stadt/Arche* und harrte dort aus.

57. c1: Schon als kleiner Junge hing Aramis sehr an seinen Eltern.

    c2: Schon als kleiner Junge war Aramis ein hervorragender Fechter.

ns: Niemals verließ er das Haus, ohne seinen *Vater/Degen* nach draußen mitzunehmen.

58. c1: Robert wollte die ganze Wohnung neu streichen.
    c2: Zum Renovieren wollte Robert den ganzen Fußboden abdecken.
    ns: Er ging in den Baumarkt und kaufte *Farbe/Folie* für achtzig Quadratmeter.
59. c1: Paula sah, dass ihr Hund mittlerweile schlief, und sie wollte ihn nicht wecken.
    c2: Paula sah, dass die Kohlen mittlerweile glühten, und sie bekam Hunger.
    ns: Sie legte die Würstchen vorsichtig auf den *Boden/Grill* und trat zurück.
60. c1: In all den Jahren hat Stefan seinen Eltern noch nie Kummer bereitet.
    c2: In all den Jahren, seit Stefan die Ziegenherde hütet, hat er noch kein Tier verloren.
    ns: Alle sagten, er sei ein guter *Junge/Hirte* mit recht erstaunlichen Fähigkeiten.
61. c1: Frau Beyer war begeistert, als sie die neue Lampe im Wohnzimmer anschaltete.
    c2: Frau Beyer war begeistert, als sie die Ausstattung des 6-Sterne Hotels sah.
    ns: Sie staunte über so viel *Licht/Luxus* und klatschte in die Hände.
62. c1: Als junger Mann entdeckte van Gogh sein Talent für die Malerei.
    c2: Als junger Mann war van Gogh schwer alkohol- und drogenabhängig.
    ns: Er verfiel ganz und gar der *Kunst/Sucht* und vernachlässigte alles andere.
63. c1: Manche fangen bei großer Nervosität an zu krächzen.
    c2: Manche fangen bei großer Nervosität an zu hyperventilieren.
    ns: Das wichtigste ist dann, die Kontrolle der *Stimme/Atmung* wieder zu erlangen.
64. c1: Alle Gläubigen hatten fröhliche Gesichter, als sie nach dem Gottesdienst nach Hause gingen.
    c2: Alle Spieler hatten fröhliche Gesichter, als sie nach der Halbzeitpause wieder auf den Platz liefen.
    ns: Auch Toni kam lachend aus der *Kirche/Kabine* und schnappte nach Luft.

Potsdam Sentence Corpus 3

65. c1: Das Verkehrsamt hatte bei dem hohen Verkehrsaufkommen bis zuletzt vor Unfällen gewarnt.

    c2: Die Bergwacht warnte nach dem starken Schneefall vor Abgängen, bis das Unglück geschah.

    ns: Mitten durch den Ort ging die gefährliche *Straße/Lawine* bis ins Tal.

66. c1: Der Kunde hatte plötzlich einen ganz trockenen Hals und musste husten.

    c2: Der Kunde kaufte auf einen Schlag mehr als hundert Computer.

    ns: Der Händler gab ihm deshalb ein bisschen *Wasser/Rabatt* und nickte großmütig.

67. c1: Schon Stunden vor dem Wirbelsturm legte der Hund die Ohren an und begann zu knurren.

    c2: Dort, wo der Hirsch gelegen hatte, begann der Hund zu schnuppern und zielstrebig der Spur zu folgen.

    ns: Offensichtlich witterte er bereits die *Gefahr/Fährte* und wollte darauf aufmerksam machen.

68. c1: Marco sah ein, dass er das Problem auf diese Weise nicht in den Griff bekommen würde.

    c2: Marcos Rasierer war mittlerweile völlig stumpf geworden.

    ns: Also suchte er nach einer neuen *Lösung/Klinge* und rief seine Frau.

69. c1: Dieter war anscheinend sehr stolz auf seinen neuen Job.

    c2: Dieter war es anscheinend nicht peinlich, dass er kein Haar mehr auf dem Kopf hatte.

    ns: Er redete nur noch von seiner *Arbeit/Glatze* und nervte die anderen.

70. c1: Nils hatte heute eine Mathearbeit, war aber ziemlich spät aufgestanden.

    c2: Nils war völlig verschwitzt, als er vom Joggen nach Hause kam.

    ns: Seine Mutter schickte ihn sofort in die *Schule/Dusche* und schimpfte laut.

71. c1: Fred telefonierte schon ewig und um sein Gespräch zu beenden, forderte er eine weitere Stunde.

    c2: Fred wollte Spiegeleier für alle machen, fand aber nichts zum Braten.

ns: Matthias gab ihm dafür lediglich eine *Minute/Pfanne* und zudem klare Anweisungen.

72. c1: In der Prüfung hatte Anna keine Ahnung, was der Professor mit seiner letzten Frage wollte.
    c2: Der Professor hatte gefragt, ob Anna mit ihm ins Kino ginge, aber sie hatte überhaupt keine Lust.
    ns: Jetzt suchte sie verzweifelt nach einer *Antwort/Ausrede* und dachte angestrengt nach.
73. c1: Friedrich war nun schon König, aber damit war er immer noch nicht zufrieden.
    c2: Friedrich machte schon als Kind leckere Brezeln und für Brot und Brötchen war er Spezialist.
    ns: Er wollte später unbedingt einmal *Kaiser/Bäcker* werden und dachte täglich daran.
74. c1: Der Nomade war sehr einsam und suchte eine Gemahlin.
    c2: Der Nomade wanderte durch die Wüste und langsam ging der Wasservorrat zur Neige.
    ns: Eher zufällig fand er dann endlich eine *Frau/Oase* und er jubelte.
75. c1: Bruno half gerne alten und bedürftigen Menschen und brachte sie häufig zum Arzt.
    c2: Fahrgäste fuhren gerne mit Bruno, weil sein gelbes Auto gepflegt und der Fahrpreis günstig war.
    ns: Bruno hatte zweifellos ein gutes *Herz/Taxi* und er war deswegen beliebt.
76. c1: Adalbert flüsterte sterbend, dass seine Nachbarin seinen Besitz erben sollte.
    c2: Adalbert schenkte der Nachbarin seinen Balsamico, weil ihrer leer war.
    ns: Dies war gleichzeitig auch sein letzter *Wille/Essig* und seine letzten Worte.
77. c1: Als die Sonne untergegangen war, setzten die Forscher in der Wildnis starken Kaffee auf.
    c2: Die Forscher in der Wildnis ahnten nicht, dass es in den nächsten Monaten

nicht regnen würde.

ns: Vor ihnen lag eine lange *Nacht/Dürre* und der Ausgang war ungewiss.

78. 78. c1: Keiner traute sich mit dem Auto über die morsche Brücke, nur Hans trat aufs Gas.

    c2: Alle blieben mit Motorschaden oder geplatzten Reifen liegen, nur Hans schaffte es ins Ziel.

    ns: Anders als die anderen hatte Hans keine *Angst/Panne* und wurde gefeiert.

79. c1: Onkel Albert lächelte auf dem Sterbebett, als er über alles nachdachte.

    c2: Onkel Albert verkaufte auch Süßigkeiten und Zigaretten in seinem kleinen Zeitungsstand.

    ns: Er war sehr zufrieden mit seinem schönen *Leben/Kiosk* und dankbar dafür.

80. c1: Philipp regierte das Land mit gerechter Hand und er sorgte gut für seine Untertanen.

    c2: Philipp hat bisher jedes Flugzeug selbst unter schwersten Bedingungen sicher gelandet.

    ns: Im Grunde war er ein hervorragender *König/Pilot* mit einem scharfen Verstand.

81. c1: Ernst war vom Anstehen an der Kasse so müde, dass er im Bus einschlief.

    c2: Ernst sah gar nicht hin, als die Verkäuferin alles in die beiden Plastikbeutel packte.

    ns: Erst zu Hause öffnete er die *Augen/Tüten* und atmete tief ein.

82. c1: Die Sportler prügelten wie wild aufeinander ein und mehrmals ging einer blutend zu Boden.

    c2: Die Sportler schoben ihre Niederlage auf die neue und ungewohnte Beschichtung des Bodens.

    ns: Es war ein sehr harter *Kampf/Belag* und einige schüttelten den Kopf.

83. c1: Der Mann auf dem Bild hantierte mit Modellen der Flotte des Columbus.

    c2: Der Mann auf dem Bild trug eine goldene Krone und saß würdevoll auf einem

Thron.

ns: In seiner rechten Hand hielt er ein *Schiff/Zepter* von beachtlicher Länge.

84. c1: Timo kroch aus dem Zelt, streckte sich ausgiebig und atmete tief die klare, frische Luft.

    c2: Timo war begeistert, als er das riesige bunte Zelt, die vielen Tiere und die lustigen Clowns sah.

    ns: Es war ein ganz herrlicher *Morgen/Zirkus* und Timo fühlte sich prima.

85. c1: Der Entführer liebte Anna sehr und er wollte sie schon lange heiraten.

    c2: Der Entführer wollte Anna eigentlich nur fesseln, aber ihr ständiges Geplapper ging ihm auf die Nerven.

    ns: Jetzt machte er ihr endlich einen *Antrag/Knebel* und holte tief Luft.

86. c1: Ihre zwei Zimmerchen sind Karin einfach zu klein geworden.

    c2: Karin hat sich während der Schwangerschaft mit ihrer Geburtshelferin verstritten.

    ns: Sie sucht momentan überall nach einer neuen *Wohnung/Hebamme* zu günstigen Konditionen.

87. c1: Horst hatte erst gestern beim Verlag angerufen und die Frankfurter Allgemeine abonniert.

    c2: Horst hatte letzte Woche vergessen, den Rechnungsbetrag an seine Werkstatt zu überweisen.

    ns: Heute fand er im Briefkasten dann die *Zeitung/Mahnung* und war erstaunt.

88. c1: Obwohl das Telefon klingelte, hörte Jörg nicht auf, an seiner Seminararbeit zu schreiben.

    c2: Seit ein paar Tagen war Jörg ganz lustlos und deprimiert, und auch die Zukunft machte ihm Angst.

    ns: Er steckte gerade mitten in einem *Satz/Tief* und hätte Hilfe brauchen können.

89. c1: Williams kleiner Sohn war über und über mit Schlamm beschmiert, als er nach Hause kam.

    c2: Williams Diebstahl aus der Schiffskombüse wurde schnell bemerkt und nun verbüßte er die Strafe.

ns: Mit aller Sorgfalt schrubbte William das *Kind/Deck* und vergaß dabei keine Stelle.

90. c1: Für Wolfgang war es das Schönste, als sein kleiner Daniel geboren wurde.

    c2: Wolfgang liebte seine schönen, langen Haare, die meist ein Gummi zusammenhielt.

    ns: Er war sehr stolz auf seinen *Sohn/Zopf* und sprach oft über ihn.

91. 91. c1: Die Schlange an der Kasse war zwar etwas länger, aber Udo wartete geduldig.

    c2: Udo brach zum Hafen auf, denn er wollte mit seinem Auto zur Insel übersetzen.

    ns: Nach zehn Minuten war er an der *Reihe/Fähre* und löste ein Ticket.

92. c1: Der Züchter hatte sich alles genau erklären lassen und beinahe auch alles verstanden.

    c2: Der Züchter hatte soeben neun seiner zehn Pferde verkauft.

    ns: Jetzt hatte er nur noch eine *Frage/Stute* und kratzte sich am Kinn.

93. c1: Gustav wollte, dass Achim mal das Bier in dem riesigen Fass sieht.

    c2: Gustav hatte schon alle Zutaten für das Bier besorgt: Hopfen, Malz und Wasser.

    ns: Im Keller wollte er es *zeigen/brauen* und auch kosten.

94. c1: Anna fand keine Möglichkeit, ihren Cocktail kurz abzustellen.

    c2: Anna fand nicht die Zeit, sich den Cocktail selbst zuzubereiten.

    ns: Sie bat Bert, ihn zu *halten/mixen* und regelmäßig umzurühren.

95. c1: Lisa hielt einen großen Brotlaib im Arm, aber langsam wurde er ihr zu schwer.

    c2: Lisa hatte keine Zeit mehr, den Brotlaib in den Ofen zu schieben.

    ns: Ihr Mann bot an, ihn zu *tragen/backen* und aufzuschneiden.

96. c1: Helmut fiel bei der Führerscheinprüfung positiv auf.

    c2: Helmut versuchte, ein Loch in die Wand zu bekommen.

    ns: Er konnte schon recht gut *fahren/bohren* und erntete Lob.

97. c1: Der Lehrer war nicht fähig, komplexe Sachverhalte verständlich darzustellen.

    c2: Der Lehrer sollte seiner Tochter einen Zopf machen, was ihm aber nicht gelang.

    ns: Er konnte einfach nicht gut *erklären/flechten* und verzweifelte daran.

98. c1: Julia war taub.

    c2: Julia hatte keine kräftigen Hände und besaß auch keinen Schemel.

    ns: Sie konnte die muhende Kuh nicht *hören/melken* und weinte deswegen.

99. c1: Schon seit Wochen dachte Conny daran, sich umzubringen.

    c2: Conny ließ sich jede Falte operieren, denn sie war dem Jugendwahn verfallen.

    ns: Sie wollte auf keinen Fall mehr *leben/altern* und war betrübt.

100. c1: Ina schaute Heiners Hände an, aber bloßes Ansehen war ihr zu wenig.

     c2: Ina schaute Heiners Hände an und bemerkte, dass sie eiskalt waren.

     ns: Sie nahm sie, um sie zu *fühlen/wärmen* und zu drücken.

101. c1: Kurt benutzte ständig die Sachen seines Bruders, ohne ihn zu fragen.

     c2: Kurt hatte schon wegen mehrerer Diebstähle im Gefängnis gesessen.

     ns: Auch das Radio wollte er einfach *nehmen/klauen* und anschließend verkaufen.

102. c1: Knut hatte das Vermögen vor sich liegen, aber er war blind.

     c2: Knut gierte schon nach dem großen Vermögen, aber das Testament war ungültig.

     ns: Deshalb konnte er das Geld nicht *sehen/erben* und er fluchte.

103. c1: Die Wanderer hatten nur noch einen einzigen Apfel, aber jeder wollte ein Stück davon.

     c2: Die Wanderer waren erschöpft vom steilen Berganstieg und griffen nach dem Proviant.

     ns: Sie beschlossen also kurzerhand zu *teilen/rasten* und taten dies auch.

104. c1: Linda bettelte im Laden um ein bisschen Rabatt für die Hose.

     c2: Linda war die Hose viel zu lang.

ns: Sie musste das Kleidungsstück unbedingt *haben/kürzen* und zum Geburtstag anziehen.

105. c1: Da der Hund viel zu klein war, bekam er eine Hormontherapie.

c2: Der Hund entdeckte einen Eindringling in seinem Revier.

ns: Daraufhin begann das Tier zu *wachsen/bellen* und laut zu knurren.

106. c1: Emil hatte sich den Magen verdorben und beförderte nun alles wieder hinaus.

c2: Emil hatte nichts mehr zu essen.

ns: Schon seit Tagen musste er *brechen/hungern* und ihm war elend.

107. 107. c1: Annika kam nicht an das Hemd, das weit oben im Schrank lag.

c2: Annikas Hemd war völlig zerknittert.

ns: Sie bat ihre Mutter, es ihr zu *geben/bügeln* und ihr anzuziehen.

108. c1: Carola wurde noch mal für einen Moment ins Wartezimmer geschickt.

c2: Carola wollte ihren Schutz gegen Röteln auffrischen lassen.

ns: Der Arzt wollte sie nachher wieder *rufen/impfen* und tat dies auch.

109. c1: Hausmeister Tim nahm sich vor, sein Kreuz bei der SPD zu machen.

c2: Hausmeister Tim musste die Flure der Stadtverwaltung mit seinem Besen säubern.

ns: Er ging ins Rathaus, um zu *wählen/fegen* und seiner Pflicht nachzukommen.

110. c1: Die Sekretärin wollte, dass der Chef ihr einen Gefallen tut.

c2: Die Sekretärin hätte zu ihrem Chef gern "Konrad" gesagt.

ns: Aber sie traute sich nicht, ihn zu *bitten/duzen* oder zu fragen.

111. c1: Susi ruhte sich am Flussufer auf ihrer Decke aus.

c2: Susi lief zum Fluss, um Fische zu fangen.

ns: Sie liebte es sehr, dort zu *liegen/angeln* und sich zu sonnen.

112. c1: Die Musiklehrerin probte mit den Schülern ein neues Lied.

c2: Bei der Probe forderte die Musiklehrerin die Schüler auf, es den Bienen gleichzutun.

ns: Sie sollten nun die erste Strophe *singen/summen* und im Takt klatschen.

113. c1: Elvira erzählte Martin so viele Witze.
c2: Martin war so müde.
ns: Die ganze Zeit musste er laut *lachen/gähnen* und dabei grunzte er.

114. c1: Der kleine Sohn stieß immer wieder mit seinem Fuß gegen das Schienbein.
c2: Der kleine Sohn stellte immer wieder die gleiche Frage.
ns: Die Mutter schimpfte, er solle aufhören zu *treten/nerven* und ruhig sein.

115. c1: Peter hat großen Spaß, bei Versteigerungen durch häufiges Handheben den Preis in die Höhe zu treiben.
c2: Peter hat großen Spaß, mit dem Schlitten einen steilen Berg herunter zu fahren.
ns: Am liebsten würde er nie aufhören zu *bieten/rodeln* und zu grinsen.

116. c1: Anne fand es großartig, ihren Horizont zu erweitern, indem sie anspruchsvolle Bücher las oder in Museen ging.
c2: Anne fand es großartig, am Strand zu liegen und knackig braun zu werden.
ns: Sie liebte es, sich zu *bilden/sonnen* und mit Freundinnen zu diskutieren.

117. c1: Hannes und Rita hatten verschiedene Bälle zur Auswahl.
c2: Hannes und Rita aßen Kirschen und sammelten die Kerne.
ns: Sie wollten wissen, wer am weitesten *werfen/spucken* kann, ohne zu schummeln.

118. c1: Erich war an Knochenkrebs erkrankt und kämpfte um sein Leben.
c2: Erich unterließ es, in den Ring zu steigen, denn seine rechte Hand war verletzt.
ns: So wollte er auf keinen Fall *sterben/boxen* und er weinte bitterlich.

119. c1: Die Lehrerin hatte schon alles besorgt: Mathebücher, Bleistifte und kariertes Papier.
c2: Die Lehrerin hatte schon alles besorgt: Kleber, Schere, Krepppapier und Buntstifte.
ns: Sie wollte mit den Kindern heute *rechnen/basteln* und stieß auf Begeisterung.

Potsdam Sentence Corpus 3

120. c1: Der Vater wollte Linda noch nicht zum Essen rufen, weil sie gerade mit ihren Puppen beschäftigt war.

    c2: Während Linda nervös herumhüpfte, ließ sich der Vater viel Zeit, bevor er ihr das Geschenk übergab.

    ns: Er ließ sie erst noch ein bisschen *spielen/zappeln* und war belustigt.

121. c1: Kurt war vom vielen Rad fahren unglaublich müde.

    c2: Kurt war vom Camping begeistert und wollte keinen anderen Urlaub mehr machen.

    ns: Er wollte von jetzt an nur noch *schlafen/zelten* und sich entspannen.

122. c1: Hans nimmt sein Lieblingsbuch überall hin mit.

    c2: Hans entspannt sich abends gern im warmen Wasser in der Wanne.

    ns: Er liebt es, in aller Ruhe zu *lesen/baden* und zu träumen.

123. c1: Lukas störte es, der Mutter tatenlos beim Arbeiten zuzusehen.

    c2: Lukas störte es, dass der Rasen auf dem Hof schon wieder so lang war.

    ns: Deshalb wollte er an diesem Nachmittag *helfen/mähen* und die Treppe putzen.

124. c1: Achim hatte ständig Durst.

    c2: Achim rauchte einen Joint nach dem anderen.

    ns: Den halben Tag verbrachte er damit zu *trinken/kiffen* und zu schlafen.

125. c1: Der Pfarrer hatte Manuela schon oft gedroht, sie zu verprügeln.

    c2: Der Pfarrer hatte erklärt, dass er Manuela bei der Zeremonie Wasser über den Kopf schütten würde.

    ns: Heute wollte er sie nun anscheinend *schlagen/taufen* und im Anschluss predigen.

126. c1: Kevin fand, dass das Klavier mittlerweile ganz furchtbar schief klang.

    c2: Kevin wollte den Teppich auch unter dem Klavier verlegen.

    ns: Er sagte den Männern, sie sollen es *stimmen/anheben* und anschließend wegtragen.

127. c1: Carola wollte nicht, dass Dietrich bei der Kälte nach Hause geht.
c2: Carola rief Dietrich, da es sehr kalt war und sie den Ofen nicht bedienen konnte.
ns: Sie bat ihn ausdrücklich zu *bleiben/heizen* und sich zu ihr zu setzen.

128. c1: Man braucht Geduld, um Pilze zu finden, da sie oft versteckt im Unterholz wachsen.
c2: Pilze sind schwer verdaulich, wenn sie im Mund nicht gut genug zerkleinert werden.
ns: In der Regel muss man sie lange *suchen/kauen* und darf nicht aufgeben.

129. c1: Die Mutter sagte, dass Äpfel viele Vitamine hätten und sehr gesund seien.
c2: Die Mutter mochte Äpfel so gern, aber sie traute sich nicht auf den hohen Baum im Garten.
ns: Martin musste täglich ein paar Äpfel *essen/pflücken* und langsam reichte es ihm.

130. c1: Mein Opa befindet sich schon im hundertsten Lebensjahr.
c2: Mein Opa lässt sich von niemandem etwas sagen und will immer seinen Kopf durchsetzen.
ns: Nicht viele Menschen sind so *alt/stur* und so eigensinnig.

131. c1: Die beiden geometrischen Figuren unterscheiden sich praktisch gar nicht.
c2: Die beiden geometrischen Figuren sind nicht rund, sondern eiförmig.
ns: Jeder Betrachter bezeichnet sie als *gleich/oval* und relativ klein.

132. c1: Bäckerin Lisa bekam beim Backen eine Menge Mehl ab, weil es so staubte.
c2: Bäckerin Lisa litt unter einer Ohrenerkrankung, die sich in den letzten Jahren immer mehr verschlimmerte.
ns: Mittlerweile war sie eigentlich völlig *weiß/taub* und deswegen recht mürrisch.

133. c1: Der Wasserkanister ist bis zum Rand hin gefüllt.
c2: Der Wasserkanister ist nicht rund.
ns: Der Behälter ist wirklich ganz *voll/eckig* und aus weißem Plastik.

Potsdam Sentence Corpus 3

134. c1: Fritz betastete die Eingeweide und war überrascht, denn er hatte sie sich viel lockerer vorgestellt.
 c2: Fritz musste sich beim Anblick der Eingeweide übergeben.
 ns: Die Gedärme des Schweins waren so *fest/eklig* und rochen unangenehm.
135. c1: Nach zwei Stunden Kochzeit nahm Johanna die Kartoffeln vom Herd.
 c2: Nach dem Kochen der Kartoffeln bemerkte Johanna, dass sie das Salz vergessen hatte.
 ns: Sie waren nun bestimmt richtig *gar/fad* und hatten eine gelbliche Farbe.
136. c1: Christian hatte nicht einen einzigen Freund.
 c2: Christian konnte sich in seinem winzigen Zimmer kaum bewegen.
 ns: Er fühlte sich hier so *allein/beengt* und rief seine Mutter an.
137. c1: Inge bemerkte, dass die Tapete noch nicht so alt war.
 c2: Inge bemerkte, dass sich die Tapete gar nicht glatt anfühlte.
 ns: Tatsächlich war die Tapete recht *neu/rau* und das konnte man sehen.
138. c1: Die Blüten dieser Blume gleichen einem vollkommenen Kreis.
 c2: Die Blüten dieser Blume hängen schlaff und trocken herunter.
 ns: Sie sind in der Tat ganz *rund/welk* und dennoch sehr schön.
139. c1: Der Schrank passte nicht an die schmale Wand des Schlafzimmers.
 c2: Der Schrank war in einer Farbe gestrichen, die an Flamingos erinnerte.
 ns: Er war eindeutig viel zu *breit/rosa* und auch sonst recht hässlich.
140. c1: Matti hatte keinerlei Ähnlichkeiten mit seinen Brüdern.
 c2: Matti stand oft stundenlang vor dem Spiegel und legte viel Wert auf sein Äußeres.
 ns: Alle sagten, er sei total *anders/eitel* und vor allem recht überheblich.
141. c1: Andreas trat auf die Hängebrücke und diese brach unter der enormen Last entzwei.
 c2: Andreas hatte noch nie eine Freundin, denn er liebte nur Männer.
 ns: Er war ohne jeden Zweifel richtig *schwer/schwul* und er stand dazu.

142. c1: Arno ist ein Schiedsrichter, der mit ohrenbetäubender Stimme über den Platz brüllen kann.

c2: Arno ist ein Schiedsrichter, der nie ungerechte Entscheidungen fällt oder parteiisch ist.

ns: Kein anderer Schiedsrichter ist so *laut/fair* und zudem ein guter Trainer.

143. c1: Kleine Tiere sind für bestimmte Fotoaufnahmen nicht geeignet.

c2: Wilde Tiere sind für bestimmte Fotoaufnahmen nicht geeignet.

ns: Es ist leichter, wenn die Tiere *groß/zahm* sind und ruhig dasitzen.

144. c1: Hermann lief vor seinen Verfolgern davon, aber sie holten auf.

c2: Hermann kam schmutzig aus dem Schweinestall und konnte so unmöglich ins saubere Wohnzimmer.

ns: Er bemerkte, dass er einfach zu *langsam/dreckig* und auch zu ungeschickt war.

Pseudoword stimuli

item #	target	pseudoword
1	Job	Jub
2	Uhr	Ubr
3	Idee	Ibee
4	Form	Forn
5	Musik	Murik
6	Beine	Belne
7	Feind	Feird
8	Seife	Soife
9	Wunsch	Wumsch
10	Himmel	Hirmel
11	Zimmer	Zimner
12	Bericht	Baricht
13	Plan	Plun
14	Fenster	Femster
15	Arm	Azm
16	Geld	Geid
17	Buch	Bech
18	Arzt	Arst
19	Waffe	Wuffe
20	Brief	Briaf
21	Bauer	Bamer
22	Kraft	Kreft
23	Kreis	Krels
24	Mitte	Milte
25	Geist	Gelst
26	Besuch	Besach

item #	**target**	**pseudoword**
27	Bruder	Brader
28	Lehrer	Lebrer
59	Boden	Bodon
60	Junge	Jurge
61	Licht	Lecht
62	Kunst	Kumst
63	Stimme	Stirme
64	Kirche	Kerche
65	Straße	Striße
66	Wasser	Wusser
67	Gefahr	Getahr
68	Lösung	Lösang
69	Arbeit	Ardeit
70	Schule	Schude
71	Minute	Menute
72	Antwort	Antmort
73	Kaiser	Kairer
74	Frau	Fnau
75	Herz	Henz
76	Wille	Wikle
77	Nacht	Nucht
78	Angst	Andst
79	Leben	Lefen
80	König	Kömig
81	Augen	Angen
82	Kampf	Kanpf
83	Schiff	Schuff
84	Morgen	Mongen
85	Antrag	Antreg
86	Wohnung	Wohrung
87	Zeitung	Zeifung
88	Satz	Sotz
89	Kind	Kend
90	Sohn	Suhn

Pseudoword stimuli

item #	target	pseudoword
91	Reihe	Reide
92	Frage	Fruge
93	zeigen	zeipen
94	halten	hulten
95	tragen	tregen
96	fahren	fehren
97	erklären	ertlären
98	hören	horen
99	leben	leden
100	fühlen	füblen
101	nehmen	nelmen
102	sehen	seden
103	teilen	teifen
104	haben	haden
105	wachsen	wachren
106	brechen	brichen
107	geben	geden
108	rufen	ruken
109	wählen	wöhlen
110	bitten	bilten
111	liegen	liepen
112	singen	simgen
113	lachen	luchen
114	treten	trelen
115	bieten	bielen
116	bilden	bilben
117	werfen	wenfen
118	sterben	sterden
119	rechnen	rechmen
120	spielen	spiefen
121	schlafen	schlufen
122	lesen	lezen
123	helfen	heffen
124	trinken	trimken

item #	target	pseudoword
125	schlagen	schragen
126	stimmen	stimnen
127	bleiben	blelben
128	suchen	süchen
129	essen	ersen
130	alt	aht
131	gleich	gloich
132	weiß	welß
133	voll	voil
134	fest	fert
135	gar	gor
136	allein	altein
137	neu	nev
138	rund	rumd
139	breit	brelt
140	anders	anbers
141	schwer	schmer
142	laut	lant
143	groß	greß
144	langsam	largsam