Fachbereich Erziehungswissenschaft und Psychologie
der Freien Universität Berlin

Reading complex Words:
The Role of syllabic Units
A cross-language Approach

zur Rolle phonologischer Prozesse beim Lesen komplexer Wörter
Ein sprachvergleichender Ansatz

Dissertation
zur Erlangung des akademischen Grades
Doktor der Philosophie
Dr. phil.

Vorgelegt von
Diplompsychologe Markus Conrad
im Jahre 2008

Erstgutachter:
Prof. Arthur M. Jacobs, Freie Universität Berlin

Zweitgutachter:
Prof. Manuel Carreiras Valiña, Universidad de La Laguna, Teneriffa, Spanien

Disputation an der Freien Universität Berlin am 4.Juli 2008 meinem Großvater

Dr. Jakob Conrad

* 27.8.1913   † 8.1.2008

Table of Contents

Chapter 3

Syllables and bigrams: Orthographic redundancy and syllabic units affect visual word recognition at different processing levels.

Chapter 4

Phonology as the source of syllable frequency effects in visual word recognition:

Acknowledgements

I would like to thank my supervisor Arthur Jacobs for opening me the door to an international research community and for being somebody to completely rely on when things turned difficult.

I am deeply grateful to Manuel Carreiras and Jonathan Grainger for welcoming me in the most generous ways - much more like a friend than like a stranger - at their laboratories in Tenerife and Aix en Provence and for providing me with all possible support from the first to the last day of my staying there.

I would like to thank all other people who helped me during the different phases of this work without ever asking what they would get for in exchange - in particular this goes to Margaret Gillon Dowens and Marta Vergara. Without people like you, University would be a place not half as good to be in.

Last but definitely not least, I am grateful to my colleague and friend Mario Braun, without whose unselfish dedication to work and others the Laboratory of General and Neurocognitive Psychology at the Freie Universität Berlin wouldn’t ever be as functional and human as it uses to.

Zusammenfassung

Die vorliegende Dissertationsschrift befaßt sich mit Effekten der Frequenz einzelner Silben, insbesondere der Anfangssilbe eines mehrsilbigen Wortes, in der visuellen Worterkennung. Derartige Effekte werden als Indiz für eine an im einzelnen Wort enthaltenen Silben orientierte Segmentation ganzer Wörter während des Prozesses des leisen oder lauten Lesens – empirischer Beobachtung zugänglich gemacht in der „lexikalischen Entscheidungsaufgabe“ bzw. der „Wortbenennungsaufgabe“ – gewertet. Die solcher Schlußfolgerung zugrunde liegende Logik besagt, daß eine systematische Abhängigkeit der in solchen Experimenten erhaltenen Reaktionslatenzen von der experimentellen Manipulation der Auftretenshäufigkeit einer bestimmten Untereinheit eines Wortes die entsprechende sublexikalische Einheit als funktional für den Leseprozeß erscheinen läßt, vorrausgesetzt, daß ein gegebener Effekt ausschließlich auf die experimentelle Manipulation und nicht auf mit dieser eventuell konfundierte Variablen zurückzuführen ist.

Das Konzept einer Silbe ist primär phonologischer Natur, und in der psycholinguistischen Forschungsliteratur finden sich zahlreiche Belege für die Bedeutsamkeit von Silben bei der Rezeption gesprochener Wörter, in erster Linie innerhalb romanischer Sprachen, deren Klangbild im Unterschied zu germanischen Sprachen als syllabisch akzentuierend beschrieben wird (siehe Cutler, Mehler, Norris, & Seguí, 1986; Mehler, Dommergues, Frauenfelder, & Seguí, 1981; Morais, Content, Cary, Mehler, & Seguí, 1989). Aber auch den Prozeß der visuellen Worterkennung betreffend und selbst für die Englische Sprache, auf die sich die experimentelle Forschung in diesem Gebiet lange Zeit schwerpunktmäßig konzentriert hatte, wiesen einige Forschungsbefunde darauf hin, daß die Silbenstruktur eines Wortes auch beim Prozeß des leisen Lesens eine funktionale Rolle spielen könnte (Lima & Pollatsek, 1983; Millis, 1986; Prinzmetal, Treiman, & Rho, 1986; Spoehr & Smith, 1973; Taft & Forster, 1976; Tousman & Inhoff, 1992).

Jedoch wurde die Interpretation einiger dieser Befunde als Evidenz für die syllabische Segmentation visueller Wortformen von anderen Forschern in Frage gestellt, indem die Ergebnisse als Nebenprodukt rein orthographischer, an der spezifischen Auftretenshäufigkeit von Buchstabenfolgen orientierter Verarbeitung interpretiert wurden. (siehe Seidenberg 1987; 1989, Schiller 1998; 2000, siehe aber auch Rapp, 1992).

Neuere empirische Befunde aus dem Spanischen rückten den potentiellen Charakter von Silben als funktionale Einheiten auch des leisen Leseprozesses aber erneut in den Vordergrund aktueller Forschung: Carreiras, Álvarez und de Vega (1993) sowie Perea und Carreiras (1998) konnten zeigen, daß Wörter, die mit einer hochfrequenten Silbe beginnen, längere Reaktionslatenzen in der lexikalischen Entscheidungsaufgabe nach sich ziehen als Wörter, deren Anfangssilbe in vergleichsweise wenigen anderen Wörtern ebenfalls enthalten ist. Dieser Effekt konnte von Mathey und Zagar (2002) erfolgreich für die Französische Sprache repliziert werden, ebenso von Conrad und Jacobs (2004) im Deutschen und damit erstmals in einer nicht-romanischen Sprache (siehe aber Macizo & Van Petten, 2007 für einen vergeblichen Replikationsversuch im Englischen). Alle genannten Forscher sehen diesen empirischen Effekt in der mit zunehmender Frequenz der Anfangssilbe gesteigerten Schwierigkeit der Identifikation eines Zielwortes innerhalb einer über die gemeinsame Anfangssilbe definierten Kohorte von Kandidaten begründet, die mit der Verarbeitung des Zielwortes interferieren. Auf der Ebene komputationaler Modelle der visuellen Worterkennung lassen sich solche Effekte über den Mechanismus lateraler Inhibition auf der Ebene von Ganzwortrepräsentationen erklären (siehe McClelland & Rumelhart, 1981; Grainger & Jacobs, 1996). Dieser inhibitorische Effekt der Silbenfrequenz in Aufgaben, die expliziten lexikalischen Zugriff erfordern, wird kontrastiert vom Befund schnellerer Benennungslatenzen für spanische Wörter mit hochfrequenten Silben sobald, wie in der Wortbenennungsaufgabe, offene Artikulationsprozesse im Zentrum des experimentellen Verfahrens stehen (Perea & Carreiras, 1998; siehe auch Carreiras and Perea, 2004, sowie Brand, Rey, Peereman, & Spieler, 2002, für ähnliche Ergebnisse im Französischen).

Die vorliegende Dissertation enthält Experimente mit zweisilbigem Wortmaterial aus drei verschiedenen Sprachen: Deutsch, Spanisch und Französisch. Dieser sprachübergreifende Ansatz soll nicht nur der Breite der gelieferten Evidenz für syllabische Verarbeitung als wesentliches inhärentes Merkmal des Lesprozesses dienen, sondern auch die hypothesengeleitete Suche nach sprachspezifischen Unterschieden solcher syllabischer Verarbeitung ermöglichen.

Die drei genannten Sprachen unterscheiden sich zum Teil deutlich hinsichtlich der Transparenz ihrer Silbenstruktur. Diese ist im Spanischen in besonders hohem Maße gegeben, das Französische kennzeichnet spezifische Inkonsistenz hinsichtlich der orthographischen Repräsentation phonologischer Silben, während die Transparenz der Silbenstruktur des Deutschen von der Komplexität möglicher Konsonantenverbindungen am Silben An- und Auslaut beeinträchtigt sein mag und weiterhin bereits im Bereich zweisilbiger Wörter von morphologischer Komplexität entscheidend mitgeprägt ist.

Aus diesen sprachspezifischen Unterschieden ergibt sich die Hypothese einer unterschiedlichen Ausprägung syllabischer Effekte im Vergleich der drei Sprachen.

In Kapitel 1 wird überprüft, ob sich eine ähnliche Dissoziation von Silbenfrequenzeffekten über Aufgaben mit unterschiedlicher Involvierung offener Artikulation, wie sie für das Spanische beschrieben worden ist, auch im Deutschen zeigen läßt. Im Gegensatz zu den Befunden für das Spanische (Perea & Carreiras, 1998; Carreiras & Perea, 2004) ergaben sich dieselben inhibitorischen Effekte für die Frequenz der Anfangsilbe zweisilbiger deutscher Wörter sowohl in der lexikalischen Entscheidungsaufgabe als auch in der Wortbenennungsaufgabe. Dieser sprachübergreifende Unterschied läßt sich über eine notwendigerweise stärkere Gewichtung lexikalischer Verarbeitung bei der Wortbenennungsaufgabe im Deutschen erklären: Voraussetzung der korrekten Aussprache eines mehrsilbigen Wortes ist die Kenntnis seines Betonungsmusters, das Wissen, ob - im Falle eines zweisilbigen Wortes - die erste oder zweite Silbe zu akzentuieren ist. Im Spanischen ist ein solcher Wortakzent grundsätzlich syllabisch definiert, er liegt regelhaft auf der vorletzten Silbe eines Wortes. Ausnahmen sind mit orthographischen Akzenten gekennzeichnet oder definieren sich über das letzte im Wort enthaltene Phonem, orthographisch realisiert in den Buchstaben L, R, D oder Z. Somit kann das Akzentmuster eines jeden spanischen Wortes aus einfacher orthographisch-prälexikalischer Analyse erschlossen werden, und korrekte Artikulation kann initiiert werden, ohne daß das auszusprechende Wort notwendigerweise in vollem Umfang erkannt worden sein muß.

Derartiges ist im Deutschen nicht möglich, Abweichungen vom vorherrschenden Muster des Akzentes am Wortanfang können erst aufgrund tiefergehender Wortverarbeitung erschlossen werden. Der vergleichbare Einfluß der Silbenfrequenz in Wortbenennungsaufgabe und lexikalischer Entscheidungsaufgabe im Deutschen spiegelt die starke Bedeutung lexikalischer Verarbeitungsprozesse in beiden Aufgaben wieder.

Die von Levelt, Roelofs und Meyer (1999) postulierte leichtere Wiedergabe hochfrequenter Silben auf der Ebene von Artikulationsprozessen konnte in diesem Experiment für das Deutsche nur im Bereich nichtlexikalischen Materials, dem mangels semantischen Gehalts ein Standardakzent auf der ersten Silbe zugewiesen werden kann, gezeigt werden.

Grundsätzlich stellen Befunde, die eine automatische syllabische Segmentation visuell präsentierter Wortformen nahelegen, existierende komputationale Modelle der visuellen Worterkennung vor folgendes Problem: Da die meisten dieser Modelle ausschließlich für die Verarbeitung einsilbigen Wortmaterials konzipiert sind, verfügen sie über keine silbisch definierten Repräsentationseinheiten (siehe z.B.., Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001; Grainger & Jacobs, 1996; Jacobs, Graf, & Kinder, 2003; Ziegler, Perry, & Coltheart, 2000; Zorzi, Houghton, Butterworth, 1998; siehe aber auch Ans, Carbonnel, & Valdois, 1998; für ein Modell zur Benennung mehrsilbiger Wörter). Würden sich syllabische Effekte bei der Verarbeitung mehrsilbigen Wortmaterials als reliabel erweisen, so würde dies den Geltungsbereich dieser Modelle und der von ihnen postulierten Mechanismen der visuellen Worterkennung in erheblichem Maße einschränken, da die meisten Wörter der meisten Sprachen mehrsilbig sind.

Ein Schwerpunkt der experimentellen Erforschung der Rolle von Silben beim leisen Lesen innerhalb dieser Dissertation liegt deshalb in der näheren Untersuchung der Auftretensbedingungen des Silbenfrequenzeffektes in der lexikalischen Entscheidungsaufgabe, um zu ermitteln, ob dieser tatsächlich einer syllabischen Segmentation orthographischer Wortformen geschuldet ist. Dies war angesichts der bisherigen Befundlage insofern fraglich, als einer wesentlichen Konfundierung der Frequenz silbischer Einheiten mit rein orthographisch definierten Mustern innerhalb eines Wortes in den Experimenten von Carreiras et al (1993), Perea und Carreiras (1998), Mathey und Zagar (2002) sowie Conrad & Jacobs (2004) nicht in differenzierender Weise Rechnung getragen wurde: Die Frequenz einer Silbe korreliert stark positiv mit der Frequenz der diese Silbe bildenden Buchstabenverbindung, ohne daß letztere zwangsläufig in systematischer Beziehung zur Silbenstruktur der betreffenden Wörter, aus deren kumulierter Frequenz sie sich errechnet, stünde. Empirische Effekte, die sich über die Manipulation von Silbenfrequenzen ergeben, könnten somit durchaus auch als Niederschlag rein orthographischer Verarbeitungsprozesse zu verstehen sein.

Die getrennte und unabhängige Manipulation der Frequenz des Wortbeginns spanischer zweisilbiger Wörter ergab jedoch in den in Kapitel 3 dieser Dissertation präsentierten Experimenten differentielle und einander entgegengesetzte Effekte der Silbenfrequenz einerseits und der rein orthographisch definierten Bigrammfrequenz andererseits. Der erhaltene inhibitorische Effekt der Silbenfrequenz, der unter ähnlichen Kontrollbedingungen auch in einem Experiment in Französischer Sprache erhalten wurde (siehe Kapitel 4), ist daher ein eindeutiger Beleg für den tatsächlich syllabischen Charakter dieses empirischen Effektes, der somit die Hypothese einer automatischen syllabischen Segmentation orthographischer Wortformen bedeutend stützt. In einem weiteren in Kapitel 3 enthaltenen Experiment fand sich darüber hinaus keinerlei Evidenz für eine Modulierung des Silbenfrequenzeffektes durch spezifische Muster orthographischer Redundanz, wie sie sich aus Überlegungen Seidenbergs (1987; 1989) hätte ableiten lassen. Die Diskrepanz dieses Ergebnisses zu Studien die Relation orthographischer und syllabischer Verarbeitung im Französischen betreffend (Doignon & Zagar, 2005; Mathey, Zagar, Doignon, & Seigneuric, 2006) eröffnet eine interessante sprachvergleichende Perspektive hinsichtlich der Abhängigkeit dieser Wechselbeziehung von der Transparenz der Silbenstruktur einzelner Sprachen.

Die phonologische Natur des linguistischen Konzeptes der Silbe als größte in einem kontinuierlichen Strom aussprechbare Lautverbindung innerhalb eines Wortes legt grundsätzlich nahe, daß eine syllabische Segmentation ebenfalls als von phonologischer Verarbeitung geprägter Prozeß zu verstehen ist, ein orthographische Wortform also während des Lesens in ihre phonologischen Silben zerlegt wird. Jedoch konnte eine solche spezifische Attribution von Silbenfrequenzeffekten aufgrund bisheriger Forschungsergebnisse nicht geleistet werden, da – zumindest in Sprachen mit einer konsistenten Schrift-Laut Beziehung wie das Deutsche und das Spanische – eine experimentelle Unterscheidung zwischen orthographischen und phonologischen Silben kaum zu realisieren ist.

In Kapitel 4 werden mehrere Experimente vorgestellt, die sich die relativ inkonsistente orthographische Realisierung phonologischer Silben im Französischen zunutze machen, um dieser theoretisch bedeutsamen Forschungsfrage nachzugehen. Manipulationen der initialen Silbenfrequenz französischer Wörter bezogen sich entweder auf die Frequenz orthographischer oder auf die Frequenz phonologischer Silben, wobei das jeweilige alternative Frequenzmaß konstant gehalten wurde.

Es ergaben sich die klassischen inhibitorischen Silbenfrequenzeffekte in der lexikalischen Entscheidungsaufgabe nur für die Frequenz phonologischer Silben. Dieser Befund bestätigt die phonologische Natur syllabischer Segmentierung mehrsilbiger orthographischer Wortformen während des Leseprozesses. Gleichzeitig kann in Kapitel 4 gezeigt werden, daß eine automatische syllabische Segmentierung, wie im Silbenfrequenzeffekt sich zeigend, in dem Maße abnimmt, wie die Frequenz der zu lesenden Wörter steigt, da im Falle hochfrequenter Wörter lexikalischer Zugriff vermutlich schon anhand ihres hinreichend gelernten Erscheinungsbildes in direkterer, von rein orthographische Verarbeitung geprägter Weise möglich ist.

Fußend auf die im Rahmen dieser Dissertation erhaltenen empirischen Ergebnisse, beinhalten Kapitel 3 und 4 spezifische Vorschläge, wie interaktive komputationale Modelle der visuellen Worterkennung zu erweitern wären, um der Verarbeitung mehrsilbiger Wörter, welche auf Modellebene nicht ohne die Implementierung syllabischer Repräsentationseinheiten auskommen kann, Rechnung tragen zu können. Die diesbezüglich nicht hinreichende Performanz eines existierenden komputationalen Modells visueller Worterkennung ohne syllabische Repräsentationseinheiten (Grainger & Jacobs, 1996) wird in Kapitel 3 anhand der empirischen Daten aus den Experimenten zu differentiellen Effekten von Silben- und Bigrammfrequenz illustriert.

Kapitel 2 ist einem weiteren spezifischen Aspekt von Frequenzeffekten in visueller Worterkennung und komputationaler Modellierung gewidmet: der Unterscheidung von type- und token basierten Frequenzmaßen und ihrer potentiell differentiellen Effekte im Prozeß der visuellen Worterkennung. Bezüglich empirischer Effekte der Silbenfrequenz war die mangelhafte Unterscheidung zwischen diesen unterschiedlichen Maßen ein weiteres Manko bisherigen experimentellen Vorgehens. Die Bedeutung einer solchen Unterscheidung wird am Beispiel der Dissoziation von Effekten orthographischer Nachbarschaftsdichte (type) und –Frequenz (token) in der visuellen Worterkennung verdeutlicht.

Die erfolgreiche differentielle Simulation beider Effekte ist ein wesentliches Merkmal eines einflußreichen Modells visueller Worterkennung (Grainger & Jacobs, 1996). Anhand spanischen Wortmaterials konnte in Kapitel 2 eine ähnliche Dissoziation für Effekte initialer Silbenfrequenz in der lexikalischen Entscheidungsaufgabe gezeigt werden: Nachdem die hohe Korrelation beider Maße experimentell aufgelöst wurde, ergab sich der klassische inhibitorische Effekt der Silbenfrequenz nur für das token Maß der Silbenfrequenz, während –zumindest unter Kontrolle der Anzahl höherfrequenter Silbenfrequenznachbarn eines Wortes – das type Maß der Silbenfrequenz mit kürzeren Reaktionslatenzen verbunden war.

Die Tatsache, daß beide Effekte in ein und demselben Aufgabenkontext erwuchsen, ist von besonderer theoretischer Bedeutung, da dies schwer vereinbar ist mit der Art und Weise wie das „Multiple Read-Out Model“ von Grainger & Jacobs (1996) derartige Effekte als das Resultat unterschiedlichem Aufgabenkontext angepaßter unterschiedlicher Antwortstrategien simuliert.

Abstract

This dissertation thesis is about syllable frequency effects in visual word recognition. Before the seminal study of Carreiras, Álvarez and De Vega (1993), only rather sparse empirical evidence for syllabic processing during the process of silent reading had been reported in psycholinguistic research focusing mainly on the English orthography (Lima & Pollatsek, 1983; Millis, 1986; Prinzmetal, Treiman, & Rho, 1986; Spoehr & Smith, 1973; Taft & Forster, 1976; Tousman & Inhoff, 1992). And at least some of these findings have been highly contested: It had been argued that they would possibly occur as a by-product of orthographic processing – given the relation of syllabic structure to orthographic redundancy (see Seidenberg 1987; 1989, see also Schiller 1998; 2000, but see Rapp, 1992). Longstanding evidence for the role of syllabic units had rather been obtained for the domain of speech perception (e.g., Cutler, Mehler, Norris, & Seguí, 1986; Mehler, Dommergues, Frauenfelder, & Seguí, 1981; Morais, Content, Cary, Mehler, & Seguí, 1989).

But using the Spanish language, which unlike English is a shallow orthography with a consistent bidirectional spelling to sound relation and transparent syllabic structure, Carreiras et al. (1993, see also Perea & Carreiras, 1998) reported that words comprising high frequency syllables – syllables shared by many other words in identical position – were responded to more slowly in the lexical decision task than words with low frequency syllables.

This finding suggested that during visual word recognition, orthographic word forms were automatically segmented into their syllabic constituents. The processing delay for high syllable frequency words was attributed to syllabic neighbours (words sharing a syllable with the target in identical position) interfering with the processing of the target (see the framework of interactive activation models of visual word recognition by McClelland & Rumelhart, 1981).

Such syllabic effects present a serious challenge for existing computational models of visual word recognition, because none of these models possesses a layer of syllabic representation units (see e.g., Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001; Grainger & Jacobs, 1996; Jacobs, Graf, & Kinder, 2003; Ziegler, Perry, & Coltheart, 2000; Zorzi, Houghton, Butterworth, 1998; but see Ans, Carbonnel, & Valdois, 1998; for a model of naming polysyllabic words).

Most of these models are exclusively implemented for the processing of monosyllabic words. If syllabic effects like the syllable frequency effect on lexical access proved to be reliable and could not be attributed to other than syllabic processing, this would present an important qualitative difference in the processing of polysyllabic words compared to monosyllabic words. In consequence, the scope of these computational models would be severely limited, because most words in most languages are polysyllabic.

The inhibitory syllable frequency effect in lexical decision has since been replicated in two other languages, French (Mathey & Zagar, 2002) and German (Conrad & Jacobs, 2004). Therefore, an assumed automatic syllabic processing cannot be understood as a phenomenon specific to the Spanish language neither as occurring exclusively in Roman languages (but see Macizo & Van Petten, 2007, for a failure to replicate the effect in English).

In contrast to the inhibition caused by syllable frequency in a task requiring lexical access but no overt pronunciation, words starting with high frequency syllables produced shorter naming latencies than words with low initial syllable frequency in naming tasks with visually presented word stimuli in Spanish (Perea & Carreiras, 1998; see also Carreiras and Perea, 2004, as well as Brand, Rey, Peereman, & Spieler, 2002, for similar data obtained in French). This dissociation of syllable frequency effects across different tasks was explained by a shift of the locus of effect to the level of motor output in the naming task (see Levelt & Wheeldon, 1994; Levelt, Roelofs, & Meyer, 1999).

The experimental work presented in this thesis tried to further examine the nature of syllabic processing in visual word recognition focusing on different aspects of syllable frequency effects. Results are presented in four chapters using a cross language approach as general guideline of research: The transparency of syllabic structure varies considerably across different languages. This leads to the question of whether visual word recognition in different languages would be characterized by an automatic syllabic processing to the same extent, or whether specific differences regarding syllabic processing could be observed that might be attributed to specific features of syllabic structure in a particular language.

Chapter 1 The cross language approach in investigating effects of syllabic processing motivated the investigating of whether the same dissociation of syllable frequency effects across lexical decision and naming as suggested by the literature for the Spanish language would be observable using a manipulation of initial syllable frequency in German words and nonwords.

In contrast to the findings of Perea & Carreiras (1998) and Carreiras & Perea (2004a) an inhibitory effect of syllable frequency was obtained in both tasks for German word stimuli. Shorter naming latencies due to initial syllable frequency were restricted to the German nonword stimuli. This pattern of results suggests that processes related to lexical access are more strongly influencing the production of overt pronunciation of polysyllabic word stimuli in German compared to Spanish. This finding might relate to different stress assignment of polysyllabic words’ in the two languages.

In contrast to Spanish where stress is syllable timed – with the penultimate syllable receiving stressed -, stress in German bisyllabic words is lexically assigned depending, for instance, on a word’s morphology. Lexical access – being inhibited by initial syllable frequency – is therefore necessary in order to know which of the two syllables within a bisyllabic German word has to be stressed. Stress information, on the other hand, is a necessary prerequisite for correct pronunciation. This might be the reason why syllable frequency seems to influence not only lexical decision but also naming latencies for German words in an inhibitory manner. In contrast, the same involvement of lexical processing seems not necessarily to be given in Spanish, because for all Spanish words with other than penultimate stress, stress assignment can de inferred via prelexical processing using orthographic accents or the identity of the last letter in a word as sufficient stress information. Therefore, overt pronunciation in Spanish could theoretically already be initiated before lexical access has been completed and syllable frequency’s facilitative role for motor output processes is not cancelled out by its potential to inhibit lexical access.

Only in the case of German nonwords, where first syllable stress is probably assigned by default, participants naming latencies could be shown to be influenced by the assumed facilitation of motor output processes due to initial syllable frequency.

Chapter 2 Previous research documenting inhibitory effects of syllable frequency in lexical decision had uncritically applied different measures of syllable frequency. They had either used the number of syllabic neighbours (a type measure), the cumulated frequency of syllabic neighbours (a token measure) or the number of higher frequency syllabic neighbours (being suggested by Perea & Carreiras, 1998, as probably responsible for the empirical effect) as independent variables.

This was clearly weakening comparability between different studies and made a theoretical attribution of the empirical effect in general more difficult - see the differential effects of orthographic neighbourhood density and frequency in visual word recognition (see Andrews, 1997, for a review) - especially because all these different measures of syllable frequency are highly correlated.

Furthermore, the question of whether a type or a token based measure of syllable frequency effect is driving the empirical effect has important implications for any future attempt to simulate this effect using computational modelling. The question of potentially differential effects of these different measures of syllable frequency was addressed by several experiments conducted in the Spanish language presented in Chapter 2.

In the first of these experiments involving the independent manipulation of type and token syllable frequency, the typical inhibitory effect of syllable frequency on lexical access was obtained only for the token measure of syllable frequency, whereas the type measure produced a tendency of facilitation on response latencies and a significant facilitative effect on error rates. In a subsequent experiment using the same independent variables as in the previous manipulation but providing additional control for the number of higher frequency syllabic neighbours, the facilitative effect of type syllable frequency turned out to be significant in both response latencies and error rates, whereas the inhibitory effect of token syllable frequency remained unaffected. This pattern of results provides empirical evidence for what had been formulated in previous theoretical accounts of the syllable frequency effect in lexical decision: The locus of the effect has to be seen at a lexical level of competition between candidate words sharing the initial syllable with the target and competing for identification. The amount of interference caused by these candidates (the syllabic neighbours) does not depend on their mere number, but on their frequency. A similar argument had been used by Perea & Carreiras (1998), who proposed the number of higher frequency syllabic neighbours as being responsible for the inhibitory effect of syllable frequency in the lexical decision task, but the present results could show that also token syllable frequency alone can hold responsible for this effect.

Token syllable frequency was accordingly applied for all manipulations of syllable frequency in all other experiments presented in this dissertation. The observed dissociation for the type and the token syllable frequency measures suggests that a syllable's frequency can influence the reading process in different ways at different processing levels:

The high typicality (possibly best reflected by the type measure of syllable frequency) of a syllable seems to facilitate the processing of sublexical units at a prelexical processing stage, whereas the inhibitory potential of syllabic neighbours (reflected in the token measure of syllable frequency) makes lexical access to high syllable frequency words more difficult. Furthermore, the dissociation of these two effects that were obtained in one and the same task environment has important implications for computational modelling, questioning, e.g., the account of the dissociated effects of orthographic neighbourhood density and frequency given by the MROM (Grainger & Jacobs, 1996), which modulated the involvement of different read-out procedures as an adaptation to different task environments in order to successfully simulate the two effects.

Chapter 3 All previous studies reporting syllable frequency effects in lexical decision interpreted this empirical effect as evidence for an automatic syllabic segmentation of orthographic word forms during the reading process. It was outlined above why this would present a serious challenge for computational models of visual word recognition. But looking closely at the relation between syllable frequency and orthographic redundancy, the question arises of whether this attribution of the empirical effect has not been premature.

Syllable frequency is generally confounded with orthographic redundancy in two ways: First, the bigram straddling the syllabic boundary is typically less frequent than intrasyllabic bigrams. This phenomenon had inspired the bigram trough hypothesis (Seidenberg, 1987; 1989), which argued that the orthographic salience of a relatively low frequent bigram at the syllable boundary might be the only reason for any apparent syllabic segmentation. This would mean that alleged "syllabic" effects might arise as a mere by-product of orthographic processing questioning whether phonologically or orthographically defined syllabic units would possess themselves the status of functional units during visual word recognition.

Some empirical studies reporting syllable frequency effects had tried to dismiss this critic by using only words not showing the bigram trough pattern at the syllable boundary (e.g., Carreiras et al., 1993; Perea & Carreiras, 1998).

However, the question of whether the kind of orthographic segmentation device proposed by Seidenberg (1987; 1989) had any influence on syllabic processing or not, had never been directly examined. The first experiment presented in Chapter 3 was designed to fill this gap addressing the theoretically interesting question regarding a possible role of orthographic redundancy for syllabic segmentation with bigram troughs facilitating the syllabic parsing process. A manipulation of initial syllable frequency was realized in bisyllabic Spanish words that either showed the bigram trough pattern at the syllable boundary or not.

Besides an inhibitory main effect of syllable frequency and a weak facilitation of response latencies in the absence (relative to the presence) of a bigram trough at the syllable boundary that – according to multiple regression analyses - seemed to be attributable rather to global patterns of orthographic redundancy than to the relative position of a bigram with respect to the syllable boundary, no interaction between the two effects was observed. This pattern of results suggesting that syllabic processing in Spanish is completely independent from orthographic redundancy - at least as reflected by the concept of bigram troughs – is partially incompatible with recent results obtained for the French language (Doignon & Zagar, 2005; Mathey, Zagar, Doignon, & Seigneuric, 2006).

This discrepancy might present an interesting case of language dependent features of syllabic processing with orthographic redundancy becoming more important for syllabic segmentation in languages where transparency of syllabic structure is attenuated by the inconsistent mapping between phonological syllables and their orthographic representations.

But there is a second natural confound between the frequency of syllabic units and orthographic redundancy, which is even more important for a reliable attribution of syllable frequency effects: A high frequency syllable can generally also be described as a high frequency letter cluster the definition of which does not necessarily relate to syllabic structure. None of the experiments reported in the previous literature had controlled for the frequency of the letter cluster formed by the initial syllable when applying a manipulation of initial syllable frequency. Therefore, all empirical effects of syllable frequency might have been triggered by the frequency of a purely orthographically defined letter cluster – regardless of syllabic structure. Such effects of letter cluster frequency might well be accounted for by computational models comprising letter representation units and they would not necessarily present evidence for syllabic processing in visual word recognition (see Schiller, 1998; 2000).

Disentangling the empirical confound of syllable frequency and letter cluster frequency, two experiments were conducted using bisyllabic Spanish words starting always with a two letter CV-syllable. These experiments involved a) the manipulation of initial syllable frequency controlling for the frequency of the initial bigram, and b) the manipulation of initial bigram frequency controlling for the frequency of the initial syllable. A perfect contrast for the effects of the frequency of the first two letters within a Spanish word was observed, depending on how this frequency was defined: Syllable frequency had an inhibitory effect on response latencies and error rates, whereas response latencies and error rates decreased with initial bigram frequency.

Therefore, it is shown for the first time that syllable frequency effects in the lexical decision task cannot be understood without assuming the involvement of syllabic processing.

In contrast to syllabic units, which seem to have an important role for the activation of whole word candidates competing with the target for identification, the frequency of bigrams rather seems to facilitate prelexical orthographic processing (see also Hauk et al., 2006). Simulation data using an extended version of the MROM (Grainger & Jacobs, 1996) is provided showing that a model without syllabic representations is not capable of reproducing the syllable frequency effect when letter cluster frequency is controlled for.

On the other hand, global lexical activation in the model (which is responsible for fast-guess responses of the model) was shown to be sensitive to bigram frequency, even though this effect did not reach statistical significance. Future research has to determine whether the facilitative effect of bigram frequency that was obtained for words where the relevant bigram always coincided with the initial syllable has a specific relation to syllabic processing with bigram frequency possibly facilitating the processing of syllabic units.

Chapter 4 Even when it was shown in the experiments presented in Chapter 3 that syllabic processing appears to be indeed an automatic feature of polysyllabic visual word recognition, there is one remaining question regarding the nature of this effect. The concept of the syllable is derived from a phonological perspective – a syllable is defined as the largest combination of sounds that can be produced in an uninterrupted stream. This might lead to a bias to implicitly attribute syllabic effects to phonological processing without that the phonological nature – involving the processing of phonological vs. orthographic syllables - of this effect had ever been sufficiently examined.

There is evidence for the processing of phonological syllables in visual word recognition from a priming study in Spanish showing comparable priming effects for bisyllabic words preceded by nonwords matching either the target's initial orthographic and phonological syllable or the target's phonological syllable alone (Álvarez, Carreiras, & Perea, 2004). But generally, for manipulations of syllable frequency in Spanish and German it is hardly possible to distinguish between effects of orthographic and phonological syllable frequency because of the too consistent spelling to sound relation in these two languages. The French language instead, with its high degree of inconsistency regarding the orthographic representation of phonemes (see Ziegler, Jacobs, & Stone, 1996) offers the possibility to experimentally disentangle the frequencies of phonological and orthographic syllables. The only study investigating syllable frequency effects in French (Mathey & Zagar, 2002) had not taken this perspective. Therefore, one lexical decision experiment including six critical comparisons is presented in Chapter 4 using bisyllabic French stimulus material in order to examine the phonological nature of syllabic processing.

Comparison 1 revealed a significant but weak general effect of initial syllable frequency manipulating both orthographic and phonological syllable frequency conjointly.

Comparison 2, manipulating orthographic and phonological syllable frequency independently, – controlling for the respective alternative variable – revealed a significant inhibitory effect of syllable frequency only for phonological syllable frequency.

Comparison 3 involved the same manipulations using this time the number of higher frequency neighbours as independent variable instead of token syllable frequency. Results were comparable to those obtained in Comparison 2.

Comparison 4 replicated the finding presented in Chapter 3 for the Spanish language, this time manipulating phonological syllable frequency: A very robust inhibitory effect of syllable frequency was obtained when both orthographic syllable frequency and the frequency of the letter cluster forming the syllable had been controlled for.

Comparison 5 extended the examination of possible alternative sources of syllable frequency effects to testing whether the frequency of the first initial phonemes within words starting with CV-syllables would have any significant effect on lexical access when controlling for initial syllable frequency. The null effect (showing a tendency towards facilitation) obtained in this comparison is additional evidence that only syllabic processing can be seen as the source of syllable frequency effects in visual word recognition.

Comparison 6, crossing the factor syllable frequency with a manipulation of word frequency, revealed a significant interaction between the effects of the two factors:

Syllable frequency was found to influence only the processing of low frequency, but not the processing of high frequency words.

Taken together, the results presented in Chapter 4 show that syllable frequency effects in lexical decision have indeed to be seen as evidence for an automatic processing of phonological syllables.

In an interactive activation model of visual word recognition containing a level of phonological syllable representations, these effects could arise as the result of lateral inhibition at the level of whole word phonological word forms, the activation of which would be mediated by the representations of phonological syllables. Lateral inhibition would be stronger for word representations containing high frequency phonological syllables, because inhibition would be sent out by more highly activated competing candidate representations than in the case of low syllable frequency words.

The fact that this effect seems to diminish with increasing word frequency of the target fits well with the general architecture of models containing both orthographic and phonological representation units: The activation of phonological units’ representations in these models always requires the previous activation of their corresponding orthographic units’ representations. The resulting delay in the onset of phonological processing in these models can hinder phonological effects to arise whenever fast direct access to a high frequency word’s representation via the connections between orthographic representations is possible.

As a conclusion, orthographic word forms seem to be segmented into their phonological syllables whenever fast lexical access to the over-learned orthographic representations of high frequency words is not sufficient to assure lexical access in visual word recognition.

General Introduction

Reading is one of the basic cultural skills in modern life. Human life is hardly conceivable without language based communication. The possibility to write a message or a thought on a piece of parchment or paper or on a webpage on the internet, that other people are able to perceive and understand not only at the exact moment and the place where a verbal act is pronounced, but even many years later and wherever they are, is closely related to the evolution of human society. The spread of an alphabetic writing system over the Mediterranean by Phoenician traders between the twelfth and ninth century before Christ or the invention of a printing technique using moveable letter types by Gutenberg in the middle of the fifteenth century after Christ have been the sources of substantial progress in the evolution of our culture.

From enjoying the most sophisticated products of cultural achievement like reading a novel or a philosophical essay to the simplest necessities of everyday life - reading the expiration date on a packet of food bought in the supermarket or the contraindications for a medication - reading has become an unavoidable part of almost any aspect of our life.

Language in general can be described as a symbolic system assigning specific meaning to single words or phrases. Proficient use of this system, the understanding and production of speech is normally acquired during the first years of childhood.

Reading and writing instead, is normally not being taught to children before entering school around the age of six and it involves an additional level of symbolic transformation:

Linguistic contents originally belonging to the domain of sounds are represented visually using a symbolic system; and in the case of alphabetic writing systems, the combination of about 30 little signs has to provide a sufficient level of differentiation to represent all words of a particular language in a distinguishable manner.

Some writing systems like the Chinese have maintained a relatively high level of direct symbolic relatedness between words and their written representations using single symbols for single words, the formal features of which relate to the semantic proprieties of the words they stand for. It could in theory be argued that something similar would hold true even in alphabetic writing systems: That words would be recognized as entire symbols directly assessing a word's meaning from its orthographic word form.

The luminous advertising of a hotel might in fact be perceived as an integral symbol when arriving at night in foreign city without having to encode the specific letters "H", "O", "T", "E" and "L", but we are also able to fluently read and correctly pronounce words from a text in a foreign language without knowing what the words mean or ever having seen them before, at least when we are familiar with the alphabet and the phoneme inventory of this language and when there is a consistent relation of the language's orthography to the latter one.

Psycholinguistic research has tried for many years to improve the understanding of how being presented with a white page filled with many little signs can trigger the most complex cognitive operations on the base of associating meaning to combinations of visual symbols.

The focus of interest varies considerably between different scientific approaches investigating the reading process, because language in general and, of course, also written language can be described on many different levels of decreasing grain size starting with entire texts going from phrases down to the word level ending up with sublexical units - not to mention the role of single letters' visual features.

The experimental work presented in this thesis focuses exclusively on processes underlying the recognition of visually presented isolated words. It might be argued that this restricted focus is problematic, because it definitely ignores or might even foil some aspects of the natural reading process. Single words are normally embedded in sentences with specific syntax and syntactic structure of phrases is known to influence the reading process (see e.g., Friederici, 1995; Hoeks, Stowe, & Doedens, 2004; Newman, Pancheva, Ozawa, Neville, & Ullman, 2001; Rösler, Putz, Friederici, & Hahne, 1993). The processing of single words has also been shown to depend on the context they appear in as a function of predictability determined by preceding information within a sentence (see e.g., Dambacher & Kliegl, 2007; Dambacher, Kliegl, Hofmann, & Jacobs, 2006). On the other hand, the processing of more complex structures like entire texts or phrases would be impossible without the efficient processing of single words being their basic constituents.

And the question of how this basic process of accessing the meaning of single (isolated) words in visual word recognition is achieved by the human mind is still far from being completely resolved.

Sublexical units in visual word recognition

The view that some words in some context may be recognized holistically, – see the example of "HOTEL" mentioned above – but that such an efficient direct access to an over-learned visual word form can not sufficiently describe visual word recognition in general, is widely accepted in the field of psycholinguistics. Assuming that lexical access does not always occur in a holistic manner leads to the question of which parts of a word – being referred to as sublexical units – would play which specific role in mediating the process of lexical access. In other words, what are the functional units of visual word recognition?

A wide range of theories and models – from verbal models to parallel distributed or localist-connectionist computational models - have been formulated or implemented to account for the process of lexical access in visual word recognition (see Jacobs & Grainger, 1994; Barber & Kutas, 2007, for reviews). These models do not only differ in their degree of specification, their general architecture or their computational principles, they also operationalize specific views on which sublexical units might be functional during visual word recognition.

The experiments presented in this dissertation have been designed to explore the role of syllabic units and their frequency during the process of silent reading in three different languages: German, Spanish and French.

The classical task to examine lexical access to visually presented single words is the lexical decision task, introduced by Rubenstein, Lewis and Rubenstein (1971). All experiments presented in this dissertation used this task – together with a word naming task used in one experiment to examine specific influences of syllable frequency on overt pronunciation.

In the lexical decision task, participants are presented with letter strings on a computer screen that either represent an existing word – e.g., "HAND" or not, e.g., "HOND". They have to press a button to indicate their decision upon the lexicality of the stimulus as being a word or a nonword. The time between the onset of stimulus presentation and the (correct) response to a word is generally understood as to offer a relative estimation for the time participants need to lexically access a presented word stimulus (but see Grainger & Jacobs, 1996, for a model simulating lexical decision latencies as corresponding to either full identification or to a "fast guess").

Prolonged lexical decision latencies are therefore interpreted as indicating a more complicated processing of words possessing specific properties or being presented within a specific context - operationalized by the experimental design.

In the following, some perspectives on how a sublexical unit can be defined will be briefly described. The basic patterns of the theoretical framework of an interactive activation models (see McClelland & Rumelhart, 1981; Grainger & Jacobs, 1996) - the results obtained in the experiments presented in this thesis are mainly discussed within - will be introduced.

The orthographic perspective

It is evident that single letters are the basic units that an orthographic word form in alphabetic writing systems is composed of. In an influential framework for modelling visual word recognition, the interactive activation model (McClelland & Rumelhart, 1981), visual feature detectors encoding the orthographic input activate corresponding letter representations, which in turn send activation to whole word representations containing a specific letter in a specific position. A word is recognized by the model when its representation reaches a predefined threshold of activation. The basic principles of interactive activation are: each representation unit sends excitatory activation to all corresponding units located at a superior layer of representations (e.g., word representations containing a specific letter) and inhibits all non-corresponding units (e.g., letter units not containing a specific visual feature). But activation within the model is not only spread from low level to high level representations, but is also fed back from the layer of word representations to the layer of letter representations.

Letter and Word units belonging to the same layer of representations (letters or words) possess only inhibitory connections with each other. This mechanism of lateral inhibition allows the model to account for effects of interference between co-activated candidate representations.

The model's architecture and an example for the (un-quantified) spread of activation over the model's different representation layers are shown in Figure 1.

Figure 1 (taken from McClelland & Rumelhart, 1981)

Exemplary interconnections between representational units in the Interactive Activation Model of McClelland & Rumelhart (1981) processing the letter "T" in the first letter position of a four letter word.
Note: excitatory connections are represented with an arrow at the end of the connection; inhibitory connections are represented with a circle at the end of the connection.

Adopting the principles of interactive activation and the general architecture presented in Figure 1, but providing their new model called MROM with a multiple read out procedure for generating responses in lexical decision and perceptive identification tasks, Grainger and Jacobs (1996) presented a computational model, which could account for a number of empirical effects possibly arising via purely orthographic processing in visual word recognition. Some important exemplary empirical findings are:

- The word superiority effect (see Grainger & Jacobs, 1994), which refers to the empirical finding that correct responses to words are faster in the lexical decision task than correct rejections of nonwords.

- The word frequency effect (see Grainger & Jacobs, 1996), being another classical finding of visual word recognition with faster responses to high frequency than to low frequency words.

These two effects arise in the interactive activation model, because, in the first place, only words but not nonwords possess the status of representation units in the model; rejection of nonwords in the MROM is achieved when a time-out criterion of processing has been reached. Furthermore, word representations possess a resting level of activation corresponding to word frequency, which assures that high frequency words will reach a crucial threshold of activation more quickly than low frequency words.

- Effects of orthographic neighbourhood density and frequency (e.g., Carreiras, Perea, & Grainger, 1997; Grainger, O'Regan, Jacobs, & Seguí, 1998; Grainger & Jacobs, 1996; see Andrews, 1997 for a review).
- Positional letter frequency effects (see Grainger & Jacobs, 1993).

In contrast to the two effects mentioned above, effects of letter frequency or orthographic neighbourhood relate not only to the representational status of an orthographic word form, but also to the representational status of single letters in the model and to the way letter units send activation to the level of whole word representations.

The term “orthographic neighbour” refers to orthographic similarity between words. Whenever replacing a single letter within a word, e.g., DOG/DOT, would result in another word the respective words are called orthographic neighbours (Coltheart, Davelaar, Jonasson, & Besner, 1977). A target word’s orthographic neighbours’ representations would receive only slightly less activation in an interactive activation model of visual word recognition than the target’s representation itself, because they share all but one letter with the target. Words with a high density of orthographic neighbourhood have been found to be named more quickly and to yield faster responses in the lexical decision task than words with few orthographic neighbours (see Andrews, 1997). The MROM accounts for the latter finding via its fast-guess mechanism that is sensitive to the summed activation in the model's orthographic lexicon, which would increase with the number of a target's orthographic neighbours. In contrast, words possessing orthographic neighbours of superior word frequency have been found to be recognized more slowly, at least in perceptive identification tasks, where unlike in lexical decision, stimuli have to be explicitly identified to fulfil the task demands (see Grainger et al., 1998, Grainger & Jacobs, 1996).

Within an interactive activation model, this effect - arising as a product of interference between co-activated word candidates competing for identification - can be accounted for by the mechanism of lateral inhibition between candidates representations on the whole word level. A higher frequency orthographic neighbor's representation would inhibit the target's representation in an especially efficient way, because of its high resting level of activation, thus prolonging the time necessary for a target's representation to reach the threshold of activation corresponding to "full identification" in the MROM.

It is evident that such effects would not occur if words were recognized in a completely holistic way. Together with effects of the frequency of single letters (see Grainger & Jacobs, 1993), they can only be understood and accounted for by computational models when single letters are seen as functional units of visual word recognition.

But not only single letters, also specific letter combinations are proposed to play a special role for the process of visual word recognition. Such orthographically defined letter combinations could be bigrams - two adjacent letters - (Massaro & Cohen, 1994; but see Paap & Johansen, 1994) or trigrams - three adjacent letters – (Seidenberg, 1987).

Note that a specific problem of an interactive activation model of visual word recognition like the one presented in Figure 1 lies in the slot based letter position coding, which makes them rather inflexible regarding the activation of word representations coming from single letter representations. In the classical model of McClelland & Rumelhart, as well as in the MROM (Grainger & Jacobs, 1996), the representation of a letter occurring e.g., in letter position two would only activate those word representation sharing this letter in exactly the same position.

The representation of the letter "I" occurring for instance in letter position two of the target word WILD would not activate the representation of the word THING containing this letter in letter position three.

Therefore, these models cannot account for empirical effects suggesting less position-dependent orthographic processing in visual word recognition, e.g., the letter transposition effect obtained with prime-target pairs as CANISO/CASINO (see Perea & Lupker, 2004; Schoonbaert & Grainger, 2004). To overcome the problem of too rigid letter position coding, different recent models use a more flexible coding scheme for letter positions within orthographic word forms (see Davis & Bowers, 2005; Grainger, 2007, for an overview).

The morphological perspective

Morphemes are the smallest linguistic units of a language with semantic meaning. Semantic is known to influence not only sentence, but also single word reading (e.g., Gold et al., 2006; Buchanan, Westbury, & Burgess, 2001; Hino, Lupker, & Pexman, 2002). Therefore, the reading system might use morphemes as functional reading units. A word can contain different types of morphemes: free morphemes, which can stand alone as a single word e.g., the two parts of the word *DESK*TOP, or bound morphemes, which are used exclusively alongside free morphemes. Examples for bound morphemes are prefixes like *RE*TURN, suffixes like WIRE*LESS*, or morphemes determining tense, plural and number. A word's stem like "START" in RES*TART* or *START*ING is referred to as root or stem morpheme.

Anyone familiar with the German language will not question that a morphological segmentation of a letter string can be an important strategy for word comprehension: A purely orthographic analysis of words like PROMOTIONSORDNUNG, VERDINGUNGSUNTERLAGE or FACHBEREICHSVERWALTUNG (hard to translate idiosyncratic German administration terms) comprising each three bound and two or three free morphemes might not assure fast lexical access.

But it is not only for the German language and not only for such extreme examples that empirical evidence for morphological processing in speech production and perception and in visual word recognition has been obtained (Roelofs & Baayen, 2002; Schiller & Costa, 2006; Dohmes, Zwitserlood, & Bölte, 2004; Zwitserlood, 2004; Isel, Gunter, & Friederici, 2003;

McKinnon, Allen, & Osterhout, 2003; Drews & Zwitserlood, 1995). Words containing frequent stem morphemes are responded to more quickly in the lexical decision task (De Jong, Schreuder, & Baayen, 2000; see also Taft 1979a). Nonwords starting with a letter string usually occurring as a prefix take longer to be rejected (Laudanna, Burani, & Cermele, 1994). Taft & Forster (1975) proposed that lexical access to prefixed words would use their stem morpheme as an access code implying an early "strip off" of prefixes during visual word recognition. Evidence from priming studies suggests that morphological processing of a visual word form is not restricted to words with transparent semantic structure – where morphemes are indeed carriers of semantic information – but occurs also for semantically opaque words, e.g., *CORN*ER (Gold & Rastle, 2007; Rastle, Davis, & New, 2004).

Morphological processing in addition to orthographic processing is a central feature of some computational models of visual word recognition (Giraudo & Grainger, 2003; Reichle & Perfetti, 2003; Schreuder & Baayen, 1995, see also Gonnerman, Seidenberg, & Andersen, 2007; Taft, 1994).

The phonological perspective

One of the most demonstrative findings showing that orthographic or morphological processing alone cannot sufficiently describe all aspects of the process of visual word recognition is the "pseudohomophone effect" (see Ziegler, Jacobs, & Klüppel, 2001). Letter strings that don't match an orthographic word form, but sound like a word when being pronounced have been found to be relatively hard to correctly reject in the lexical decision task. Examples in German would be TEHREN and FEDAN (the pronunciation of these letter stings corresponds to the German words for "tar" and "feather"), which seem to be much more word-alike even if orthographic or morphological similarity to their respective base-words is not higher than in the case of nonword letter strings like TEFREN and FEDUN (the base words are TEEREN and FEDERN). This specific finding in the lexical decision task can only be explained when assuming that phonological encoding or internal pronunciation of the presented stimulus occurs even if no overt pronunciation is required by the task. In everyday life we can observe this phenomenon when somebody is moving his lips while reading a book.

Observing this kind of behaviour in an adult person will probably make you think that he or she is not extraordinary gifted. From a more general perspective, it has been shown that phonological processing increases with the difficulty of lexical access. But it has also been described as an automatic feature of the reading process (e.g., Lukatela, Eaton, Lee, Carello, & Turvey, 2002; Frost, 1998; Van Orden, 1987).

The importance of phonological encoding during visual word - especially when the attempt of a fast direct access to an orthographic word form fails – is reflected in the architecture of another influential computational model of visual word recognition: The dual route model of visual word recognition and reading aloud (Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001; Ziegler, Perry, & Coltheart, 2000).

Within the phonological route of this model, letters are matched onto graphemes and graphemes are converted into phonemes via the application of a grapheme-phoneme conversion rules before the whole phonological word form can be accessed as the combination of the word’s phonemes. See Jacobs, Rey, Ziegler and Grainger (1998, see also Ziegler et al., 2001) for an extension of the MROM (Grainger & Jacobs, 1996) processing both orthographic and phonological sublexical units.

A phoneme is the smallest unit of speech in a particular language affecting word meaning. The orthographic representation of a phoneme is called a grapheme. There is empirical evidence suggesting that graphemes and phonemes are functional units of visual word recognition (Rey, Ziegler, & Jacobs, 2000; Rey, Jacobs, Schmidt-Weigand, & Ziegler, 1998). Languages differ considerably regarding the regularity of the relation between phonemes and their orthographic representations. Especially the English language is characterized by a high degree of respective inconsistency (see Ziegler, Stone, & Jacobs, 1997). The phonological value of the grapheme A is not the same in the word HAVE as in the word CAVE (feed-forward inconsistency). On the other hand, the same phoneme can have different spelling realizations in different words (feed-back inconsistency). It was George Bernhard Shaw, who suggested that the word FISH could be spelled as GHOTI, referring to the fact that the phonemes comprised in this word occur in an orthographically unrecognizable manner in other words like ROU*GH*, *WO*MEN and NA*TI*ON (see Kessler & Treiman, 2001; Treiman, Kessler, & Bick, 2002, for consistency effects of a word’s grapheme to phoneme mapping on reading and spelling performance in English).

Among the languages used for the experiments presented in this dissertation, both Spanish and German have a relatively consistent grapheme-phoneme relation. However, a considerable degree of inconsistency characterizes the orthographic realization of French phonemes, whereas the conversion of French graphemes into phonemes is relatively consistent (see Ziegler, Jacobs, & Stone, 1996).

The role of syllabic units

Besides a word's phonemes, the basic phonologically defined sublexical unit comprising more than one phoneme or grapheme is the syllable.

A syllable is the largest combination of phonemes within a word that can be pronounced in a non-disrupted stream. The point of maximum sonority within a syllable is called the syllable peak or nucleus. It is normally orthographically represented by a vowel (V) grapheme, but some orthographies also have entire words without vowels, e.g., the Serbo-Croatian words KRK (the name of an island) or SMRT (death). The syllabic nucleus can be surrounded by single (C) or several (CC, CCC) consonants either preceding it as syllable onset or following it as syllable coda or offset. The principle of sonority hierarchy within a given syllable is considered a universal feature of syllabic structure: Sonority is ascending towards the syllable nucleus and descending from the nucleus to the coda. The sonority of consonants forming syllable onset and coda generally decreases with distance from the syllable peak and a minimum of sonority is found at the syllable boundary. A CV-syllable is considered the optimal syllabic structure according to the principle of a maximum sonority contrast within and between syllables (see Pulgram, 1970; MacNeilage & Davis, 2001, Stenneken, Bastiaanse, Huber, & Jacobs, 2005).

Phonemes are classified as obstruents and sonorants, according to their degree of sonority, which is higher for the latter ones compared to the first ones. All vowels are sonorants and the sonority of consonants increases from plosives to fricatives (belonging to the obstruent class) and from nasals to liquids (belonging to the sonorant class) (see Selkirk, 1984; Wiese, 1996).

The principle of sonority hierarchy within the constituents of a syllable is illustrated for the German monosyllabic word KRAMPF (cramp): sonority increases within the syllable onset where the plosive /k/ is followed by the fricative /r/. The maximum of sonority is reached at the syllable nucleus formed by the vowel /&/, and sonority decreases again step by step towards the end via the nasal /m/ and the fricative /+/ forming the syllable coda.

But languages differ considerably regarding the number or the type of consonants licensed to occur in combinations at syllable onset or coda. For instance, the Spanish language, which is characterized by a strong tendency to maximize the sonority contrast for syllabic units, only licenses a single consonant as syllable coda.

The presence of a fricative followed by a plosive at the syllable onset – violating the principle of syllabic sonority hierarchy, but occurring at some word beginnings in Germanic languages like *SP*ORT or *ST*RUCTURE – would also be illegal in Spanish. The corresponding Spanish (lean) words are DEPORTE and ESTRUCTURA, which either eliminate one of these incompatible phonemes at the syllable onset or assign them to coda and onset of separate syllables.

Furthermore, morphology can be more powerful in constraining syllabification of particular words than the principle of maximum sonority contrast - with sonority increasing towards the syllable nucleus. This affects syllabification in different languages differently depending on their morphological structure. All experiments presented in this dissertation will focus on the processing of bisyllabic words; and in comparison to Roman languages, bisyllabic German words often have more complex morphological structure. As a consequence, for instance, whenever a German prefix with VC syllabic structure is followed by a monosyllabic stem starting with a vowel, the syllabic structure of the resulting bisyllabic German phonological word form violates the principle of maximum sonority contrast, which would request a consonant syllabic onset of the second syllable to have sonority ascending from the syllable onset to the syllable nucleus. Instead, prefixed words like UNART (bad habit), or also compound words like MEINEID (false oath), are syllabified VC-VCC or CVC-VC according to their morphological structure. Such cases never occur in bisyllabic Spanish words (see Conrad, Carreiras, & Jacobs, submitted). In Spanish (and, even though to a lesser degree, also in French), a prefixed word has to contain at least three syllables and two nouns cannot be combined in a compound word. Nevertheless, also in German, the principles of sonority hierarchy and of maximum sonority contrast can generally be observed in the syllabification of bisyllabic word forms with less complex morphological structure.

On the assumption that words, or at least parts of words, are phonologically encoded or internally pronounced during silent reading, one might expect that a word's syllabic structure should influence the process of visual word recognition, because we cannot know how to pronounce a polysyllabic word form before we know which parts of it can be pronounced in a continuous stream.

For many years – despite this rationale- evidence for syllables being functional units of the reading process was sparse and contested: Prinzmetal, Treiman and Rho (1986), for instance, reported that illusionary conjunctions where higher when two letters were part of a syllable than when they were not, but this finding was later on interpreted as possibly arising as a mere by product of orthographic redundancy (Seidenberg, 1987, 1989, but see Rapp, 1992; see also Lima & Pollatsek, 1983; Millis, 1986; Spoehr & Smith, 1973; Taft & Forster, 1976; Tousman & Inhoff, 1992, for additional evidence regarding the role of syllables during visual word recognition in English).

More generally, syllabic effects had been examined more extensively in the domain of speech perception and note that most of the relevant studies were based on Roman languages (e.g., Cutler, Mehler, Norris, & Seguí, 1986; Mehler, Dommergues, Frauenfelder, & Seguí, 1981; Morais, Content, Cary, Mehler, & Seguí, 1989).

The reason for the apparent lack of attention to the syllable in the domain of visual word recognition research might lie in the fact that most of this research had focused on the English language where – as a consequence of the inconsistent relation between spelling and sound – syllable boundaries are completely ill-defined. Instead of seeing the syllable per se as a functional reading unit, research on phonological processing during visual word recognition in English often concentrated on sub-syllabic units as e.g., syllabic onset, body and rime (Taft, 1992; Treiman & Chafetz, 1987).

Given the problems with syllabic structure in English, Taft (1979b; 1987, see also Rouibah & Taft, 2001; Álvarez, Carreiras, & Taft, 2001) proposed a hybrid sublexical unit - as a substitute to the phonological syllable - as an access code for visual word recognition, the definition of which combines orthographic and morphological features:

The basic orthographic syllable structure (BOSS) comprising all letters following the first letter of a word's stem morpheme the combination of which would not result in an illegal word ending.

But the picture changed completely with two empirical studies undertaken in two Roman languages, Spanish and French reporting an inhibitory effect of syllable frequency on lexical access in Spanish (Carreiras, Álvarez, & de Vega, 1993) and a syllabic priming effect for naming latencies for visually presented French words (Ferrand, Seguí, & Grainger, 1996). Whereas the latter finding has turned out to be a much contested empirical report (see Perret, Bonin, & Meot, 2006; Brand, Rey, & Peereman, 2003; Schiller, 1998, 2000), the syllable frequency effect in lexical decision has already been replicated in two other orthographies: French and German (Conrad & Jacobs, 2004), one Roman and one non-Roman language. But note that a recent attempt to replicate this effect in English has failed (Macizo & Van Petten, 2007).

The Focus of this investigation

It was outlined above why the specific characteristics of a particular language might strongly determine the involvement of syllabic units in the process of silent reading.

The experiments presented in this dissertation tried to further specify the nature of the syllable frequency effect from a cross-linguistic perspective.

Experimental data from the Spanish language, which has a very consistent spelling to sound relation and a most transparent syllabic structure will be compared to experimental data from German – being almost as consistent as Spanish, but having a syllabic structure the transparency of which suffers from morphological constraints and considerably complex consonant combinations in syllabic onsets and codas. Transparency of syllabic structure in French, the third language used for the presented experiments and a Roman language as well, is - at least phonologically - comparable to the Spanish language, but the inconsistent orthographic representation of phonemes make this language an interesting candidate for studying the interplay between orthographic and phonological processing.

Generally, if syllabic effects in visual word recognition can reliably be distinguished from purely orthographic processing in visual word recognition, this would have an important impact on computational models of visual word recognition. Not only because it would make a strong case for the importance of phonological processing, but more specifically because most currently used computational models could not account for such effects for the simple reason that they don't contain a layer of syllabic representation units (Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001; Grainger & Jacobs, 1996; Jacobs, Graf, & Kinder, 2003; Ziegler, Perry, & Coltheart, 2000; Zorzi, Houghton, Butterworth, 1998; but see Ans, Carbonnel, & Valdois, 1998; for a model of naming polysyllabic words).

Several outstanding questions regarding the nature of syllable frequency effects in general and specific aspects of computational modelling in particular will be addressed by the experiments presented in this thesis in the following way:

In Chapter 1, the question of whether syllable frequency would influence two different aspects of the reading process, lexical access during silent reading and overt pronunciation during word naming in Spanish and German in the same or in different ways is addressed comparing findings from Spanish with new empirical data from German.

Chapter 2 addresses the question of differential effects on lexical access for different measures of syllable frequency providing empirical data from Spanish.

Chapter 3 examines an outstanding issue regarding the interpretation of syllable frequency effects as arising in fact through syllabic processing: Previous research had not sufficiently examined whether these effects occur independently of orthographic redundancy. New empirical data is presented manipulating measures of syllable frequency and orthographic redundancy independently for Spanish word material.

Chapter 4 presents experiments run in French making use of the typically inconsistent orthographic representation of French phonological syllables in order to investigate the phonological nature of the syllable frequency effect in lexical decision.

All four chapters have been published in international journals. Each of them is written to be understood independently from the rest of this thesis. Some redundancy between the chapters is an unavoidable consequence.

Chapter 1

Associated or dissociated effects of syllable-frequency in lexical decision and naming[1]

A comparison of Spanish findings with German data

Markus Conrad, Prisca Stenneken & Arthur M. Jacobs

Abstract

Most empirical work investigating the role of syllable-frequency in visual word recognition has focused on the Spanish language where syllable-frequency seems to produce a classic dissociation: inhibition in lexical-decision-tasks but facilitation in naming. In the present study, two experiments using identical stimulus material in a lexical decision and a naming-task were run in German. In both tasks there was an inhibitory effect for words with a high-frequency first syllable. This pattern of results suggesting a stronger weight of lexical access in the naming process in German than in Spanish is discussed regarding the issue of stress assignment in the two languages and within the framework of word production models.

---

[1] Published (2006) in Psychonomic Bulletin & Review, 13, 339-345.

Introduction

The finding of an inhibitory effect of first-syllable-frequency has been the starting point for an intense debate in the field of visual word recognition. The question of whether syllables are automatically processed when polysyllabic words are read is of special interest, because, if it proves to be the case, then current computational models of visual word recognition that do not contain any syllabic representations would have to be revised (Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001; Grainger & Jacobs, 1996; Zorzi, Houghton, & Butterworth, 1998).

For the Spanish language the effect has been shown to be reliable in several studies reporting increased lexical decision latencies when the frequency of the first syllable in a disyllabic word is high. This inhibitory effect in a task usually requiring lexical access is accounted for in terms of a non-implemented interactive activation model in which competing word representations that are activated via the first syllable of a given target interfere with the processing of the target (Carreiras, Álvarez, & de Vega, 1993; Perea & Carreiras, 1998). More interference would be the consequence of increasing syllable-frequency, because a syllable that is shared by many words would activate more competing candidates in a hypothetical mental lexicon.

Recently, the inhibitory effect of syllable-frequency on lexical access has been replicated in one other romance language, French (Mathey & Zagar, 2002), and in German (Conrad & Jacobs, 2004), a non-romance language.

However, the picture is less clear for the naming-task: the only language for which an effect of first-syllable-frequency in disyllabic words has been reported is Spanish: Perea and Carreiras (1998) could show that naming-latencies are reduced when first-syllable-frequency is high. This theoretically interesting dissociation of the syllable-frequency-effect in two different tasks was accounted for by Perea and Carreiras (1998) assuming that when overt pronunciation is required the locus of the effect would shift to motor output where high-frequency syllables representing well-learned units of speech could be produced more rapidly.

This argument is in line with the findings of Levelt and Wheeldon (1994), who obtained reduced naming-latencies when the second syllable of a disyllabic word was of high frequency.

Thus, a dissociation of initial-syllable-frequency effects between lexical decision and naming can be stated for the Spanish language.

Are there reasons that the same would hold true for German? A facilitative effect of first-syllable-frequency on naming-latencies can only appear when either:

> (A) The postulated facilitation on motor output is strong enough to override the inhibition due to syllable-frequency that must have been effective when this word was lexically accessed (postlexical locus of effect),
> (B) Inhibition during lexical access becomes less relevant, because words can be named according to phonological regularities without necessarily being fully identified (nonlexical locus of effect), or
> (C) Despite lexical processing, at an early moment during the time course of word processing the gestural stores of syllabic units do already receive activation from syllabic units (pre- and postlexical locus of effect).

In the experiment of Perea and Carreiras (1998) documenting a facilitative effect of syllable-frequency in naming, also a facilitative effect of word-frequency was obtained. This is interpreted by the authors as strong evidence for the involvement of lexical processes in the naming-task in Spanish. They explain their empirical findings in the naming-task, a facilitative effect for first-syllable-frequency that is very robust for nonwords (Carreiras & Perea, 2004a; Perea & Carreiras, 1996) and diminished but still significant for words (Perea & Carreiras, 1998) as follows: Due to an ease of articulation at a late stage of word processing, the state of phonological output, high-frequency syllables are accessed and produced faster than low-frequency syllables and in the case of naming bisyllabic words this facilitation is only slightly affected but not cancelled out by the inhibitory effect of syllable-frequency on lexical access (Perea & Carreiras, 1998).

The question of whether and to what extent processes related to lexical access influence the performance of subjects in a naming-task is a crucial issue.

In theory, readers in shallow orthographies should be able to correctly pronounce any word without necessarily fully accessing it in the mental lexicon because of a one–to-one translation of graphemes into phonemes. Perea and Carreiras (1998) interpret the presence of a word-frequency effect in their naming experiment as evidence against such a nonlexical strategy.

Still, effects of word-frequency in naming have also been reported for a delayed naming-task by Balota and Chumbley (1985), who stated that "a large component of the frequency effect in the pronunciation tasks involves production rather than simple lexical access". Therefore, it still seems possible to attribute the facilitative effect syllable-frequency on naming-latencies in the study of Perea and Carreiras (1998) to pre- or nonlexical processing.

In the model presented by Ferrand, Grainger, and Seguí (1994) articulatory output units can be activated directly by sublexical orthographic or phonological units without the orthographic or phonological lexicon necessarily being involved. We suppose that at a prelexical level syllable-frequency might affect performance in a naming-task in Spanish and in German in a specific way determined by a differential involvement of lexical processing during the naming-task.

German is almost as consistent as Spanish concerning the conversion of graphemes into phonemes, but when bisyllabic words have to be named there is a reason why it is more difficult to do so correctly in German than in Spanish before a word has been lexically accessed: Any word containing several syllables is stressed in one specific position and, when asked to pronounce it, a reader has to know exactly which syllable has to be stressed. Thus, stress information is a necessary prerequisite of correct naming. Therefore, if correct pronunciation is possible without lexical access, how could readers know how to stress a disyllabic word before they know what the word means?

To find out whether there are statistical regularities of stress assignment in Spanish and in German that could help readers to correctly infer the stress pattern of a disyllabic word at a prelexical level, we analysed two Databases: LEXESP (Sebastián, Martí, Carreiras, & Cuetos, 2000) for Spanish, and CELEX (Baayen, Piepenbrock, & van Rijn, 1993) for German. In both languages, penultimate stress is the most common pattern: 82% of all Spanish and 87% of all German disyllabic words have initial stress. However, the percentage of words that do not follow this pattern seems high enough to assume that stress assignment in both languages is not unambiguous.

Now, there is an interesting pattern that perfectly reduces this ambiguity in Spanish, but not in German:

In Spanish, accents (“tilde”) are used to orthographically mark irregular stress (for the use of the tilde, see Real Academica Española, 1982). For all Spanish words[2] without orthographic accent, statistically, there is one feature that predicts the word’s stress pattern with a reliability of almost 100%: the word’s last letter.

A specific letter can either appear at the end of a word with penultimate stress or at the end of a word with ultimate stress, but never in both.

In addition, for both words with penultimate and words with ultimate stress, there are only four letters that they can end with in more than 99% of the relevant cases. More than 99% of all words with ultimate stress and no accent end with one of these letters: “r”,”l”,”d”, or ”z”. In contrast, all Spanish words with penultimate stress and no accent end with one of these letters: “a”,”o”,”s”, or ”e”.

None of this holds true for German. There are no orthographic accents in German. Neither can the stress pattern of a bisyllabic German word be predicted by the identity of its last letter: German words with ultimate stress can end with 25 different letters, those with penultimate stress can end with 23 different letters.

Given this simple account for the variance of stress pattern in Spanish we assume that Spanish readers are able to reliably infer the stress pattern of a disyllabic word after a superficial, prelexical analysis: screening for orthographic accents and final letters. The same would not hold true for German. Thus, Spanish but not German readers could correctly pronounce any word of their orthography without necessarily fully accessing the mental lexicon. In German this would less efficiently be possible, because one aspect of phonological information that is crucial for the selection of the appropriate articulatory motor program would not be available before lexical access is achieved: The word’s stress pattern.

The aim of the present study is to clarify in which way syllable-frequency is influential in the naming-task in German where stress pattern is more ambiguous than in Spanish.

---

[2] Words like „sandwich“ that are included in the database (Sebastián et al., 2000) that are not original Spanish words but words from other languages were excluded from this analysis.

If early prelexical processing is responsible for the facilitative effect of syllable-frequency in the naming-task in Spanish, then the same effect is not likely to appear in German.

If in German full lexical access is necessary for obtaining the stress pattern of a disyllabic word, a facilitative effect of syllable-frequency on naming-latencies as documented by Perea and Carreiras (1998) should strongly suffer from the inhibitory effect of syllable-frequency on lexical access documented for lexical decision.

If the locus of the effect is only to be seen at a late stage of processing where phonological output is produced after a word has been lexically accessed and its whole phonological word form is available, then the same effect of syllable-frequency in the naming-task as in Spanish should be observed in German.

However, it is unclear whether facilitation of motor output that only arises when the complete phonological word form has become available is sufficient to produce facilitation for words with high frequency initial syllables in the naming-task, given that these words had already been the object of inhibitory processes related to lexical access.

For nonwords, a different pattern of results can be expected: Nonwords are not supposed to have an entry in the mental lexicon and thus no lexical access will occur. For German nonwords, stress assignment could easily be achieved using the global stress pattern of German language as a default principle. 87% of bisyllabic German words have initial stress. Only a word’s meaning but no superficial prelexical features determine differing ultimate stress. When asked to pronounce a German nonword that has no meaning, subjects can always do so stressing the first syllable following this default principle of German stress. The assumed facilitation for high-frequency syllabic units at the level of motor output should lead to speeded naming-latencies for nonwords with high-frequency initial syllables. In the lexical-decision-task, syllable-frequency should cause inhibition for nonwords as well as for words because a high-frequency initial syllable would open a wider search space for any possible lexical candidate activating the representations of words sharing the nonword’s first syllable (Conrad & Jacobs, 2004).

Experiment 1 (Lexical Decision)

Before investigating the effects of syllable-frequency on naming-latencies it should be clear to what extent the difficulty of lexical access varies within the given stimulus material. This was examined using a lexical-decision-task.

Method

Participants

Twenty-eight students from the Catholic University of Eichstätt-Ingolstadt participated in the experiment. Their participation was rewarded with course credits. All were native speakers of German and had normal or corrected-to-normal vision.

Stimuli and Design

112 disyllabic German words of five and six letters length were selected from the CELEX-database (Baayen et al., 1993) according to the orthogonal combination of two factors in a within-participant 2x2 design: word-frequency and positional frequency of the first syllable. Words were matched across the experimental conditions for initial phoneme, length, number of phonemes.

None of the words had orthographic neighbors of higher word-frequency. In addition, words belonging to the conditions that differed in syllable-frequency but not in word-frequency were also matched for number of orthographic neighbors and positional frequency of the second syllable. 112 nonwords were constructed combining first and second syllables of real words. Controlling for initial phoneme, orthographic neighborhood density, the positional frequency of the second syllable and length, nonwords were organized in two groups, according to the manipulation of the factor first-syllable-frequency (high vs. low). Stimuli were presented in uppercase letters using Courier 24 type font. Characteristics for the stimuli are shown in Table 1.1.

Table 1.1

Characteristics of Words and Nonwords used in Experiments 1 and 2
Means (M) and Ranges of the Independent Variables Word Frequency (WF) and Frequency of the First Syllable (SF1). Means and Ranges of Variables that were held constant: Frequency of the Second Syllable (SF2), Density of orthographic Neighborhood (N), Stimulus Length (L) and Number of Phonemes (Ph)

	WF		Log WF (10)		SF1		Log SF1 (10)	
Word Class	M	*Range*	M	*Range*	M	*Range*	M	*Range*
High WF High SF	633	101-9923	2.37	2.00-4.00	7445	1712-16450	3.73	3.23-4.22
High WF Low SF	204	108-750	2.27	2.03-2.68	364	125-633	2.53	2.10-2.80
Low WF High SF	4.26	0.67-9.17	0.53	-0.17-0.96	15136	1677-110013	3.84	3.22-5.04
Low WF Low SF	3.92	0.50 9.00	0.48	-0.30-0.95	108	1-614	1.52	-0.08-2.78
Nonword Class								
High SF					9901	1712-110013	3.77	3.23-5.04
Low SF					112	0.17-786	1.10	-0.78-2.90

	SF2		Log SF2 (10)		N		L		Ph	
Word Class	M	*Range*	M	*Range*	M	*Range*	M	*Range*	M	*Range*
High WF High SF	2990	108-16350	3.01	2.03-4.21	2.00	0-7	5.64	5-6	5.14	4-6
High WF Low SF	3858	131-14485	3.26	2.12-4.16	2.89	0-8	5.64	5-6	5.25	4-6
Low WF High SF	215	2-1279	1.79	0.30-3.11	0.71	0-3	5.64	5-6	5.29	4-6
Low WF Low SF	364	3-1406	2.12	0.40-3.15	0.75	0-4	5.68	5-6	5.25	4-6
Nonword Class										
High SF	224	0.17-1435	0.12	-0.78-3.16	0.32	0-6	5.36	5-6		
Low SF	207	0.17-1435	0.28	-0.78-3.16	0.21	0-3	5.48	5-6		

Note: WF = frequency of occurrence per 1 million words; SF = calculated as cumulated frequency of all words sharing a given syllable in identical position.

Apparatus and Procedure

Each trial was initiated by a fixation point appearing at the centre of the computer screen for 500 ms. The fixation point was then replaced by the word or nonword stimulus that remained visible until participants pressed a button indicating their decision concerning the lexicality ("yes"-button for a word; "no"-button for a nonword) of the stimulus. No error feedback was given. Stimuli appeared in randomized order for each participant. There were ten initial training trials.

Results and Discussion

Words: Mean correct response-latencies and error percentages (see Table 1.2) were submitted to separate analyses of variance (ANOVAs) by participants and by items (F1 and F2, respectively). Concerning response times, the analyses revealed significant main-effects of both word-frequency and syllable-frequency. High-frequency words were responded to 71 ms faster than low-frequency words, F1 (1,27) = 133.09, p ≤.0001; F2 (1,108) = 61.25, p ≤.0001, whereas the frequency of a word's first syllable caused a delay of 17 ms in the latencies, F1 (1,27) = 18.88, p ≤.0003; F2 (1,108) = 5.66, p ≤.01. There was no interaction between the two factors, F1 (1,27) = 0.69, p >.4; F2 (1,108) = 0.86, p >.3.

The error data mirrored this pattern of results, showing a facilitative effect of word-frequency with 2.2% errors for high-frequency words vs. 8.7% for low-frequency words, F1 (1,27) = 48.13, p ≤.0001; F2 (1,108) = 15.76, p ≤.0001, and an inhibitory effect of syllable-frequency with 7.7% errors vs. 3.2% for high vs. low syllable-frequency, respectively, F1 (1,27) = 36.63, p ≤.0001; F2 (1,108) = 7.42, p ≤.007. The interaction between the two factors reached statistical significance in the analysis over subjects, high syllable-frequency provoking more errors in low-frequency words than in high-frequency words, F1 (1,27) = 16.49, p ≤.0003; F2 (1,108) = 2.19, p >.1.

Nonwords: Correct rejections of nonwords with high first-syllable-frequency were 38 ms slower than when the first syllable was low-frequent, F1 (1,27) = 30.59, p ≤.0001; F2 (1,110) = 19.23, p ≤.0001. Similarly, high first-syllable-frequency in nonwords provoked more errors than low first-syllable-frequency (4.4% vs. 1.8%), F1 (1,18) = 15.43, p ≤.0004; F2 (1,110) = 5.84, p ≤.01.

The significant inhibitory effects of initial-syllable-frequency for words and for nonwords in the lexical-decision-task are in line with previous research in German (Conrad & Jacobs, 2004).

Table 1.2

Mean Reaction Times (RT; in Milliseconds), Standard Deviation of Reaction Times (Std. Dev.; in Milliseconds) and Percentage of Errors for Words and Nonwords in Experiment 1

Words						
			Word Frequency			
	High			Low		
First Syllable Frequency	RT	Std. Dev.	% error	RT	Std. Dev.	% error
High	581	76	3.2	656	101	12.1
Low	567	79	1.1	635	87	5.2
Nonwords						
			First Syllable-Frequency			
	High			Low		
	RT	Std. Dev.	% error	RT	Std. Dev.	% error
	664	108	4.4	626	82	1.8

Experiment 2 (Naming)

After establishing that with the selected stimulus material the standard inhibitory effect of syllable-frequency in lexical decision could be obtained, we used the same stimuli for a naming-task. The aim of Experiment 2 is to examine whether initial-syllable-frequency would produce any effect on naming-latencies in German and whether such an effect would be associated or dissociated with the effect in lexical decision.

Method

Thirty-four students from the Catholic University of Eichstaett-Ingolstadt participated in the experiment. Stimuli, design and procedure were the same as in Experiment 1 but this time the task consisted in naming a presented stimulus. Mispronunciations and voice-key errors were coded off-line from tapes.

Results and Discussion

Words: There were significant main-effects of both word-frequency and syllable-frequency. High-frequency words were named 28 ms faster than low-frequency words, F1 (1,33) = 37.39, p ≤.0001; F2 (1,108) = 29.11, p ≤.0001.

But, more importantly, initial-syllable-frequency caused a delay of 11 ms on naming-latencies, F1 (1,33) = 24.56, p ≤.0001; F2 (1,108) = 4.56, p ≤.03 (see Table 1.3). There was no interaction between the two factors, F1 (1,33) = 1.26, p >.2; F2 (1,108) = 0.33, p >.5. There were no effects on mispronunciation rates.

Nonwords: Nonwords with a high-frequency first syllable were named 18 ms faster than nonwords starting with a low-frequency syllable, F1 (1,22) = 33.97, p ≤.0001; F2 (1,110) = 6.97, p ≤.01. Additionally, fewer mispronunciations occurred when nonwords with a high-frequency first syllable had to be named (7.5% vs. 10.8%), F1 (1,33) = 9.25, p ≤.004; F2 (1,110) = 4.96, p ≤.03.

Table 1.3

Mean Latencies of Naming Onset (ON; in Milliseconds), Standard Deviation of Naming Onset (Std. Dev.; in Milliseconds) and Percentage of Mispronunciations for Words and Nonwords in Experiment 2

Words

	Word Frequency					
	High			Low		
First Syllable Frequency	ON	Std. Dev.	% error	ON	Std. Dev.	% error
High	549	80	4.2	579	101	3.9
Low	540	75	2.6	565	90	4.0

Nonwords

	First Syllable Frequency					
	High			Low		
	ON	Std. Dev.	% error	ON	Std. Dev.	% error
	601	109	7.5	619	114	10.8

The first important finding of Experiment 2 is that it shows for the first time that syllable-frequency affects naming-latencies in German. Second, an interesting pattern in the results of Experiment 2 is the dissociation of the effects of syllable-frequency for nonwords and words. We found a facilitative effect of syllable-frequency for nonwords as predicted by the assumption that phonological output is organized syllabically with faster access to high-frequency units. Interestingly, this does not hold true when the given stimulus is a real word. For words, the results were comparable to Experiment 1 where syllable-frequency led to prolonged latencies in lexical decision.

Reanalysis of Experiments 1 and 2

The fact that orthographic neighborhood and second-syllable-frequency had been closely controlled for in the stimulus material concerning the factor first-syllable-frequency but not the factor word-frequency motivated a regression analysis of the data of both experiments using all manipulated and control variables as predictors of response latencies (see Table 1.4). Analyses revealed no significant effects for any of the control variables. In contrast, the log of word frequency significantly predicted response latencies in a facilitative way in lexical decision, F(1, 105) = 40.32, p ≤.0001 and in naming, F(1, 105) = 12.22, p ≤.0008. Significant inhibition was the result for the log of first-syllable-frequency in lexical decision, F(1, 105) = 10.64, p ≤.002, and in naming, F(1, 105) = 5.48, p ≤.02. Thus, the outcome of both experiments was confirmed in the regression analysis.

Table 1.4
Pearson Product-Moment (r) and Partial Correlations (pr) Between Response Latencies and Six Predictors in Experiments 1(Lexical Decision) and 2 (Naming)

	Lexical Decision		Naming	
Predictor	r	pr	r	pr
Log Word Frequency	-.635	-.653*	-.457	-.416*
Log first Syllable Frequency	.106	.255*	.110	.212*
Log second Syllable Frequency	-.510	-.082	-.411	-.099
Number of orthographic Neighbors	-.348	.016	-.321	-.058
Number of Letters	.049	.052	.175	.191
Number of Phonemes	.090	-.008	.130	-.042

*p<.05

General Discussion

The present study provides evidence that effects of syllable-frequency can depend on the specific structure of different languages. We could show again that German readers apparently do rely on the syllabic structure of words.

But concerning the naming-task, the effect of first-syllable-frequency is contrary to what is reported for Spanish: German words are named more slowly when their first syllable is of high frequency. This finding does not oppose to the proposal that phonological output is organized by syllabic units (Ferrand, Seguí, & Grainger, 1996) and that a syllable's frequency facilitates motor output (Levelt & Wheeldon, 1994). The facilitative effect of syllable-frequency for nonwords in Experiment 2 replicates the findings of Carreiras and Perea (2004). Only when words are presented and lexical access becomes involved, this facilitation disappears.

In order to account for this intriguing finding we propose a simple hypothesis emphasizing one aspect in the process of naming polysyllabic words: the consistency or inconsistency of stress assignment. Before a disyllabic word can be correctly pronounced, the reader has to know which syllable receives stress. Phonological output effects, the direction of which is the opposite of what is observed for lexical access, do strongly depend on the involvement of lexical access in the given task. Even if assuming that lexical processing is involved in the naming-task in Spanish (Perea & Carreiras, 1998; but see Balota & Chumbley, 1985), the fact remains that it is possible to correctly pronounce a Spanish word without necessarily having accessed its mental representation. Therefore, in Spanish, where stress pattern can be inferred via superficial orthographic analyses syllabic units can activate their corresponding motor programs already at an early level of word processing before lexical access has occurred which leads to faster motor output for words with high initial-syllable-frequency.

In German, this prelexical facilitation of motor output via syllabic units would not be possible, because only when lexical access is achieved the complete phonological information concerning a word's syllables including the crucial information whether a syllable has to be stressed becomes available. The importance of processes related to lexical access in the naming-task in German explains the inhibitory effect of syllable frequency for words in both experiments.

Taken together, the data for words and nonwords allow drawing new conclusions about the locus of the syllable frequency-effect in naming: Our nonword data indicate that the facilitation of mere motor output processes due to syllable frequency is the same in German as in Spanish.

This would mean that at late stages of word processing when lexical access has already occurred phonological output in both languages should be influenced by syllable frequency in the same way. Thus, the differential effects of syllable frequency in word naming for Spanish and German can only be explained assuming that at an early stage of word processing syllable frequency influences the preparation of motor output in each language in a different way.

The model of Levelt and Wheeldon (1994) could not account for this facilitation of motor output arising at a prelexical level, because the gestural stores of syllabic units in this model can only be accessed once the whole phonological word form is available. Therefore, this model predicts facilitative effects in word naming only for second but not for first-syllable frequency, syllables are accessed successively from the syllabary after the whole phonological word form is available and a possible advantage for retrieving a high-frequency first syllable would already have decayed by the time the second syllable is accessed and pronunciation occurs. In fact, Levelt and Wheeldon (1994) obtained effects in the word naming-task only for second-syllable frequency, but not for first-syllable frequency.

In contrast, the finding of reduced naming-latencies for words with high-frequency initial syllables fits well with the model proposed by Ferrand et al. (1994). In their model, motor output is thought to be prepared not only via the phonological lexicon, but also directly via the sublexical input. Note that the model of Ferrand et al. (1994) has been formulated considering empirical results from a Romance language (French) whereas the Levelt and Wheeldon model rather relates to Germanic languages (Dutch and English).

Typically, these two groups of languages differ in the degree of stress ambiguity. In French, stress assignment is regular, words always having ultimate stress.

For Spanish, we could show how stress information for a bisyllabic word can be obtained by a superficial orthographic analysis. In English, there is lexical stress which depends to some degree on the morphological structure of words. German words might need full lexical access before uncertainty about their stress pattern is completely resolved.

We suggest that facilitative effects of initial syllable frequency are more likely to be obtained in Romance languages because of their high degree of stress consistency.

An important issue for future research is the question of whether orthographic or phonological syllables are responsible for the segmentation of polysyllabic words. This question can not be answered by the present study, because the high spelling to sound consistency in German does not allow attributing the empirical effects to either of them exclusively (see Álvarez, Carreiras, & Perea, 2004 and Stenneken, Conrad, Hutzler, Braun, & Jacobs, 2005, for different views on this issue).

In sum, we think that the proposal of stress ambiguity as a factor responsible for differential effects of syllable frequency in naming across different languages might motivate interesting cross-language research. The specific pattern of stress assignment in different languages is a crucial issue that models of word production would have to consider.

Chapter 2

Contrasting effects of token and type syllable frequency in lexical decision[3]

Empirical evidence from Spanish and implications for computational modelling

Markus Conrad, Manuel Carreiras & Arthur M. Jacobs

Abstract

In psycholinguistic research, there is still considerable debate about whether the type or token count of the frequency of a particular unit of language better predicts word recognition performance. The present study extends this distinction of type and token measures to the investigation of possible causes underlying syllable frequency effects. In two lexical decision experiments we found a dissociation suggesting that the token measure of syllable frequency adequately predicts the inhibitory effect of initial syllable frequency, whereas the type measure led to facilitation, especially when the number of higher frequency syllabic neighbours was controlled for. This specific pattern of results, suggesting the involvement of two different processes in effects of syllable frequency, provides a strong constraint for current and future models of visual word recognition.

---

[3] To appear (2008) in Language and Cognitive Processes, Volume 2, available online since September 2007

Introduction

The question of how the frequency of syllables influences processing of polysyllabic words has led to a series of studies reporting effects of syllable frequency for a broad range of tasks and dependent variables across different languages. An inhibitory effect of the positional frequency of a word's first syllable has so far been documented for three languages in the lexical decision task: Spanish (Álvarez, Carreiras, & Taft, 2001; Carreiras, Álvarez, & de Vega, 1993; Perea & Carreiras, 1998), French (Mathey & Zagar, 2002; Conrad, Grainger, & Jacobs, 2007) and German (Conrad & Jacobs, 2004; Conrad, Stenneken, & Jacobs, 2006). Words are responded to slower when their first syllable is of high frequency. Similar inhibition of lexical access has also been documented for perceptual identification paradigms (Conrad & Jacobs, 2004; Perea & Carreiras, 1995) and eye-movement measures (Carreiras & Perea, 2004b; Hutzler, Conrad, & Jacobs, 2005).

Concerning speech production, there is also evidence that the speed of naming bisyllabic words is modulated by syllable frequency (Carreiras & Perea, 2004a; Cholin, Levelt, & Schiller, 2006; Levelt & Wheeldon, 1994; Perea & Carreiras, 1998). In contrast to the inhibitory effect on lexical access, bisyllabic words seem to be named faster when their first syllable is of high frequency (but see Conrad et al., 2006, for an inhibitory effect of syllable frequency in naming).

Effects of syllable frequency are evident not only in reaction times, but are also reflected in physiological correlates of cognitive processes. In two studies, event related potentials were shown to be sensitive to the manipulation of syllable frequency in lexical decision tasks (Barber, Vergara, & Carreiras, 2004; Hutzler, Bergmann, Conrad, Kronbichler, Stenneken, & Jacobs, 2004).

Together, these results provide evidence that the syllable is a functional unit in the process of visual word recognition. If this is indeed the case, current computational models of visual word recognition will have to be revised to account for this (Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001; Grainger & Jacobs, 1996; Jacobs, Graf, & Kinder, 2003;

Ziegler, Perry, & Coltheart, 2000; Zorzi, Houghton, Butterworth, 1998; but see Ans, Carbonnel, & Valdois, 1998; for a model of naming polysyllabic words).

However, despite the increasing evidence for the importance of syllabic units and their frequency in visual word recognition, it is still not clear how syllable frequency is best defined or how it should be computed. Especially for a potential implementation of syllabic units into computational models, it is important to know how syllable frequency is quantified best, in order to reproduce the empirical effects.

In the first study documenting effects of syllable frequency, Carreiras et al. (1993) used bisyllabic words with either high or low mean positional frequency of the two syllables. In subsequent studies, only the positional frequency of the initial syllable has been manipulated as the independent variable. Positional syllable frequency is usually computed by taking into account all words that share a given syllable in identical position. In general, the authors of studies on syllable frequency have adopted Perea and Carreiras' (1998) theoretical account of the inhibitory effect of syllable frequency on lexical access:

When reading a bisyllabic word, the first syllable of this word activates those entries in the mental lexicon that share this syllable in first position. These co-activated candidate representations interfere with the processing of the target word through the mechanism of lateral inhibition at the word unit level of an interactive activation model of visual word recognition. The consequence of increased syllable frequency would be a greater amount of lateral inhibition and therefore, words starting with a high-frequency first syllable take longer to be lexically accessed. However, what exactly is a high-frequency first syllable? In the literature, there are two standard ways to measure syllable frequency, both based on syllabic neighbours, that is, all words sharing a syllable in identical position.

A) The type measure of syllable frequency: the number of syllabic neighbours.
B) The token measure of syllable frequency: the accumulated word frequency of all syllabic neighbours.

The comparison of type and token frequency measures has been the object of several empirical studies on word processing, mostly in the field of morphology, where this is still a controversial issue (e.g., Bailey & Hahn, 2001; De Jong, Schreuder, & Baayen, 2000; Ernestus & Baayen, 2003; Ernestus & Baayen, 2001).

In terms of the effects of syllable frequency, no empirical evidence has yet been provided addressing the issue of a possible differential role of these two measures.

Furthermore, the authors of relevant studies sometimes have not even documented which of these measures was used as independent variable. If they did so, as did Álvarez et al. (2001) using type syllable frequency, or Conrad and Jacobs (2004) using token syllable frequency, the reasoning for their preference was of a speculative nature, as the two different measures had never been experimentally compared.

To improve comparability between different studies, but also for a better theoretical understanding of the empirical effects obtained, it is essential to clarify the influence of each of the two different measures of syllable frequency in visual word recognition. The present study examines, in the first place, which of these measures is the better predictor of the inhibitory effect of syllable frequency on lexical access.

However, even opposite effects of these two alternative measures could be expected when they are experimentally disentangled – particularly relevant here is the analogy of the term "syllabic neighbour" with the concept of orthographic neighbours (see Coltheart, Davelaar, Jonasson, & Besner, 1977). Research on the effects of orthographic neighbourhood, has revealed that different aspects of this variable, e.g. neighbourhood size and neighbourhood frequency, can influence word processing in opposite ways. Whereas neighbourhood size mostly leads to facilitation in the lexical decision task (see Andrews, 1997, for a review), inhibitory effects of neighbourhood frequency have been reported (e.g. Carreiras, Perea, & Grainger, 1997; Grainger & Jacobs, 1996).

In fact, the finding of opposite effects for these different measures of orthographic neighbourhood has had an important impact on the development of models of visual word recognition: A computational model with a multiple read-out procedure has been proposed by Grainger and Jacobs (1996) in order to account for the opposite effects of the number of orthographic neighbours on the one hand and of their frequency on the other. Obviously, then the question arises of whether a similar pattern of results can be obtained for syllabic neighbourhood: does the mere number of syllabic neighbours produce the same or a different effect from the accumulated frequency of these syllabic neighbours?

This question cannot be answered by the studies available to date, as for both measures significant inhibitory effects have been reported, but in any case the high positive correlation between them does not allow for a clear attribution of these effects. Note that two ERP-studies assessing the time course of syllabic processing converged on one interesting finding: syllable frequency effects were found at two distinct time windows, suggesting a multi-dimensional influence of this variable (Barber et al. 2004; Hutzler et al., 2004).

Therefore, disentangling the effects of type and token syllable frequency might help to better understand the nature of syllabic processing and would provide an important constraint for the modelling of polysyllabic word recognition and of visual word recognition in general, especially if dissociated effects for the two measures were obtained. We tested for differential effects of token and type syllable frequency in Experiments 1A and 1B.

Experiments 2A and 2B were designed to find out whether either of these two measures of syllable frequency would be sufficient to produce a reliable effect, when controlling for another variable that has been proposed to be responsible for the inhibitory syllable frequency effect: the number of higher frequency syllabic neighbours (Perea & Carreiras, 1998). All together, these special constraints for the selection of stimuli might help to better understand the relation between familiarity-based word processing and competition between lexical candidates. To date, the heterogeneous findings from the domain of orthographic neighbourhood have been very hard to reconcile, partly, because neighbourhood size and frequency have rarely been manipulated independently (but see Carreiras et al., 1997) and the differences between experimental tasks may have largely contributed to the variety of results.

The experiments in the present study involve the independent manipulation of type and token syllable frequency, while closely controlling for the respective alternative variable, and all stimuli are presented in the same task environment of a lexical decision experiment.

Experiments 1A and B

Method

Participants

Thirty-seven students from the University of La Laguna participated in the experiment. All were native speakers of Spanish, with normal or corrected-to-normal vision. Their participation was rewarded with course credits.

Stimuli and Design

For each of the two experiments, two sets of 48 bisyllabic Spanish words were selected from the LEXESP database (Sebastián-Gallés, Martí, Carreiras, & Cuetos, 2000), according to the manipulation of the factor positional frequency (high vs. low) of the first syllable, realized as token syllable frequency in Experiment 1A and type syllable frequency in Experiment 1B. In consequence, in Experiment 1A type syllable frequency was controlled for, whereas token syllable frequency was held constant in Experiment 1B. All measures of syllable frequency were computed based on a word's orthographic syllables[4]. In both experiments, the frequency of the second syllable of words was held constant, as well as word length, the number of orthographic neighbours and the number of higher-frequency orthographic neighbours and word frequency. None of the words was of high word frequency. Characteristics of the words in Experiments 1A and B are shown in Table 2.1.

---

[4] Very recently, measures of phonological syllable frequency were also made available for Spanish orthography (BuscaPalabras: Davis & Perea, 2005). All syllable frequency computations used for the present study are based on the 16,466 bisyllabic entries in the LEXESP database (Sebastián-Gallés et al., 2000). The BuscaPalabras corpus contains 4,914 bisyllabic entries. This considerable reduction of corpus size relative to the LEXESP is due to two reasons: the elimination of words that do not stem from the Spanish language and the exclusion of inflected forms for nouns, verbs and adjectives. Whereas the first elimination principle is clearly an advantage of the BuscaPalabras, the second is a matter of debate: Some word initial syllables, for instance, are not the same in a verb's infinitive form and in inflected forms. E.g., "pensar" (to think) and "pienso" (I think). However, the impact of these differences between corpora on the syllable frequency measures computed for our stimulus material was negligible: the correlation of our initial type syllable frequency measure with the orthographic one provided by BuscaPalabras is .93; for initial token syllable frequency the correlation is .94. Also phonological syllable frequency as provided by BuscaPalabras always co-varied with the orthographic syllable frequency measures manipulated for the present experiments, thus no hypotheses regarding differential effects of orthographic or phonological syllable frequency can be formulated (but see Álvarez, Carreiras & Perea, 2004, and Conrad et al., 2007, for this issue).

Table 2.1

Characteristics of Words used in Experiments 1A and B
Means and Ranges for the different Measures of first Syllable Frequency (SF1): Token Syllable Frequency, Type Syllable Frequency, Mean Frequency of Syllabic Neighbours (MeanF SN), Number of higher Frequency Syllabic Neighbours (HFSN), Summed Frequency of higher Frequency Syllabic Neighbours (SumF HFSN), Mean Frequency of higher Frequency Syllabic Neighbours (MeanF HFSN), Frequency of the highest Frequency Syllabic Neighbour (Fmax SN).
Means and Ranges for Control Variables: Word Frequency (WF), orthographic Neighbourhood Density (N), Number of higher Frequency orthographic Neighbours (HFN); second Syllable Frequency (SF2) and Word Length (L).
Means and Ranges for mean Word Token and Type Bigram Frequency (Mean Token BiF and Mean Type BiF) computed according to the non-positional Occurrence of Bigrams in all bisyllabic Words. P-Values (p) corresponding to t-tests for Significance of Mean Differences are reported for Control Variables and for Measures of Syllable or Bigram Frequency that were not explicitly manipulated or controlled for.

	1A Manipulated Variable: Token Syllable Frequency							
	High			Low				
	Mean		Range	Mean		Range	p	
Token SF1	1212	*3.06*	852-2262	272	*2.41*	100-387		
Type SF1	70		62-75	69		53-117	.63	
MeanF SN	17.60	*1.22*	13-34	4.05	*0.59*	2-5	.0001	*.0001*
HFSN	15.79		2-30	7.96		0-26	.001	
SumF HFSN	1072	*2.99*	526-2227	155	*1.98*	0-312	.0001	*.0001*
MeanF HFSN	105	*1.89*	33-418	26	*1.26*	0-86	.0003	*.0001*
Fmax SN	336	*2.47*	179-704	60	*1.70*	18-149	.0001	*.0001*
WF	16.06	*1.02*	3.00-59	14.88	*1.00*	2.40-58 .	79	*.87*
N	10.33		1-22	10.58		0-23	.89	
HFN	2.71		0-9	2.00		0-6	.28	
Token SF2	3024	*3.48*	8-10867	1797	*3.51*	7-8037	.18	*.90*
Type SF2	73		1-240	83		1-250	.59	
L	4.50		4-5	4.54		4-5	.78	
Mean Token BiF	6976	*3.78*	1299-14771	6107	*3.72*	1300-11416	.35	*.48*
Mean Type BiF	521		142-941	472		142-941	.39	

	1B Manipulated Variable: Type Syllable Frequency							
	High			Low				
	Mean		Range	Mean		Range	p	
Token SF1	521	*2.69*	358-827	460	*2.54*	133-1441	.46	*.05*
Type SF1	109		101-126	36		24-46		
MeanF SN	4.82	*0.66*	3-8	12.74	*1.00*	4-38	.0002	*.0001*
HFSN	12.46		0-34	5.33		1-13	.002	
SumF HFSN	345	*2.39*	0-771	366	*2.40*	41-1019.	78	*.97*
MeanF HFSN	46	*1.49*	0-164	80	*1.77*	17-282	.04	*.03*
Fmax SN	139	*2.11*	79-256	166	*2.08*	33-527	.36	*.70*
WF	18.32	*0.99*	2.60-94	20.90	*1.09*	2.20-72	.69	*.51*
N	7.66		0-22	5.17		0-20	.13	
HFN	1.50		0-9	1.33		0-9	.78	
Token SF2	766	*2.92*	3-3352	1125	*3.18*	8-5323	.40	*.30*
Type SF2	43		2-141	58		2-250	.39	
L	4.88		4-6	4.79		4-6	.63	
Mean Token BiF	6195	*3.71*	1164-13412	5079	*3.65*	1048-8416	.21	*.42*
Mean Type BiF	496		184-1007	417		163-768	.16	

Note: Frequency counts are given per million occurrences
For all token measures, means and p-values corresponding to a logarithmic transformation of these measures (Log10) are presented in italics.

For all words used as stimuli in any of the experiments reported in this study, a strict criterion was applied in order to rule out the possibility that the effects obtained might be due to processes that do not necessarily rely on syllabic structure: the frequency of the bigram representing the syllable boundary within a word was always at least as high as the mean frequency of all other bigrams of the word.

Thus, when readers apparently perform a segmentation of words into sublexical units corresponding to syllables, this segmentation has to refer to syllabic structure per se and can not be achieved by purely orthographic processing which focuses on a remarkably low-frequency bigram within a word, referred to as "bigram trough" (Seidenberg, 1987; 1989).

In addition, in order to control for possible effects of syllabic structure, only words starting with a CV-syllable were used. These restrictions, together with the need to disentangle two strongly correlated variables - token syllable frequency and type syllable frequency - resulted in a severe limitation of the number of words that could be used as stimuli in the experimental design. Therefore, it was necessary to use some of the words of Experiments 1A and B again as stimuli for Experiments 2A and B where an additional variable, the number of higher frequency syllabic neighbours, was controlled for. However, there was no overlap of the stimulus material between Experiments 1A and B.

Because of the very close logical analogy between the four experiments in this study, we presented all four stimuli sets together in one experimental session. Therefore, all reported effects are based on the performance of identical subjects, which clearly enhances the comparability of analogous empirical effects, because the amount of variance caused by individual performance of subjects in each experiment can be considered as equal. Any word that was used as an item in more than one experiment was only once presented in the experimental session.

Nonwords were constructed by combining the first syllable of a stimulus word with another letter string that exists as a second syllable in Spanish. Nonwords were made difficult to reject by ensuring that there were always at least four Spanish words that could be considered orthographic neighbours of this nonword.

Apparatus and Procedure

Stimuli were presented in lowercase letters on a 17" Samtron color monitor (resolution 1024x768 pixel, 75 Hz) driven by a GenuineIntel computer. Stimulus presentation and response recording was controlled by EXPE 6.02 software (Pallier, Dupoux, & Jeannin, 1997).

Subjects were seated approximately 50-60 cm in front of the computer screen. They were instructed to make a decision concerning the lexicality of the stimulus as quickly and as accurately as possible, pressing a "yes"-button for a word and a "no"-button for a nonword. The complete stimulus list contained 119 words and 119 nonwords. The experiment lasted about fifteen minutes. Order of stimulus appearance was randomized for each participant. Stimuli remained visible until a response was given with an inter-trial interval of 1000 milliseconds. There were ten initial training trials.

Results and Discussion

In this and the following analyses, mean correct response latencies and error percentages (see Table 2.2) were submitted to separate analyses of variance (ANOVAs) by participants and by items (F1 and F2, respectively). For all experiments reported in this study, response latencies differing more than two standard deviations from the mean for each subject and experimental condition were excluded from the analyses. This led to the exclusion of 4.4% of the data. Moreover, items with error rates exceeding 50 percent[5] were excluded from all analyses. Generally, words were responded to 143 ms faster than nonwords, F1 (1,36) = 132,82, p<.0001; F2 (1,233) = 251.76, p<.0001. No significant effect of lexicality was obtained for the error data. One of the word stimuli in Experiment 1B had to be excluded from the analysis, because of its corresponding error rate.

Experiment 1A (token frequency). Concerning response latencies, there was a significant effect of the factor token syllable frequency. Words were responded to 45 ms slower when their first syllable was of high frequency measured as token syllable frequency, F1 (1,36) = 16.84, p <.0003; F2 (1,46) = 5.60, p <.03.

---

[5] Before the rejection of outlier response latencies

A similar effect appeared in the analysis of error rates, significant in the analysis over subjects, words provoked more errors when starting with a high than with a low-frequency first syllable (9.5% vs. 6.2%), F1 (1,36) = 6.57, p <.02; F2 (1,46) = 1.53, p >.2.

Experiment 1B (type frequency). Concerning response latencies, syllable frequency caused no significant effect when realized as type syllable frequency. In contrast to the inhibitory effects of Experiment 1A, responses were 6 ms faster for words with many than with few syllabic neighbours, p>.6. This facilitative tendency in response latencies, although far from being statistically significant, was underlined by an effect in the analysis of error rates, significant over subjects, where words with many syllabic neighbours provoked less errors (4.5% vs. 8.5%) than those with few, F1 (1,36) = 9.78, p <.004; F2 (1,45) = 1.95, p >.1.

Table 2.2

Mean Reaction Times (RT; in Milliseconds), Standard Deviation of Reaction Times (Std. Dev. in Milliseconds) and Percentage of Errors for Words in Experiment 1A and B

Experiment 1A		
	Token Syllable Frequency	
	High	Low
RT	716	671
Std. Dev.	142	102
% error	9.5	6.2
Experiment 1B		
	Type Syllable Frequency	
	High	Low
RT	685	691
Std. Dev.	119	117
% error	4.5	8.5

The outcome of Experiments 1A and B provides an answer to the question of which measure of syllable frequency is appropriate in order to obtain the inhibitory effect on lexical access described in the literature. A clear and reliable inhibitory effect is obtained when token syllable frequency is manipulated, controlling for the type measure, whereas there is no inhibition at all on response latencies, but a significant facilitative effect on error rates in the inverse case. Thus, the inhibitory effect of syllable frequency seems not to be driven by the number of times a syllable appears in the dictionary of a language, but by the number of times it actually appears in everyday language.

This frequency of usage is reflected only by the token measure, which takes into account the frequency of words sharing a given syllable.

Regarding a potential effect of type syllable frequency that would be independent from token syllable frequency, the outcome of Experiments 1A and B does not allow for any reliable conclusions. Even if responses were faster to words with many syllabic neighbours than to words with few, this mean difference was not statistically significant.

A significant facilitative effect of type syllable frequency was only obtained in the analysis of error rates over participants. Perea and Carreiras (1998) have argued that the number of higher frequency syllabic neighbours of a word is responsible for the inhibitory effect of syllable frequency on lexical access. As evident from Table 2.1, this variable co-varied with the manipulation of both type and token syllable frequency in Experiments 1A and B. The fact that words with high type syllable frequency have many higher frequency syllabic neighbours may have prevented a facilitative effect for this syllable frequency measure from significantly appearing in the response latencies in Experiment 1B. A potential facilitative effect for the type measure of syllable frequency might be obtained when the inhibitory influence of both token syllable frequency and of the number of higher frequency syllabic neighbours is controlled for. We controlled for this variable in Experiments 2A and 2B. It is also important to examine whether the inhibitory effect of token syllable frequency in Experiment 1A will still be obtained when controlling for the number of higher frequency syllabic neighbours – proposed as the source of this effect by Perea & Carreiras (1998).

Experiments 2A and B

Method

Participants and procedure were the same as in Experiments 1A and B.

Stimuli and Design

Two sets of 40 bisyllabic Spanish words were selected from the LEXESP database (Sebastián-Gallés et al., 2000). In parallel to Experiments 1A and B, the manipulated factors were positional token frequency of the first syllable in Experiment 2A and positional type frequency of the first syllable in Experiment 2B. The same selection and matching criteria as in Experiment 1 were applied. In addition, the number of higher frequency syllabic neighbours was held constant between the conditions of the factor syllable frequency (see Table 2.3).

We mentioned previously why only a very limited number of words could be used for the experiments of the present study. The stimuli list of Experiments 2A and B is a subset of the one used for the previous experiments, to which some new words were added in order to achieve control of an additional variable. Specifically, 15 of the 40 words of the stimulus set of Experiment 2A were taken from the stimuli of Experiment 1A, whereas 32 of the 40 stimuli of Experiment 2B were items taken from Experiment 1B. Seven words were present in both stimuli lists of Experiments 2A and 2B. Thus, Experiments 2A and B can be considered an enhanced version of Experiments 1A and B, controlling for the influence of one variable, the number of higher frequency syllabic neighbours, that had systematically co-varied with the experimental factors of Experiments 1A and B.

Table 2.3

Characteristics of Words used in Experiments 2A and B

Means and Ranges for the different Measures of first Syllable Frequency (SF1): Token Syllable Frequency, Type Syllable Frequency, Mean Frequency of Syllabic Neighbours (MeanF SN), Number of higher Frequency Syllabic Neighbours (HFSN), Summed Frequency of higher Frequency Syllabic Neighbours (SumF HFSN), Mean Frequency of higher Frequency Syllabic Neighbours (MeanF HFSN), Frequency of the highest Frequency Syllabic Neighbour (Fmax SN).

Means and Ranges for Control Variables: Word Frequency (WF), orthographic Neighbourhood Density (N), Number of higher Frequency orthographic Neighbours (HFN); second Syllable Frequency (SF2) and Word Length (L).

Means and Ranges for mean Word Token and Type Bigram Frequency (Mean Token BiF and Mean Type BiF) computed according to the non-positional Occurrence of Bigrams in all bisyllabic Words. P-Values (p) corresponding to t-tests for Significance of Mean Differences are reported for Control Variables and for Measures of Syllable or Bigram Frequency that were not explicitly manipulated or controlled for.

	2A Manipulated Variable: Token Syllable Frequency							
	High			Low				
	Mean		Range	Mean		Range	p	
Token SF1	1282	*3.07*	826-2262	321	*2.50*	174-387		
Type SF1	83		40-122	84		32-117	.94	
HFSN	13.25		4-27	12.70		2-26	.82	
MeanF SN	17.21	*1.17*	7-34	4.08	*0.60*	3-6	.0001	*.0001*
SumF HFSN	1151	*3.00*	537-2227	218	*2.31*	72-312	.0001	*.0001*
MeanF HFSN	113	*1.95*	28-418	22	*1.31*	11-44	.0001	*.0001*
Fmax SN	428	*2.58*	218-761	70	*1.80*	25-104	.0001	*.0001*
WF	10.91	*0.91*	2.80-31	10.53	*0.87*	2.40-35	.90	*.72*
N	10.10		0-22	9.00		0-23	.65	
HFN	2.30		0-9	1.95		0-9	.66	
Token SF2	2145	*3.26*	3-9745	1103	*3.05*	3-5323	.20	*.53*
Type SF2	57		1-118	64		1-250	.71	
L	4.55		4-5	4.65		4-6	.57	
Mean Token BiF	6540	*3.71*	1164-19419	5582	*3.69*	1300-11416	.44	*.78*
Mean Type BiF	524		142-1223	442		146-822	.25	

	2B Manipulated Variable: Type Syllable Frequency							
	High			Low				
	Mean		Range	Mean		Range	p	
Token SF1	780	*2.77*	358-4175	490	*2.56*	133-1441	.18	*.05*
Type SF1	110		101-136	36		29-46		
HFSN	6.65		0-15	5.35		1-13	.34	
MeanF SN	7.20	*0.73*	3-42	13.53	*1.02*	4-38	.04	*.006*
SumF HFSN	516	*2.41*	0-3834	384	*2.40*	54-1019	.50	.95
MeanF HFSN	97	*1.73*	0-548	85	*1.77*	13-282	.70	*.78*
Fmax SN	242	2.23	79-1634	176	2.09	33-527	.42	.21
WF	29.07	1.25	5.20-94	24.41	1.17	2.20-72	.58	.59
N	8.60		2-21	6.10		0-20	.19	
HFN	1.65		0-9	1.50		0-9	.84	
Token SF2	767	*3.08*	29-3352	1665	*3.38*	19-7646	.12	*.20*
Type SF2	47		1-141	67		4-250	.34	
L	4.90		4-6	4.75		4-6	.46	
Mean Token BiF	5719	*3.68*	1164-13412	4495	*3.58*	1048-8416	.18	*.29*
Mean Type BiF	517		184-1007	391		163-768	.05	

Note: Frequency counts are given per million occurrences

For all token measures, means and p-values corresponding to a logarithmic transformation of these measures (Log10) are presented in italics.

Results and Discussion

One word in each Experiment 2A and B had to be excluded from the analyses, because of an error rate higher than 50 percent. Mean response latencies and error rates for words in Experiments 2A and B are shown in Table 2.4.

Experiment 2A (token frequency): Concerning response latencies, there was a significant effect of the factor token syllable frequency. Responses were 50 ms slower to words with high than with low initial token syllable frequency, F1 (1,36) = 21.22, p <.0001; F2 (1,37) = 7.43, p <.01. The same inhibitory effect of token syllable frequency appeared in the analysis of error rates, with words provoking more errors when starting with a high than with a low-frequency first syllable (11.4% vs. 4.2%), F1 (1,36) = 38.14, p <.0001; F2 (1,37) = 4.87, p <.04.

Experiment 2B (type frequency): The analysis revealed a significant effect of the factor type syllable frequency. Responses to words with many syllabic neighbours were 27 ms faster than to words with few, F1 (1,36) = 14.36, p <.0007; F2 (1,37) = 4.25, p <.05. Consistently and significant in the analysis over subjects, less errors (3.0% vs. 7.1%) occurred for words with high than for words with low type syllable frequency, F1 (1,36) = 10.38, p <.003; F2 (1,37) = 2.21, p >.1.

There are two interesting features in the results of Experiment 2: First, the token frequency of the first syllable still produced an inhibitory effect on lexical access, even when the number of higher frequency syllabic neighbours was held constant.

Second, the consequence of this control of the number of higher frequency syllabic neighbours is a clearer facilitative effect of type syllable frequency, the number of syllabic neighbours per se. Now, this effect that had only been obtained for error rates in Experiment 1B is also present for response latencies. This evidence for a facilitative effect of type syllable frequency completes the comparison of type and token syllable frequency in visual word recognition, suggesting a differential and dissociated influence of these two frequency measures.

It might be argued that the facilitative effect obtained in Experiment 2B cannot be attributed exclusively to type syllable frequency, because, as evident from Table 2.3, words in the relevant conditions also differ to some degree in the overall mean type frequency count of their bigrams. But this difference is exclusively due to the type frequency of the words' first bigram, which coincides, with the initial syllable of these words. Therefore, we believe that the empirical effect is better attributed to type syllable frequency than to overall orthographic redundancy. Still, the fact that there was an important overlap for the stimulus materials of Experiments 1 and 2 may be considered a methodological weakness, questioning the validity of discussing the data of Experiment 2 as the outcome of a separate experiment that is independent from Experiment 1. Therefore, we decided to re-run Experiment 2 using only the word stimuli of Experiments 2A and B, with a different set of participants who had not participated in the lexical decision experiment described above.

Table 2.4

Mean Reaction Times (RT; in Milliseconds), Standard Deviation of Reaction Times (Std. Dev. in Milliseconds) and Percentage of Errors for Words in Experiment 2A and B

Experiment 2A		
	Token Syllable Frequency (HFSN controlled for)	
	High	Low
RT	728	678
Std. Dev.	128	94
% error	11.4	4.2
Experiment 2B		
	Type Syllable Frequency (HFSN controlled for)	
	High	Low
RT	659	686
Std. Dev.	98	117
% error	3.0	7.1

Note: HFSN = Number of higher frequency syllabic neighbours

Experiments 3A and B

Method

Apparatus and procedure were the same as for the Experiments described above, apart from the fact that the stimulus list now contained only seventy-three words and nonwords respectively. The same stimuli as in Experiment 2 were used. Forty-seven students from the University of La Laguna participated in the experiment.

Results and Discussion

The empirical effects described above for Experiment 2 also appeared in the data analyses of what now has been conducted as a separate Experiment 3 (see Table 2.5).

Two words from the stimulus material of Experiment 3A and one word from the stimulus material of Experiment 3B had to be excluded because of high error rates.

Generally, words were responded to 119 ms faster than nonwords, F1 (1,46) = 54,32, p<.0001; F2 (1,139) = 176.78, p<.0001. No significant effect of lexicality was obtained in the analysis of error rates. Analyses revealed a significant inhibitory effect of token syllable frequency on response latencies, with a delay of 45 ms for words with high syllable frequency relative to words with low syllable frequency, F1 (1,46) = 36.11, p <.0001; F2 (1,36) = 8.40, p <.007. This inhibitory effect was also present in error rates, significant in the analysis over subjects, with 7.4 % errors for high and 5.3% errors for low token syllable frequency words, F1 (1,46) = 5.71, p <.03; F2 (1,36) = 1.59, p >.3. These inhibitory effects for token syllable frequency were again contrasted by a significant facilitative effect of type syllable frequency when controlling for the number of higher frequency syllabic neighbours: Responses to words were 29 ms faster when their initial syllable was shared by many than by few other words, F1 (1,46) = 15.93, p <.0003; F2 (1,37) = 5.19, p <.03. Concerning error rates, this time there was no significant effect of type syllable frequency. Given that also the effect of token syllable frequency on error rates was no longer statistically significant in the analysis over items in Experiment 3A and that error rates were generally reduced when comparing the present analyses with the output of Experiment 2, we conclude that this change in the pattern of results in the error data is best attributed to the fact that the reduced stimulus list for this replication of Experiment 2 allowed participants to perform the task more accurately.

Table 2.5

Mean Reaction Times (RT; in Milliseconds), Standard Deviation of Reaction Times (Std. Dev. in Milliseconds) and Percentage of Errors for Words in Experiment 3A and B

Experiment 3A		
	Token Syllable Frequency (HFSN controlled for)	
	High	Low
RT	732	687
Std. Dev.	91	88
% error	7.4	5.3
Experiment 3B		
	Type Syllable Frequency (HFSN controlled for)	
	High	Low
RT	664	693
Std. Dev.	82	90
% error	3.7	4.2

Note: HFSN = Number of higher frequency syllabic neighbours

Both the inhibitory effect of token and the facilitative effect of type syllable frequency on response latencies in Experiment 2 were successfully replicated. Still, one might argue that the specific design of the present experiments might lead to a false interpretation of the present results as evidence for dissociated effects of type and token syllable frequency. That is, when manipulating type syllable frequency and controlling for both token syllable frequency and the number of higher frequency syllabic neighbours in Experiments 2 and 3 B, words with low type syllable frequency might have some syllabic neighbours with especially high word frequency. Such very high-frequency syllabic neighbours might have interfered with the processing of the target in an especially efficient way. Therefore, what appears to be a facilitative effect of type syllable frequency - a processing advantage for words with many syllabic neighbours - might in fact result from especially high inhibition for words with a few very high-frequency syllabic neighbours.

However, the information provided in Table 2.3 questions such an alternative interpretation of the effects in Experiment 2 and 3B: not only did the number of higher frequency syllabic neighbours not co-vary with the manipulation of type syllable frequency in Experiment 2 and 3B, but neither did their accumulated mean and maximum word frequency. To further explore how different operationalizations of syllable frequency affect performance in the lexical decision task, we conducted multiple regression analyses on the data of Experiments 1 and 2, where a total of 119 words were responded to by the same group of participants[6]

Re-analyses of Experiments 1 and 2

In a first analysis, the two measures of syllable frequency used as independent variables in Experiments 1 and 2, type and token syllable frequency, as well as word frequency were log-transformed before being used as predictors of response latencies and error rates. We obtained a facilitative influence of word frequency on both response latencies, F (1,114) = 47.30, p <.0001, and error rates, F (1,114) = 28.81, p <.0001. Furthermore, this analysis confirmed the pattern of results obtained in Experiment 1 and 2: For token syllable frequency there was a significant inhibitory effect on response latencies, F (1,114) = 11.86, p <.0009 and error rates, F (1,114) = 5.29, p <.03. A facilitative influence of type syllable frequency was revealed after the influence of the two other factors had been partialized out by the multiple regression analysis. This effect was marginally significant in the analysis of response latencies, F (1,114) = 3.06, p <.09, and significant in the error data, F (1,114) = 6.46, p <.02. Coefficients of correlations and partial correlations between predictors and the dependent variables are given in Table 2.6.

---

[6] Words that had been excluded from the analyses of Experiments 1 and 2 were not used in multiple regression analyses either.

Table 2.6

Pearson Product-Moment (r) and Partial Correlations (pr) between Response Latencies (RT) and Error Rates (%err) and three Predictors for Words used in Experiments 1 and 2. The Predictors are: Log (10) of Word Frequency (LogWF), Log (10) of Token Frequency of the first Syllable (LogSF), Type Frequency of the first Syllable.
P-values (p) for Multiple Regression Analyses where all Factors were entered at the same Step. Increment of R^2 (incr. R^2) for entering each Predictor into a Stepwise Regression Analysis. Order of Entry (1.,2.,3.).

	RT					%err				
	r	pr	p	incr. R^2		r	pr	p	incr. R^2)	
LogWF	-.50	-.54	.0001	.2528	(1.)	-.43	-.45	.0001	.1816	(1.)
LogSF	.16	.31	.0008	.0535	(2.)	.06	.21	.02	.0353	(3.)
Type SF	-.06	-.16	.08	.0181	(3.)	-.17	-.23	.01	.0218	(2.)
	total: R^2=.324		R^2adj.=.307			total: R^2=.239		R^2adj.=.219		

Beside the distinction between type and token measures, the frequency of a word's syllabic neighbourhood can be numerically expressed in several alternative ways. All these alternative syllable frequency measures are more or less systematically affected by the experimental manipulations we used for these experiments.

As evident from Tables 2.1 and 2.3, the only one of these measures that systematically co-varied with all experimental manipulations regardless of whether type or token frequency was the independent variable was the mean frequency of syllabic neighbours. This variable increased with the manipulation of token syllable frequency and decreased with the manipulation of type syllable frequency. Note that this cannot be considered a confound, because the mean frequency of syllabic neighbours will automatically be affected when either of these two syllable frequency measures is manipulated while controlling for the other. The way that token and type syllable frequency are mathematically combined when calculating the mean frequency of syllabic neighbours – with the former being divided by the latter - makes this variable a promising candidate for a single predictor that could account for both the inhibitory effect of token syllable frequency and the facilitative effect of type syllable frequency.

We therefore conducted additional multiple regression analyses using the Log of mean frequency of syllabic neighbours and the Log of word frequency as predictors of response latencies and error rates[7]. Besides the facilitative influence of word frequency on response latencies, F (1,114) = 49.53, p <.0001 and error rates, F (1,114) = 30.27, p <.0001, the analyses revealed a significant inhibitory effect of the factor mean frequency of syllabic neighbours on both response latencies, F (1,114) = 18.78, p <.0004 and error rates, F (1,114) = 6.83, p <.02 (see Table 2.7).

Table 2.7

Pearson Product-Moment (r) and Partial Correlations (pr) between Response Latencies (RT) and Error Rates (%err) and two Predictors for Words used in Experiments 1 and 2. The Predictors are: Log (10) of Word Frequency (LogWF) and Log (10) of the mean Frequency of syllabic Neighbours (Log MeanF SN).
P-values (p) for Multiple Regression Analyses where all Factors were entered at the same Step. Increment of R^2 (incr. R^2) for entering each Predictor into a Stepwise Regression Analysis. Order of Entry (1.,2.,3.).

	RT					%err				
	r	pr	p	incr. R^2		r	pr	p	incr. R^2	
LogWF	-.50	-.55	.0001	.2528	(1.)	-.43	-.46	.0001	.1816	(1.)
Log MeanF SN	.21	.33	.0003	.0799	(2.)	.16	.24	.01	.0459	(2.)
	total: R^2=.333		R^2adj.=.321			total: R^2=.227		R^2adj.=.214		

The amount of variance explained by this predictor was comparable to that accounted for by the two predictors token syllable frequency and type syllable frequency in the previous analyses. In fact, concerning response latencies, the explanation of variance was slightly better for the factor mean frequency of syllabic neighbours when compared to the combined influence of the two separate predictors and it was slightly worse concerning error rates. Thus, besides confirming the dissociation of the effects of type and token syllable frequency, the outcome of the multiple regression analyses introduces a new variable, the possible significance of which for the interpretation of the present results will be discussed in more detail during the General Discussion section.

---

[7] Token or type syllable frequency measures could not be used as additional predictors for these analyses because of the problem of co-linearity. For instance, the correlation between the Log of token syllable frequency and the Log of the mean frequency of syllabic neighbours was .83.

Finally, it seemed worthwhile to examine whether our empirical effects could possibly have been affected by word imageability. This variable has been shown to influence response latencies in lexical decision (Kroll & Merves, 1986) and it appears to be correlated with, for example, measures of orthographic neighbourhood (Bowers, Davis, & Hanley, 2005; see also Davis, 2005). We had not attempted to control for this variable when selecting our material, but after collecting corresponding imageability ratings, we discovered a confound between this variable and the token syllable frequency manipulation in Experiments 1A and 2A. Mean imageability values were higher for words with low than with high token syllable frequency (5.57 vs. 4.67 in Experiment 1A; p<.03 and 5.46 vs. 4.48; p<.04 in Experiment 2A). Regarding the manipulation of type syllable frequency in Experiments 1B and 2B, mean word imageability did not vary systematically between experimental conditions (4.91 vs. 4.52; p>.3 for high and low type syllable frequency in Experiment 1B and 4.85 vs. 4.40; p>.3 in Experiment 2B). Therefore, we decided to conduct a post-hoc comparison in order to see whether the inhibitory effect of token syllable frequency obtained with the present stimulus material might have resulted from a confound with word imageability, as high imageability could possibly have enhanced the processing of stimuli with low token syllable frequency. Within the material of Experiments 1 and 2, we identified a minimum number of words that had to be excluded in order to assure a sufficient control for the variable word imageability (p>.9) without affecting any other control variable. We obtained a set of 96 (out of 119) words that could be used for such a post hoc comparison, including the orthogonal manipulation of the factor token syllable frequency of the first syllable (high vs. low). The corresponding analyses revealed, again, a significant inhibitory effect of token syllable frequency: words with a high-frequency initial syllable were responded to 28 ms slower than words starting with a low-frequency syllable, F1 (1,36) = 18.28, p<.0001; F2 (1,94) = 4.76, p<.04. This effect was mirrored by a tendency of high syllable frequency words to provoke more errors than low syllable frequency words (8.2% vs. 6.8% respectively), F1 (1,36) = 2.97, p<.09; F2 (1,94) <1. We conclude, therefore, that the inhibitory token syllable frequency effects obtained in Experiments 1 and 2A are not due to a confound with word imageability.

General Discussion

The experiments reported in this study investigated the issue of whether type and token measures of syllable frequency have the same or differential effects on lexical decision performance. Previous studies have used either one of these two highly correlated measures indiscriminately. Therefore, the question has remained unresolved of which one was responsible for the inhibitory effect of syllable frequency in lexical decision, as well as the issue of potentially dissociable effects of these two frequency measures.

By disentangling the high correlation between these two measures when selecting the stimulus material, we were able to show in Experiment 1 that the token measure and not the type measure of syllable frequency is driving the inhibitory effect on lexical access.

Additional control for the number of higher frequency syllabic neighbours in Experiments 2 and 3 led to even more clear-cut results. Whereas the inhibitory effect of token syllable frequency remained unaffected, a significant facilitative effect for type syllable frequency was obtained. Multiple regression analyses using the data of Experiments 1 and 2 confirmed this pattern of results suggesting dissociated effects of token and type syllable frequency in lexical decision.

Establishing a methodological standard of how to compute syllable frequency in order to obtain a specific effect seemed a useful aim, given the increasing interest in the role of syllables in visual word recognition. The dissociation between the effects of token and type syllable frequency – which might best be reflected by the measure of mean frequency of syllabic neighbours - is the most interesting novel finding among the present results. In contrast to speech production (Carreiras & Perea, 2004a; Cholin et al., 2006; Perea and Carreiras, 1998), facilitative syllable frequency effects on lexical access have never been reported before. But note that, more generally, the frequency of sublexical units has mostly been shown to enhance processing of the words they are embedded in.

Subcomponent frequency (Nuerk, Rey, Graf, & Jacobs, 2000), the frequencies of bigrams (Massaro & Cohen, 1994; but see Paap & Johansen, 1994), trigrams (Seidenberg, 1987), of the BOSS (Taft, 1979) or of stem morphemes (de Jong, Schreuder, & Baayen, 2000) could serve as examples of this.

Also concerning syllable frequency, even if inhibition due to the processing of syllabic neighbours were the final result of a competition process that is triggered by the segmentation of polysyllabic words into their syllabic constituents, it seems plausible to assume that word processing would be speeded by a syllable's frequency at some stage of the reading process (see also Barber et al., 2004; Hutzler et al., 2004).

Thus, the dissociated effects of token and type syllable frequency might relate to different processing stages during visual word recognition in the following way: Inhibition due to the frequency of syllabic neighbours (token syllable frequency) would be effective at a lexical processing stage, whereas the facilitative type frequency effect could arise during prelexical processing, where a syllable's familiarity or typicality – which might best be expressed by type syllable frequency - would enhance the initial processing of the orthographic input - possibly by facilitating the syllabic parsing process. We believe that the type measure of syllable frequency – the number of words containing a given syllable - is more appropriate to reflect a syllable's typicality within a given language than the token measure. Unlike the type measure, a syllable's token frequency – which is related to the frequency of occurrence of words - can be strongly modulated by the elevated frequency of a single or a few words containing this syllable.

Our results provide important constraints for computational models of visual word recognition in two ways. First, the syllable frequency effects reported here add to the evidence for syllabic processing in reading. The lack of syllabic representations within most computational models of visual word recognition leads to the assumption that they would fall short in simulating these results (e.g., Coltheart et al., 2001; Grainger & Jacobs, 1996; Jacobs et al., 2003; Ziegler et al. 2000; Zorzi et al., 1998; but see Ans et al., 1998).

Second, the question arises of how the specific dissociation of type and token syllable frequency effects could be accounted for, even if a computational model contained syllabic representations.

The question of whether type and token frequency-based effects can be accounted for by one and the same mechanism is an important issue for computational modelling of word recognition. For instance, regarding the effects of morphology in speech production, there is debate about the necessity of separate token-sensitive and type-sensitive mechanisms (Moscoso del Prado Martín, Kostic, & Baayen, 2004; Moscoso del Prado Martín, Ernestus, and Baayen, 2004).

As far as visual word recognition is concerned, our empirical findings are highly reminiscent of the pattern of results obtained for orthographic neighbourhood, where facilitative effects of neighbourhood density were contrasted by inhibitory effects of neighbourhood frequency. The need to account for these dissociated effects has been an important motivation in the development of an influential computational model of visual word recognition, the multiple read-out model (MROM; Grainger & Jacobs, 1996). This interactive activation model (McClelland & Rumelhart, 1981; Jacobs & Grainger, 1992) implements a multiple read-out procedure providing two different mechanisms to achieve word identification, for example, in a perceptual identification task - or a correct "yes" response in a lexical decision task:

The activation of a single word entry in the model's lexicon reaches a specified threshold μ corresponding to the complete identification of the target word.

Or, the global activation in the lexicon is high enough to allow for a "yes" response (according to the threshold σ of the model) without one single word having to be fully recognized.

The facilitative neighbourhood density effect is simulated in MROM when responses are given as a function of global lexical activation corresponding to a fast-guess for words with many orthographic neighbours, whereas the presence of higher frequency orthographic neighbours would cause a delay in the processing which is necessary for the target word's representation to reach its identification threshold.

The findings related to orthographic neighbourhood effects in visual word recognition have generally been very heterogeneous and this may have been partly due to a lack of control for other relevant variables (see Andrews, 1997 for a review). The studies reporting orthographic neighbourhood effects have mostly lacked sufficient control for, for example, neighbourhood frequency or number of higher frequency orthographic neighbours when manipulating neighbourhood density and vice versa. Especially in the presence of dissociated effects for a specific variable, sufficient control for the different operationalizations of this variable is essential to be able to draw reliable conclusions regarding their dissociation.

It is important to note that how the multiple read out process of the MROM accounts for the heterogeneous findings on orthographic neighbourhood has been strongly influenced by the fact that these effects appear to be dependent on specific task demands varying between, perceptual identification and lexical decision, for example, or with the characteristics of nonwords in lexical decision.

In the present study, manipulating one variable and controlling for the other, we obtained dissociated effects for type and token syllable frequency occurring in exactly the same task environment. The question of whether such a specific pattern of effects could possibly occur within the architecture of a model like MROM deserves careful examination.

The common interpretation of the inhibitory syllable frequency effect stresses the difficulty of identifying a target word among a cohort of competing candidate representations. Within a computational model, competition between syllabic neighbours at the level of whole word representations could explain why words with high syllable frequency take longer to be responded to. Thus, an inhibitory effect of syllable frequency might best be accounted for by the μ process of the MROM. The computational principles of this model would also predict that such an effect is obtained for token syllable frequency when type syllable frequency is controlled for, but not in the inverse case. The amount of lateral inhibition a word unit competing with the target for identification would send out to the target's representation depends on this competing unit's resting level of activation, which is a function of word frequency. If syllabic units modulate the activation of whole word representations, then a target's syllabic neighbours would all form part of a cohort of word representations activated by the target. Lateral inhibition would increase with the summed frequency or resting level of activation of single units (reflected by token syllable frequency) within two cohorts of competing word representations of equal size (reflected by type syllable frequency). This would not be the case with increasing cohort size (type syllable frequency) when the summed frequency of word representations (token syllable frequency) is the same for two cohorts.

In other words, the amount of inhibition coming from word units in the syllabic neighbourhood does not depend on the number of these competitors but on their frequency of occurrence. Perea and Carreiras (1998) proposed that the number of higher frequency syllabic neighbours was the best measure to account for the inhibitory effect of syllable frequency, and control for this variable explains why the facilitative effect of type syllable frequency was more robust in Experiments 2B and 3B than in Experiment 1B. However, the results of Experiments 2A and 3A, where the inhibitory effect of token syllable frequency remained robust despite this control, stress the importance of the absolute frequency levels of syllabic neighbours for the observed inhibition of lexical access.

How could a computational model account for the facilitative effect of type syllable frequency?

It has been remarked that to account for dissociated effects within the same representational level of a model is not a simple matter (De Jong et al., 2000). In the MROM's account of the dissociated effects of orthographic neighbourhood density and frequency, a change of participant strategy, modulated by specific task conditions, could determine the dominance of processes related either to target identification or to fast-guess in a specific experiment (see also the diffusion model of the lexical decision task, Ratcliff, Gomez, & McKoon, 2004, for an account of how a specific task environment can modulate the distribution of response latencies). But how could both kinds of effects emerge in parallel in one and the same experimental task environment, as in the present experiments?

With regard to the present data, the assumption that only type but not token syllable frequency –two measures which are closely analogous to orthographic neighbourhood density and frequency – would lead to a preferential use of the σ process of the MROM corresponding to a fast-guess faces some problems: the global lexical activation within the model is the summed activation of all word representations whose resting levels correspond to their word frequency. Because token syllable frequency is computed as the cumulated frequency of all syllabic neighbours of a word, the global lexical activation within the model would initially be the same for two cohorts of syllabic neighbour representations differing in type but not in token frequency. In turn, global lexical activation would be higher for a cohort characterized by high token syllable frequency compared to a cohort of equal type but low token syllable frequency.

How could the σ process of the model, therefore, be responsible for the facilitative type syllable frequency effect and why should this facilitation not also apply to token syllable frequency? In the following we will formulate two hypotheses as possible answers to these questions:

1. We argued above why type syllable frequency might be a good estimate of the typicality of a given syllable within a language. A prelexical processing advantage for syllabic units of high typicality could be implemented in a model with syllabic representation units, by assigning them a resting level of activation determined by type syllable frequency (see Mathey, Zagar, Doignon, & Seigneuric, 2006, for a related proposal). In this case, the activation of whole word representations via syllabic representations corresponding to syllables of high type frequency would be especially efficient.

Therefore, correct responses corresponding either to full identification or to a successful fast-guess could be especially speeded by type syllable frequency. Note that this theoretical account of the facilitative type syllable frequency effect does not imply a change in participant task performance strategy. It rather implies that the dissociation of type and token syllable frequency effects arises at different processing or representational levels related to a) the familiarity of sublexical units and b) competition on the whole word level. But these effects might even be accounted for in a more straightforward manner without the need for an additional parameter such as the resting level of activation for syllabic units.

2. Multiple regression analyses of the present data showed that the mean frequency of syllabic neighbours is an excellent predictor of response latencies, explaining even more variance than the two separate predictors token and type syllable frequency together. The opposite influence of the two factors token and type syllable frequency could be adequately summarized in the regression analyses by a single predictor the calculation of which mirrors their specific influence by dividing one of them by the other. Therefore, these opposite effects could well be accounted for not only under the same task conditions, but also within the same representational layer of a model – the layer of whole word representations. For computational models, this mean frequency of syllabic neighbours might be an interesting variable, because it relates to the specific distribution of activation across a cohort of competing word candidate representations (syllabic neighbours in this case).

Given that two cohorts of syllabic neighbours do not differ regarding the summed frequency of their single word representation units (token syllable frequency), the distribution of activation (modulated by the resting levels of single word representations) over the cohort of syllabic neighbours would become flatter the more word units it contains (with increasing type syllable frequency). We call a distribution with a low mean and a high standard deviation "flat", whereas a distribution with a high mean and a low standard deviation will be referred to as "steep".

Simulations with the MROM have shown that in the case of the neighbourhood frequency effect, lateral inhibition was most effective when coming from a restricted number of competing word representations (Grainger & Jacobs, 1996). Inhibition was highest in the presence of only one higher frequency orthographic neighbour .The resulting activation distribution could be described as a steep one with a pronounced peak. In contrast, in a competitors' cohort of increased size, no single representational unit would become prominent enough to efficiently inhibit the target's representation.

This means that in a flat activation distribution, competing word units would cancel each other out in terms of their ability to interfere with the processing of the target. The size of the cohort of word representations that is co-activated by the presentation of the target could therefore influence response times in the MROM in a facilitative manner, either because a target representation that is not the object of strong inhibition might more easily reach the identification criterion, or because its increasing contribution to global lexical activation would trigger a "yes" response when the σ threshold of the model is reached. This would hold true even if global lexical activation should initially not differ between two cohorts of syllabic neighbours of great and small size matched on summed word frequency. It might be argued that this account of the facilitative effect of type syllable frequency is questionable, because facilitation is partly understood as the absence of inhibition[8]. However, the question is whether in a multidimensional and complex nonlinear dynamic system such as the reading process, these can be considered clearly separate phenomena.

---

[8] The assumption of a truly facilitative type syllable frequency effect was supported by the outcome of an additional experiment where we tried to encourage a "fast guess" strategy by the use of nonwords that were easy to reject, presenting the word stimuli of the present experiments to another group of participants. In this experiment, a significant facilitative effect of type syllable frequency was also obtained for the material of Experiment 1B, whereas all other effects remained the same.

It remains to be seen which, or if any of our hypotheses on how a computational model could account for the present empirical findings can be confirmed by simulation studies. In any case, the present results provide a good example of empirical findings that strongly constrain the development of models of visual word recognition, showing also how simulation studies with such models could help in turn to understand the processes underlying such empirical effects

Chapter 3

Syllables and bigrams: Orthographic redundancy and syllabic units affect visual word recognition at different processing levels.[9]

Empirical and simulation data from Spanish

Markus Conrad, Manuel Carreiras, Sascha Tamm, & Arthur M. Jacobs

Abstract

Over the last decade, there has been increasing evidence for syllabic processing during visual word recognition. If syllabic effects would prove to be independent from orthographic redundancy, this would seriously challenge the ability of current computational models to account for the processing of polysyllabic words. Three experiments are presented to disentangle effects of the frequency of syllabic units and orthographic segments in lexical decision. In Experiment 1 we obtained an inhibitory syllable frequency effect that was unaffected by the presence or absence of a "bigram trough" at the syllable boundary. In Experiments 2 and 3 an inhibitory effect of initial syllable frequency but a facilitative effect of initial bigram-frequency emerged when manipulating one of the two measures and controlling for the other in Spanish words starting with CV-syllables. We conclude that effects of syllable frequency and letter cluster frequency are independent and arise at different processing levels of visual word recognition. Results are discussed within the framework of an interactive activation model of visual word recognition.

---

[9] Published (in press) in Journal of Experimental Psychology, Human Perception and Performance

Introduction

Reading is one of the basic cognitive skills necessary for modern life. Much research in the field of cognitive psychology has focused on reading and computational models have been constructed to simulate the process of visual word recognition. However, while most words in many languages are polysyllabic, most current computational models deal exclusively with the processing of monosyllabic words (Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001; Grainger & Jacobs, 1996; Ziegler, Perry, & Coltheart, 2000; Zorzi, Houghton, & Butterworth, 1998; but see Ans, Carbonnel, & Valdois, 1998 for an exception). Whether and how polysyllabic words are segmented into their syllabic constituents during silent reading in different orthographies is still an open question. The first evidence for the assumption of syllabic processing was provided for the English language (e.g., Prinzmetal, Treiman, & Rho, 1986; Spoehr & Smith, 1973; Tousman & Inhoff, 1992). However, one important argument against the proposal of syllables being functional units of visual word recognition was formulated by Seidenberg (1987, 1989): He argued that a typical feature of orthographic redundancy within polysyllabic words could explain such empirical findings without any necessary reference to syllabic units: the bigram forming the boundary between two syllables is typically less frequent than intra-syllabic bigrams and therefore what might appear to be evidence for syllabic parsing could also be understood as the consequence of purely orthographic processing (but see Rapp, 1992; Carreiras & Marín, submitted).

More recently, a new approach towards the investigation of syllabic processing has been taken by research in Spanish, which, unlike English, has a shallow orthography with transparent syllabic structure: The finding of an inhibitory effect for the positional frequency of a word’s initial syllable, first reported by Carreiras, Álvarez, and de Vega (1993) has since been successfully replicated for two other languages, French (Mathey & Zagar, 2002), another Roman language, and German (Conrad & Jacobs, 2004), a non-Roman language. Words starting with a high-frequency syllable, a syllable that also forms the initial syllable of many other words, are responded to faster in lexical decision than words with low initial syllable frequency. In addition, syllable frequency has been shown to influence neurocognitive correlates of the reading process, such as event related potentials (Barber, Vergara, & Carreiras, 2004; Hutzler et al., 2004) and hemodynamic responses (Carreiras, Mechelli & Price, 2006).

Some of the studies reporting syllable frequency effects in lexical decision also tried to dismiss the criticism of Seidenberg (1987) by using only words that did not show the typical pattern of a bigram trough at the syllable boundary (e.g., Carreiras et al., 1993; Perea & Carreiras, 1998). Successfully replicating the syllable frequency effect, these studies showed that the presence of a bigram trough at the syllabic boundary is at least not a necessary condition for obtaining such a syllabic effect. Thus, the bigram trough hypothesis doesn't seem to be a sufficient explanation for the apparent syllabic segmentation of polysyllabic words. Instead, the syllable frequency effect is generally interpreted as evidence for an automatic syllabic segmentation of visually presented words: after a syllabic segmentation of the input, the first syllable activates the representations of words sharing this syllable in identical position and competition between these is responsible for the observed delay in the processing of words with high-frequency initial syllables (e. g., Perea & Carreiras, 1998).

Reconciling the view of syllables as functional units of visual word recognition and the importance of orthographic redundancy, Doignon and Zagar (2005) showed that the tendency for illusory conjunctions following syllabic structure was strongest when bigram troughs coincided with the syllable boundary of bisyllabic French words. Illusory conjunctions for syllabic units were attenuated but generally still observable when the syllable boundary did not coincide with a bigram trough[10]. Doignon and Zagar (2005) concluded that both phonological – relying on phonological syllables - and orthographic processing –relying on bigram troughs – would characterize the segmentation of orthographic word forms.

---

[10] The effect of syllable boundaries on illusory conjunctions was completely absent for words starting with a three-letter syllable in Experiment 2 of Doignon and Zagar (2005), but we believe that this specific result should be handled carefully. Internal syllabic structure (e.g., CCV vs. CVC) of words was not controlled for within the material of this experiment, initial syllables with a consonant orthographic offset (e.g., dan_ser) occurring more often in the condition where bigram troughs did not coincide with syllable boundaries. This might be important, because consonants forming the orthographic offset of French syllables are often not pronounced or become part of a nasal vowel phoneme, which might present a problem fort the mapping between phonological syllables and their orthographic representations. Furthermore, some words (e.g., piano, ruiné), which might be interpreted as trisyllabic strongly contributed to the specific empirical pattern of results -. If, e.g., the word "ruiné" would be parsed as "ru-i-né" instead of "rui-né", this would make the low-frequency second bigram "ui" (characterized as intra-syllabic in this experiment) an inter-syllabic bigram coinciding with a syllabic boundary, undermining the experimental manipulation.

In any case, most current computational models would probably fall short in accounting for polysyllabic word processing being mediated by syllabic units because of their lack of syllabic representations. However, the question of whether the processing of syllabic units in visual word recognition occurs independently of orthographic redundancy or letter cluster frequency is not yet resolved. This is because a high-frequency syllable can generally also be described as a high-frequency letter cluster, independently of syllabic structure.

Thus, regarding the nature of the syllable frequency effect, it remains to be shown that a cohort of competing word representations would in fact be activated by the target's initial syllable rather than by an initial letter cluster. In other words, it is unclear whether this empirical effect really reflects syllabic processing or whether it could also be understood as an effect of the frequency of letter clusters that are not syllabically defined.

The difficulty of making a clear statement regarding the nature of the syllable frequency effect is a general problem in the literature on syllable frequency effects in lexical decision. Although the syllable is mostly understood as a phonological concept, it is unclear – even when assuming that the effect were due to syllables and not to non-syllabically defined letter clusters - whether this effect has to be attributed to phonological syllables or to their orthographic representations. The main reason for this is that the manipulated variable in all available studies was orthographic syllable frequency – being hard to disentangle from phonological syllable frequency at least in shallow orthographies as Spanish and German. Some empirical evidence for a phonological base of syllabic effects in visual word recognition has been provided by Álvarez, Carreiras and Perea, (2004). They reported similar priming effects for primes that matched only the phonological but not the orthographic initial syllable of a target word compared to primes that matched both the phonological and the orthographic initial syllable of the target. More recently, Mathey, Zagar, Doignon and Seigneuric (2006) made a theoretical proposal of how effects related to both the processing of phonological syllables and orthographic letter clusters could be integrated into the architecture of an interactive activation model. They presented empirical data from a lexical decision task where an inhibitory initial syllable frequency effect occurred only for words starting with a high-frequency letter cluster. In the presence of a low-frequency letter cluster at the word beginning syllable frequency rather seemed to yield facilitation of word processing (Experiment 2 of Mathey et al., 2006).

They concluded that a phonological route containing syllabic units was activated via orthographic redundancy. However, the empirical data is scarce and not completely conclusive[11]. Therefore, given the important theoretical impact of this question, clearly more empirical data is needed for a better understanding of the relation between orthographic redundancy and syllabic processing.

Generally, and in contrast to syllabic effects, effects of the frequency of letter clusters or of orthographic redundancy could theoretically be accounted for by current computational models. Empirical effects related to syllabic units could be accounted for by processing mechanisms sensitive to orthographic redundancy in the two following ways:

Any apparently syllabic segmentation could be achieved by a processing mechanism sensitive to the presence of a bigram trough that typically occurs at the syllabic boundary (Seidenberg 1987; 1989).

Regardless of syllabic structure, any effect of the frequency of a syllabic unit could arise as an effect of the frequency of the letter cluster representing the syllable. This would be in line with the findings of Schiller (1998; 2000) who stated that segmental overlap rather than syllabic congruency was influencing primed word naming - see also Experiment 1 of Mathey et al. (2006) showing an inhibitory effect for the frequency of a word’s initial letter cluster not only when these letters were the initial syllable but also when they formed the beginning of a monosyllabic word.

Given the systematic relation between syllable frequency and letter cluster frequency, the claim for a round of revision of computational models of visual word recognition (e. g., Álvarez, Carreiras, and Taft, 2001; Carreiras et al, 1993; Conrad & Jacobs; 2004; Perea & Carreiras, 1998) would take another perspective if syllabic effects can be seen as effects of orthographic redundancy or at least cannot reliably be distinguished from these.

---

[11] Note that the size of the syllable frequency manipulation in Experiment 2 of Mathey et al. (2006) was much stronger in the case of high- than of low-frequency orthographic letter clusters; a relatively high number of syllabic neighbors was only present in the condition of high orthographic frequency/high syllable frequency. This represents a problem for the interpretation of the observed interaction between the effects of syllable frequency and letter cluster frequency as well as for an interpretation of the absence of a significant letter cluster frequency effect in this experiment of Mathey et al. (2006).

In this case, polysyllabic word processing might successfully be simulated applying the principles of modeling monosyllabic word processing without the involvement of syllabic representation units.

The present study addresses the question of the relatedness of syllabic and orthographic processing in the following ways: Experiment 1 readdresses the bigram trough hypothesis examining whether there are comparable effects of syllable frequency in the presence and in the absence of a bigram trough at the syllabic boundary. Experiment 2 aims to replicate the syllable frequency effect while controlling for the frequency of the letter cluster forming the initial syllable (the first bigram in words starting with a CV syllable). Experiment 3 is conducted to see if there is any effect of initial bigram-frequency for bisyllabic words when syllable frequency is controlled for (for effects of bigram-frequency and positional letter frequency in monosyllabic word processing, see Massaro & Cohen, 1994; Grainger & Jacobs, 1993).

The existence of qualitatively different processing mechanisms during visual word recognition related to syllable frequency and to bigram-frequency, would seriously question the ability of computational models that do not include syllabic representations to account for the processing of polysyllabic words. Whereas adding a layer of syllabic representations might be the first step of solving this problem at least for localist connectionist models, such a pattern of results would be a substantial challenge for connectionist models that don’t contain any representational units. However, if no independent effects of syllable and bigram-frequency are obtained, then current computational models could easily be extended to account for polysyllabic word reading without the need to implement a specific syllabic processing mechanism.

Experiment 1: Syllable frequency and bigram troughs

Some empirical studies have already shown that the syllable frequency effect can be obtained when words do not show the critical pattern of a bigram trough at the syllabic boundary. In doing so they contradicted the idea that the effect would only occur because orthographic redundancy offered a segmentation device for the extraction of the relevant sublexical unit (the syllable or the correspondent letter cluster). However, it has never been experimentally tested whether syllable frequency effects and bigram troughs really have any type of systematic relation within the process of visual word recognition. That is, even if syllabic effects can be obtained without the presence of a bigram trough at the syllable boundary, a hypothesis taking into account the proposals of Mathey et al. (2006) and Doignon and Zagar (2005) could be that a bigram trough at the syllable boundary would facilitate the syllabic parsing process and syllable frequency effects should therefore be more pronounced in the presence than in the absence of such a pattern. In turn, a syllable frequency effect that would prove to be unaffected by the presence or absence of a bigram trough at the syllable boundary would rule out the "bigram trough hypothesis" as a possible source of syllabic processing in visual word recognition at least in Spanish. This is an issue that studies using only words not showing this critical bigram trough pattern have not completely resolved. On the contrary, using such a specific control means to implicitly acknowledge that bigram troughs would be important for the processing of syllables.

This is an important outstanding question for a more detailed understanding of the relation between orthographic redundancy and syllabic processing. Experiment 1 directly manipulates the frequency relation between the bigram at the syllabic boundary and the remaining bigrams of a bisyllabic word. A syllable frequency manipulation as a second experimental factor will provide information about any hypothetical modulation of the syllable frequency effect in lexical decision depending on bigram troughs.

Method

Participants

Forty-six students of the University of La Laguna participated in the experiment. Their participation was rewarded with course credits. All were native speakers of Spanish and had normal or corrected-to-normal vision.

Stimuli and Design

108 bisyllabic Spanish words were selected from the LEXESP database (Sebastián-Gallés, Martí, Carreiras, & Cuetos, 2000) according to the orthogonal combination of two factors in a within-participant 2x2 design: relative frequency of the bigram at the syllable boundary (relative to the mean frequency of the remaining intra-syllabic bigrams; presence vs. absence of a bigram trough at the syllable boundary) and positional frequency of the first syllable (high vs. low). E.g., “li-“ is a high-frequency first syllable in Spanish whereas “fo-“ is a low-frequency initial syllable. Accordingly, the word “lila” (purple) was placed in the “bigram trough - high syllable frequency” category because of the relatively low frequency of the bigram “il” (relative to the mean frequency of the intra-syllabic bigrams “li” and “la”) whereas the word “liso” entered the “no bigram trough - high syllable frequency” category because “is” is a relatively frequent Spanish bigram (compared to the mean frequency of “li” and “so”). The entry of the words “foto” and “foca” into the two different conditions for low syllable-frequency words was determined by the different relative bigram frequencies of “ot” (low) and “oc” (high). Syllable frequencies and bigram frequencies were computed on the base of all bisyllabic entries in the LEXESP database.

Syllable frequency measures for all experiments in the present study refer to orthographic syllables given in this database. Syllable frequencies were computed position-specific: a first syllable’s frequency relates to all bisyllabic words sharing this syllable in first position, a second syllable’s frequency relates to all bisyllabic words sharing this syllable in second position. Because the focus of the present study is to investigate the relation between syllabic processing and orthographic redundancy we computed all bigram frequency or letter cluster frequency measures used for the present experiments analogously.

All bigram frequencies are also computed position-specific referring to all bisyllabic entries in the database. All syllable and bigram frequency measures are token counts. Previous studies on syllable frequency effects had uncritically either used the token (e.g., Conrad & Jacobs, 2004) or the type syllable frequency measure (e.g., Álvarez et al, 2001) as independent variable, but a recent study has shown that – although the two measures are highly correlated – it is the token and not the type measure of syllable frequency that is driving the inhibitory syllable frequency effect in lexical decision (Conrad, Carreiras, & Jacobs, 2007).

A word was entered in the "bigram trough at the syllable boundary" condition when the mean frequency of all intra-syllabic bigrams (preceding or following the syllable boundary) was at least about 1000 per million occurrences superior to the one's at the inter-syllabic boundary. In order to enter the "no bigram trough at the syllabic boundary" condition, a word's inter-syllabic bigram's frequency had to be superior (at least about 200 per million occurrences) to the mean frequency of all intra-syllabic bigrams. The ranges for initial syllable frequency were the following: less than 300 per million occurrences for low syllable frequency and more than 600 per million occurrences for high syllable frequency words. Words were matched across cells for length, word surface frequency, mean frequency of all bigrams, positional frequency of the second syllable, frequency of the letter cluster forming the second syllable, number of orthographic neighbors and number of higher frequency orthographic neighbors. Word stress was also controlled for. Between two and four words in each experimental condition containing twenty-eight words had ultimate stress, all other words had penultimate stress. Characteristics for words used in Experiment 1 are shown in Table 3.1[12]. As a consequence of the special selection criteria for the material in the experiments of the present study, it was unavoidable that some initial syllables appeared repeatedly within the words of one experimental condition.

---

[12] For all experiments, stimulus characteristics are reported only for words that actually entered the analyses of the experimental data.

Table 3.1

Characteristics of Words used in Experiment 1
Means, Ranges and Standard Deviations (SD) for
- Independent Variables: Difference (DIFF) between the mean Frequency of all intra-syllabic Bigrams (BF IntraSyll) and the frequency of the inter-syllabic Bigram (BF Bound); positional Frequency of the first Syllable (SF1)
- Variables related to the Bigram Trough Manipulation: Frequency of the least- (BF Min) and of the highest-frequent Bigram (BF Max) in a Word
- Variables correlated with initial Syllable Frequency (SF1): positional Frequency of the first two (FL2) and three (FL3) Letters and positional Frequency of the Letter Cluster representing the first Syllable (FLSyll)
- Control Variables: Whole Word mean Bigram Frequency (BF Word), Word Frequency (WF), Familiarity (Fam), Concreteness (Concr), Word Length (L), Density of orthographic Neighborhood (N), Number of higher Frequency orthographic Neighbors (HFN), positional Frequency of the second Syllable (SF2)

Probability Values are given for Mean Differences across the different Cells of the two experimental Factors Syllable Frequency (p(SF)) and relative Bigram Frequency at the Syllable Boundary (p(trough)).

	Bigram Trough at the Syllable Boundary							No Bigram Trough at the Syllable Boundary							
	High SF1			Low SF1				High SF1			Low SF1				
	Mean	SD	Range	Mean	SD	Range		Mean	SD	Range	Mean	SD	Range	p (SF)	p (trough)
BF_IntraSyll	2417	1186	1216-5872	2592	863	1160-5010		1760	517	1048-3393	1476	910	421-3850	p>.85	p>.0001
BF_Bound	553	519	15-2268	558	391	7-1445		3294	918	2208-5562	3492	1451	1013-5849	p>.89	p<.0001
DIFF	1864	878	1035-4187	2034	640	1093-3565	-	-1534	980	-3475- -273	-2016	1408	-4685- -229	p>.85	p<.0001
BF Min	543	513	15-2245	419	312	7-1224		1079	460	55-2295	774	743	16-3363	p<.06	p<.0001
BF Max	3745	2355	1780-13111	4584	2444	1377-13111		3562	1257	2208-7834	3609	1492	1302-6268	p>.25	p>.13
BF Word	1875	936	999-4971	2017	708	776-4119		2167	489	1473-3502	2010	891	642-4148	p>.94	p>.38
SF1	1101	644	607-2728	149	89	12-298		1291	923	621-4175	122	81	6-268	p<.0001	p>.52
FL2	2087	1226	974-4205	1276	1005	31-3821		1896	1029	974-4398	1059	940	15-3821	p<.0003	p>.40
FL3	380	506	2-1609	146	258	4-1054		473	440	13-1428	199	299	4-1054	p<.002	p>.34
FLSyll	1740	1266	692-4205	870	923	28-2711		1666	1056	755-4398	581	513	7-1253	p<.0001	p>.44
WF	14.58	16.90	1-71	13.03	12.90	1-46		14.34	14.47	2-55	11.50	13.19	2-57	p>.45	p>.76
Fam*	4.80	1.12	2.57-6.45	5.13	0.91	3.50-6.70		5.03	1.05	2.75-6.35	5.45	0.91	3.38-6.73	p>.07	p>.20
Concr*	4.72	1.00	3.00-6.88	4.46	1.10	2.88-6.47		4.44	1.18	2.50-6.39	5.32	0.96	2.75-6.74	p>.16	p>.17
L	4.61	0.72	4-6	4.62	0.64	4-6		4.83	0.70	4-6	4.72	0.54	4-6	p>.66	p>.21
N	7.83	5.77	0-23	8.08	4.77	0-18		8.46	6.52	0-25	7.16	5.48	0-19	p>.64	p>.85
HFN	2.43	2.81	0-10	2.46	2.20	0-7		2.83	2.46	0-8	2.40	2.22	0-8	p>.67	p>.73
SF2	2393	2207	11-8035	3033	2582	8-8035		2677	3013	37-10867	2794	3066	14-10867	p>.49	p>.99

* These variables had not explicitly been controlled for when selecting the stimulus material of Experiments 1-3. Mean rating values of familiarity and concreteness – ranging from 1 (“not familiar/concrete at all”) to 7 (“very familiar/concrete”) - are taken from the BuscaPalabras database (Davis & Perea, 2005) or - if not provided in this database - have been collected from Spanish speakers that had not participated in Experiments 1-3.

Note: Frequency counts are given per million occurrences, taken from the LEXESP database (Sebastián-Gallés et al., 2000)

In order to prevent that repetition of initial syllables would influence participants' performance, for each experiment of the present study, filler items with alternative initial syllables were used in order to provide a more natural reading context. Nonwords for all experiments in this study were constructed by combining the first syllable of a word stimulus with another syllable that exists as a second syllable in Spanish. Thus, initial syllables did not differ between words and nonwords and all nonwords were pronounceable and orthographically legal.

Apparatus and Procedure

Stimuli were presented in lowercase letters using Courier 24 type font on the computer screen. Participants were instructed to make a decision concerning the lexicality of the stimulus as quickly and as accurately as possible, pressing a "yes"-button for a word and a "no"-button for a nonword. Response buttons were located on the keyboard of the computer. Stimulus presentation and response recording was controlled by EXPE 6.02 software (Pallier, Dupoux, & Jeannin, 1997). The stimulus list contained 250 words (108 experimental stimuli and 142 filler items) and 250 nonwords. The order of appearance of the stimuli was randomized for each participant. The stimulus remained visible until any response was given with an inter-trial interval of 1000 ms. There were ten initial training trials. The whole experiment lasted about twenty minutes.

Results and Discussion

Mean correct response latencies and error percentages (see Table 3.2) were submitted to separate analyses of variance (ANOVAs) by participants and by items (F1 and F2, respectively). Response latencies differing more than two standard deviations from the mean for each participant and experimental condition were excluded from the analyses. This led to the exclusion of 4.6% of the data of Experiment 1. Ten of the word stimuli in Experiment 1 had to be excluded from the analysis, because their corresponding mean error rates were higher than 45%. The same exclusion criteria for outlier rejection and for the exclusion of error prone word stimuli were applied in all analyses presented in this study.

Words were responded to 19 ms slower when they had a bigram trough at the syllabic boundary than when they had not.

This mean difference was significant only in the analysis over participants, F1 (1,45) = 7.15, p <.02; F2 (1,94) = 0.52, p >.4. There was no effect on error rates. Syllable frequency caused significant effects on both response latencies and error rates: words were responded to 42 ms slower when starting with a high- than with a low-frequency syllable, F1 (1,45) = 24.31, p <.0001; F2 (1,94) = 5.79, p <.01. Consistently, more errors (11.3% vs. 7.5%), occurred for words starting with high- than with low-frequency syllables, F1 (1,45) = 22.81, p <.0001; F2 (1,94) = 3.46, p <.07. Importantly, there was no interaction between the effects of the two factors, either in response latencies, p>.9, or in error rates, p >.3.

Table 3.2

Mean Reaction Times (RT; in Milliseconds), Standard Deviation of Reaction Times (Std. Dev. in Milliseconds) and Percentage of Errors for Words in Experiment 1

	Bigram Trough at the Syllable Boundary					
	Yes			No		
Syllable Frequency	RT	Std. Dev.	% error	RT	Std. Dev.	% error
High	815	140	10.7	796	137	12.0
Low	773	130	7.8	754	114	7.3

One might wonder to what degree this pattern of results - suggesting no importance of bigram troughs for the syllable frequency effect - might be influenced by the fact that a relatively large number of error prone items were excluded from the analyses. In order to verify if the lack of significance of the main effect of bigram trough in the item analysis and the absence of an interaction of this effect with the syllable frequency effect are due to this loss of statistical power we conducted additional ANOVAs, using all words presented in the experiment.

This time we obtained an inhibitory syllable frequency effect of 44 ms, F1 (1,45) = 27.66, p <.0001; F2 (1,104) = 6.67, p <.01. More errors (18.9% vs. 10.7%), occurred for words starting with high- than with low-frequency syllables, F1 (1,45) = 79.44, p <.0001; F2 (1,104) = 4.47, p <.03. A main effect of bigram troughs at the syllable boundary was still present in the participant analysis with words being responded to 16 ms slower when having a bigram trough at the syllable boundary, but again, this effect was far from being significant in the analysis over items, F1 (1,45) = 5.15, p <.02; F2 (1,104) = 0.32, p >.5.

No effect for this factor was obtained on error rates. Regarding response latencies, again, there was no interaction between the effects of the two factors, p>.9, but such an interaction was observed in the error data, with a syllable frequency effect on error rates being more pronounced in the presence than in the absence of a bigram trough at the syllable boundary (20.6% vs. 9.8% relative to 17.2% vs. 11.6%), F1 (1,45) = 8.16, p <.0006; F2 (1,104) = 0.47, p >.4. But note that this effect was significant only in the analysis over participants - where it had failed to reach statistical significance after the exclusion of highly error prone items. We therefore believe that this specific effect is best attributed to idiosyncratic characteristics of some words in the experimental material the exclusion of which from the analyses has not systematically affected the results of Experiment 1 in general.

The outcome of Experiment 1 confirms that the appearance of an effect of syllable frequency does not depend on the presence of a bigram trough at the syllabic boundary. Importantly, the relation between these two phenomena was directly addressed for the first time. It turned out that the relative frequency of the bigram forming the syllabic boundary has absolutely no impact on the size of the syllable frequency effect. This suggests that bigram troughs do not modulate syllabic processing at all, at least in Spanish. One remaining question is how the processing advantage (19 ms) for words not showing the bigram trough pattern might best be interpreted when a relation between bigram troughs and syllabic processing is not assumed. In fact, the manipulation characterizing the material of Experiment 1 involves not only the specific position of a relatively low frequency bigram (at the syllable boundary or not) but also has some impact on overall features of orthographic redundancy. As evident from Table 3.1, the mean frequency of all bigrams of a word did not differ significantly between words in the two conditions of the bigram trough manipulation (presence vs. absence), but it tended to be higher for words without bigram troughs at the syllable boundary. Moreover, words with the typical bigram trough pattern at the syllable boundary often comprise at least one bigram of considerably low absolute frequency, which is not necessarily the case for words without a bigram trough at the syllable boundary. This variable had not been taken into account for the selection of the experimental material. Reanalyzing the material, we found a significant difference between the two conditions of the bigram trough manipulation regarding the frequency of the least frequent bigram of a word – computed regardless of whether this bigram formed the syllable boundary or not.

Words with a bigram trough at the syllable boundary often contained one bigram the frequency of which was much lower than the respective frequencies of all bigrams in words without a bigram trough at the syllable boundary. It might well be the case that this specific feature of orthographic redundancy – the presence of one very low-frequency bigram within the orthographic word form – might explain why words with a bigram trough at the syllable boundary were responded to slower than words without such a bigram trough. Such an effect would not necessarily have anything to do with the specific position of this low frequency bigram at the syllable boundary – in other words, it might have no relation to a word's syllables or to syllabic processing. We tested this hypothesis running a multiple regression analysis of the data of Experiment 1. Beside word surface frequency and the frequency measures of the first and the second syllable, the following bigram frequency measures were entered as predictors for response latencies in Experiment 1: the frequency of the bigram at the syllable boundary, the mean frequency of all intra-syllabic bigrams (both being related with syllabic structure) and the frequencies of the words' least frequent and highest frequent bigram (no relation to syllabic structure). All these token frequency measures were log-transformed before being entered into the regression model. Multiple regression analysis revealed a significant facilitative effect of word frequency, F1 (1,97) = 31.58, p <.0001, and a significant inhibitory effect of initial syllable frequency, F1 (1,97) = 7.92, p <.007. In addition, there were significant facilitative effects for the frequency of both the highest-frequent, F1 (1,97) = 6.05, p <.02, and the least-frequent bigram within a word, F1 (1,97) = 4.77, p <.04. No other effects were statistically significant. Coefficients of correlations and partial correlations between predictors and the dependent variables are given in Table 3.3.

Table 3.3

Pearson Product-Moment (r) and Partial Correlations (pr) between Response Latencies (RT) and seven Predictors for Words used in Experiment 1. The Predictors are: Log (10) of Word Frequency (Log WF), Log (10) of Token Frequency of the first (Log SF1) and second (Log SF2) Syllable, the Bigram at the Syllable Boundary (Log BF Bound), the mean Frequency of all intra-syllabic Bigrams (Log IntraSyll), the Frequency of the least-frequent (Log BF Min) and the highest-frequent Bigram (Log BF Max).

	r	pr
Log WF	-.500	-.510**
Log SF1	.192	.284**
Log SF2	-.053	-.016
Log BF Bound	-.248	.096
Log BF IntraSyll	-.015	.187
Log BF Min	-.200	-.224*
Log BF Max	-.270	-.251*

* p<.05
** p<.01

It is especially interesting that a hypothetical influence of the frequency of the bigram at the syllable boundary was partialized out by the multiple regression analysis. An effect of this bigram's frequency as suggested by the ANOVAs computed on the experimental data is apparently not due to the fact that this bigram is straddling the syllable boundary. We conclude that the bigram trough effect in Experiment 1 is best understood as an overall orthographic redundancy effect. Bigram frequency seems to generally enhance the processing of orthographic word forms and a very low frequency bigram slows down this processing regardless of whether this bigram is located at the syllable boundary or not.

The most important outcome of Experiment 1, however, is the absence of an interaction between the effects of syllable frequency and of the presence or absence of a bigram trough at the syllabic boundary in the ANOVA results, suggesting that syllabic effects are independent of orthographic redundancy in terms of bigram troughs at the syllable boundary. It might be argued that these results are incompatible with the ones of Doignon and Zagar (2005) who had reported an attenuation of the illusory conjunction effect for syllabic units when the syllable boundary did not coincide with a bigram trough. But there is an important difference between the illusory conjunction paradigm and the lexical decision task. The latter one is generally understood as assessing lexical access, which is not necessarily required in the former one.

The fact that participants in the illusory conjunction task perceive two letters as being more or less related as a function of both syllabic organization and orthographic redundancy – and that in consequence the specific illusory conjunction effects can cancel each other out – does not necessarily imply that a mediation of lexical access by phonological syllables as we propose it has to be influenced by orthographic redundancy or bigram troughs. The results of Doignon and Zagar (2005) suggest that both types of information (syllabic and orthographic) can make a sublexical unit more salient. But they would not allow for any exact conclusions about how both types of processing mechanisms would interact during the process of lexical access as assessed by the lexical decision task. Bigram troughs and orthographic redundancy may well play an important role for the reading process in some orthographies.

The point of Experiment 1 is to show that syllabic processing during word reading – as reflected by the syllable frequency effect - at least in Spanish is unaffected by bigram troughs. Furthermore, the discrepancy between the effects of Doignon and Zagar (2005) and those presented in the present study might be an interesting case for a cross-linguistic perspective. We will refer to this issue in the General Discussion.

In any case, the results of Experiment 1 don't allow the conclusion that the syllable frequency effect or syllabic processing in general were completely independent of orthographic redundancy. The frequency of the letter cluster being the syllable of words in Experiment 1 was always higher for high syllable frequency words than for low syllable frequency words. Therefore, it is important to examine whether the syllable frequency effect could be understood as an orthographic letter cluster frequency effect, because this would strongly question the syllabic or phonological nature of this effect.

In Experiment 2 we tested whether the standard effect of first syllable frequency can be obtained when controlling for initial letter cluster frequency. A syllable frequency effect that would prove to be independent from the syllable's letter cluster's orthographic frequency would be an important argument for syllabic processing in visual word recognition.

Experiment 2: Manipulation of syllable frequency controlling for bigram frequency

Method

Participants

Forty-six students of the University of La Laguna participated in the experiment. Their participation was rewarded with course credits. All were native speakers of Spanish and had normal or corrected-to-normal vision.

Stimuli and Design

72 bisyllabic Spanish words were selected from the LEXESP database (Sebastián-Gallés et al., 2000) according to the factor positional frequency of the first syllable (more than 1200 vs. less than 550 per million occurrences). All words started with a CV syllable of two letters length. Words were equated on second syllable frequency, word surface frequency, length, number of orthographic neighbors and number of higher frequency orthographic neighbors. Twelve words in each experimental condition had ultimate stress; all other words had penultimate stress. Concerning orthographic redundancy, all the following frequency measures were controlled for: mean frequency of all bigrams, frequency of the initial bigram, frequency of the initial trigram, frequency of the inter-syllabic bigram, mean frequency of all intra-syllabic bigrams (see Table 3.4). The specific relation between initial syllable frequency and initial bigram-frequency within the material of Experiment 2 may be highlighted by two example words from the stimulus material: "barril" (barrel) and "fuga" (flight) do not considerably differ in the frequency of the orthographic letter cluster forming their initial syllable (1864 vs. 1878 per million occurrences for the bigrams "ba" and "fu"), but "ba-" is a high-frequency initial syllable (1220 per million occurrences) which is not the case for "fu-" (134 per million occurrences). This is because for the majority of all Spanish words starting with the letters "ba" these letters form the initial syllable.

In contrast, the majority of Spanish words starting with the letters "fu" have a different syllable structure, e.g., "fuerte" (strong and "funda" (sheath) the initial syllables of which are "fuer-" and "fun-".

Table 3.4

Characteristics for Words used in Experiment 2
Means and Ranges for the independent Variable: Positional Frequency of the first Syllable (SF1). Means and Ranges for Control Variables: Positional Frequency of the first two (FL2), three (FL3), and four (FL4) Letters, mean Frequency of all intra-syllabic Bigrams (BF IntraSyll), Frequency of the inter-syllabic Bigram (BF Bound), whole Word mean Bigram Frequency (BF Word), Word Frequency (WF), Familiarity (Fam), Concreteness (Concr), Word Length (L), Density of orthographic Neighborhood (N), Number of higher Frequency orthographic Neighbors (HFN), positional Frequency of the second Syllable (SF2). Probability Values (p) are given for Mean Differences across the different Cells of the Factor Syllable Frequency.

	First Syllable Frequency						
	High			Low			
	Mean	SD	Range	Mean	SD	Range	p
SF1	1796	551	1220-2742	354	133	133-526	
FL2	2225	550	1586-3017	2242	694	1265-3084	p>.90
FL3	156	199	7-875	109	259	6-1564	p>.40
FL4	39	57	2-182	28	25	3-118	p>.30
FLSyll	2225	550	1586-3017	2223	703	1265-3084	p>.99
BF Word	1908	840	678-3871	1696	793	584-4215	p>.28
BF_IntraSyll	1703	624	801-3318	1733	735	763-3701	p>.85
BF_Bound	2606	3051	36-10690	1705	1952	13-10690	p>.14
DIFF	-903	3192	-9751-2758	28	1991	-8633-3185	p>.14
WF	12.73	12.18	2-46	12.39	9.32	2-42	p>.89
Fam	4.93	1.11	2.63-6.63	5.06	1.00	2.75-6.46	p>.62
Concr	4.72	1.28	1.75-6.88	4.91	1.23	2.75-6.88	p>.54
L	4.72	0.63	4-6	4.67	0.72	4-6	p>.75
N	9.84	7.72	1-25	8.67	7.94	0-28	p>.53
HFN	2.28	2.50	0-9	1.83	2.47	0-9	p>.46
SF2	1619	2717	6-10867	1316	2147	3-8035	p>.60

Note: Frequency counts are given per million occurrences, taken from the LEXESP database (Sebastián-Gallés et al., 2000)

Apparatus and Procedure

These were the same as in Experiment 1. The stimulus list contained 250 words (72 experimental stimuli and 178 filler items) and 250 nonwords. Nonwords were constructed in the same way as in Experiment 1.

Results and Discussion

Outlier rejection led to a loss of 4.6% of the data in Experiment 2. Four words out of the stimuli of Experiment 2 had to be excluded because of excessive error rates. Analyses revealed significant effects of syllable frequency on both correct response latencies and error rates (see Table 3.5). Words were responded to 62 ms slower when starting with a high- than with a low-frequency syllable, F1 (1,45) = 42.37, p <.0001; F2 (1,66) = 15.40, p <.0002. Consistently, more errors (11.8% vs. 6.3%) occurred for words with high-frequency initial syllables, F1 (1,45) = 21.83, p <.0001; F2 (1,66) = 4.34, p <.04.

Table 3.5

Mean Reaction Times (RT; in Milliseconds), Standard Deviation of Reaction Times (Std. Dev. in Milliseconds) and Percentage of Errors for Words in Experiment 2.

Syllable Frequency					
High			Low		
RT	Std. Dev.	% error	RT	Std. Dev.	% error
794	139	11.8	732	107	6.3

The inhibitory effect of initial syllable frequency in lexical decision was once again replicated. Importantly, for the first time it could be shown to be independent of the frequency of the letter cluster forming the first syllable, initial bigram-frequency in this case, using only words starting with a two letter CV-syllable. This means that the effect is truly syllabic in nature. It can only be explained as a consequence of syllabic processing, because the frequency of the initial bigram, the relevant alternative orthographic unit, had been controlled for. To complete the contrast of the effects of syllable frequency and letter cluster frequency, it is important to see how initial bigram-frequency influences lexical decision latencies when syllable frequency is controlled for. This was the aim of Experiment 3.

Experiment 3: Manipulation of bigram frequency controlling for syllable frequency

Method

Participants

Thirty-nine students of the University of La Laguna participated in the experiment. All were native speakers of Spanish and had normal or corrected-to-normal vision. Their participation was rewarded with course credits.

Stimuli and Design

68 bisyllabic Spanish words were selected from the LEXESP database (Sebastián-Gallés et al., 2000) according to the factor frequency of the initial bigram (more than 3000 vs. less than 1250 per million occurrences). Eight words in the condition of high and six words in the condition of low initial bigram frequency had ultimate stress; all other words had penultimate stress. All words started with a CV syllable of two letters' length. Words were equated on second syllable frequency, word surface frequency, length, number of orthographic neighbors and number of higher frequency orthographic neighbors. Words were also equated on first syllable frequency and on the number of higher frequency syllabic neighbors of the first syllable (see Table 3.6). Examples from the stimulus material: the initial syllables "da-" and "ti-" are of comparable frequency in Spanish (864 vs. 856 per million occurrences), but the initial bigram "ti" is often included in words with an initial syllable structure other than CV, e.g., "tiempo" (time) with the syllable "tiem-" and "tinto" (red wine) with the syllable "tin-". Accordingly, the word "timón" (helm) (initial bigram-frequency: 3805 per million occurrences.) was placed in the high initial bigram-frequency category contrary to the word "dama" (lady) (initial bigram-frequency: 1179 per million occurrences) which entered the low frequency category, because the majority of words starting with the bigram "da" have the same initial syllable structure as "dama".

Table 3.6

Characteristics for Words used in Experiment 3
Means and Ranges for the independent Variable: Positional Frequency of the first Bigram (FL2). Means and Ranges for Control Variables: Mean Frequency of the remaining Bigrams (BF2-5), Positional (Word Ending) Frequency of the remaining Letter Cluster (FL3-6), positional Frequency of the first Syllable (SF1), Number of higher Frequency syllabic Neighbors of the first Syllable (HFSN1), Word Frequency (WF), Familiarity (Fam), Concreteness (Concr), Word Length (L), Density of orthographic Neighborhood (N), Number of higher Frequency orthographic Neighbors (HFN), and positional Frequency of the second Syllable (SF2). Probability Values (p) are given for Mean Differences across the different Cells of the Factor Initial Bigram Frequency.

Initial Bigram Frequency

	High			Low			
	Mean	SD	Range	Mean	SD	Range	p
FL2	4161	967	3084-5988	1016	247	488-1222	
BF 2-5	1574	1239	296-4931	1695	911	228-3716	p>.65
FL 3-6	3093	3926	55-13384	2196	2551	2-10867	p>.27
SF1	781	236	358-1102	828	195	411-1058	p>.38
HFSN1	15.45	10.40	2-42	15.56	8.81	3-35	p>.96
WF	13.79	13.28	1-47	12.16	13.80	2-55	p>.62
Fam	4.98	0.99	2.63-6.39	4.76	1.19	2.88-6.61	p>.43
Concr	5.08	1.16	2.63-6.88	4.86	1.00	2.75-6.54	p>.41
L	4.45	0.62	4-6	4.44	0.56	4-6	p>.94
N	10.90	5.43	0-21	10.32	7.30	0-25	p>.71
HFN	2.87	2.33	0-8	3.09	3.01	0-10	p>.74
SF2	2724	3416	55-10867	2115	2567	2-10867	p>.41

Note: Frequency counts are given per million occurrences, taken from the LEXESP database (Sebastián-Gallés et al., 2000)

Apparatus and Procedure

They were the same as in Experiment 1. The stimulus list contained 250 words (62 experimental stimuli and 188 filler items) and 250 nonwords. Nonwords were constructed in the same way as in Experiment 1.

Results and Discussion

Outlier rejection led to a loss of 4.1% of the data of Experiment 3. Four words out of the stimuli of Experiment 3 had to be excluded because of excessive error rates. Analyses revealed significant effects of initial bigram-frequency on both correct response latencies and error rates (see Table 3.7).

Words were responded to 36 ms faster when starting with a high- than with a low-frequency bigram, F1 (1,38) = 15.65, p <.0004; F2 (1,62) = 4.13, p <.05. Consistently, more errors (10.3% vs. 16.6%) occurred for words starting with a low- than with a high-frequency bigram, F1 (1,38) = 21.26, p <.0001; F2 (1,62) = 5.07, p <.03.

Table 3.7

Mean Reaction Times (RT; in Milliseconds), Standard Deviation of Reaction Times (Std. Dev. in Milliseconds) and Percentage of Errors for Words in Experiment 3.

Bigram Frequency					
High			Low		
RT	Std. Dev.	% error	RT	Std. Dev.	% error
766	104	10.3	802	110	16.6

The interesting outcome of Experiment 3 is that an alternative frequency count of what from a superficial view could be considered the same sublexical unit, the first two letters of a bisyllabic word, produced the opposite effect to that in Experiment 2. Whereas initial syllable frequency had prolonged response latencies to bisyllabic words starting with a two-letter syllable in Experiment 2, this time the frequency of the initial bigram caused a facilitative effect when syllable frequency was controlled for. That means there is a perfect contrast for effects of syllable frequency and letter cluster frequency: When the first two letters can be defined as a syllabic unit and when their frequency is computed accordingly, inhibition of lexical access is the consequence of increasing syllable frequency. The opposite, a facilitative effect, is obtained for initial letter cluster frequency when the frequency of the first two letters is computed in a purely orthographic manner, not taking into account syllabic structure.

Simulations with the MROM using the data of Experiments 2 and 3

It has been claimed that an interactive activation model of visual word recognition (e.g., Grainger & Jacobs, 1996) might account for the inhibitory effect of syllable frequency on lexical access when implemented with a layer of syllabic representations (see Álvarez et al, 2001; Conrad & Jacobs, 2004). Before going into the details of the possible architecture of such a future model during the General Discussion, it was useful to test the performance of an existing functional version of the Multiple Read-Out Model (MROM, Grainger & Jacobs, 1996) without syllabic representations in a null-model approach (Jacobs et al., 1998) with regard to the empirical effects of Experiments 2 and 3. The MROM can generate a “yes” response in the lexical decision task through two different processes: Either activation of a single word unit (μ) reaches a threshold M corresponding to the identification of the target, or global activation in the lexicon (σ) reaches a threshold $\sum$ corresponding to a “fast guess”.

Because the model does not contain any syllabic representations, we predict that it would fail to simulate the syllable frequency effect in Experiment 2, where letter cluster frequency was controlled for. However, the model might well be capable of reproducing the facilitative bigram frequency effect in Experiment 3, due to activation sent from letter units to word representations in the orthographic lexicon. For words containing a high-frequency bigram, global activation in the orthographic lexicon of the model might increase sufficiently to trigger a quick yes-response of the model via the $\sum$-criterion of the MROM.

Note that the model’s behavior with regard to the manipulation of bigram frequency would offer a good prediction of how such a model without syllabic representations would behave regarding manipulation of syllable frequency co-varying with letter cluster frequency.

The model was implemented with a lexicon of 6,242 bisyllabic Spanish words, including bisyllabic entries of the LEXESP database (Sebastián-Gallés et al., 2000) with a frequency of at least 1 per million occurrences.

All parameters of excitatory and inhibitory connection weights between different representation units in the model were the same as in Grainger and Jacobs (1996).

Given that word length in Experiments 2 and 3 varied between four and six letters, it was necessary to enable the model for the processing of stimuli with different length[13]. The model was presented with a subset of the stimulus material of Experiments 2 and 3. For both experiments, fifty-six words each were selected out of all words that had been used in the respective previous analyses, with the constraint that not only mean word length, but also the exact number of four- five- and six-letter words had to be equated between conditions (see Footnote 4). This selection procedure preserved an optimal match between conditions (according to the manipulation of initial syllable frequency on the one hand and of initial bigram frequency on the other) on variables known to influence the MROM's performance: word frequency, orthographic neighborhood density and number of higher frequency orthographic neighbors (all p-values for t-tests for significant mean differences >0.7).

Each stimulus was processed by the model during thirty cycles and activation values for global activation (σ) and for the most activated single unit in the orthographic lexicon (μ) were recorded. We conducted consecutive t-tests in order to examine if the manipulations of syllable- and bigram frequency significantly affected any of the two activation parameters of the MROM mentioned above at any of the processing cycles of the model. These tests did not reveal any significant results (all p-values >0.2). Note that there was some oscillation due to use of different word lengths in the values of global lexical activation during the first processing cycles, but all curves stabilized after cycle number nine.

For cycles nine to thirty, no single t-test resulted in a p-value less than 0.6. Despite this lack of significant mean differences of activation on single processing cycles, global lexical activation was slightly increased between cycles thirteen to twenty for words with high compared to low initial bigram frequency (see Figure 2).

---

[13] Range of word length in the lexicon was three to eight letters. For all words with less than eight letters, the respective (missing) letter positions were filled with blanks. Blanks in specific letter positions did not activate word representations, but inhibited the representations of words having a letter in that specific position. E.g., when presented with a four letter target, all five letter words' representations in the model's lexicon received inhibition coming from the blank in position five of the target. Note that this model is not able to correctly account for a word length effect in visual word recognition – five and six letter words always receiving more summed activation from their corresponding letter representations than four letter words. But for the present purpose, the simulation of syllable and bigram frequency effects, this should not be a problem as long as word length remains closely controlled for within the stimulus material. Implementing the model with differential letter-to-word-unit activation weights for different stimulus lengths (which would be a possible solution to the paradoxical behaviour of such a model regarding the issue of word length effects) might in turn have resulted in bigram- or syllable frequency being less effective in longer compared to shorter words.

No such modulation of global lexical activation could be observed for the manipulation of syllable frequency, neither seemed any of the two manipulations to affect the activation level of the most activated single word representation in the model's lexicon.

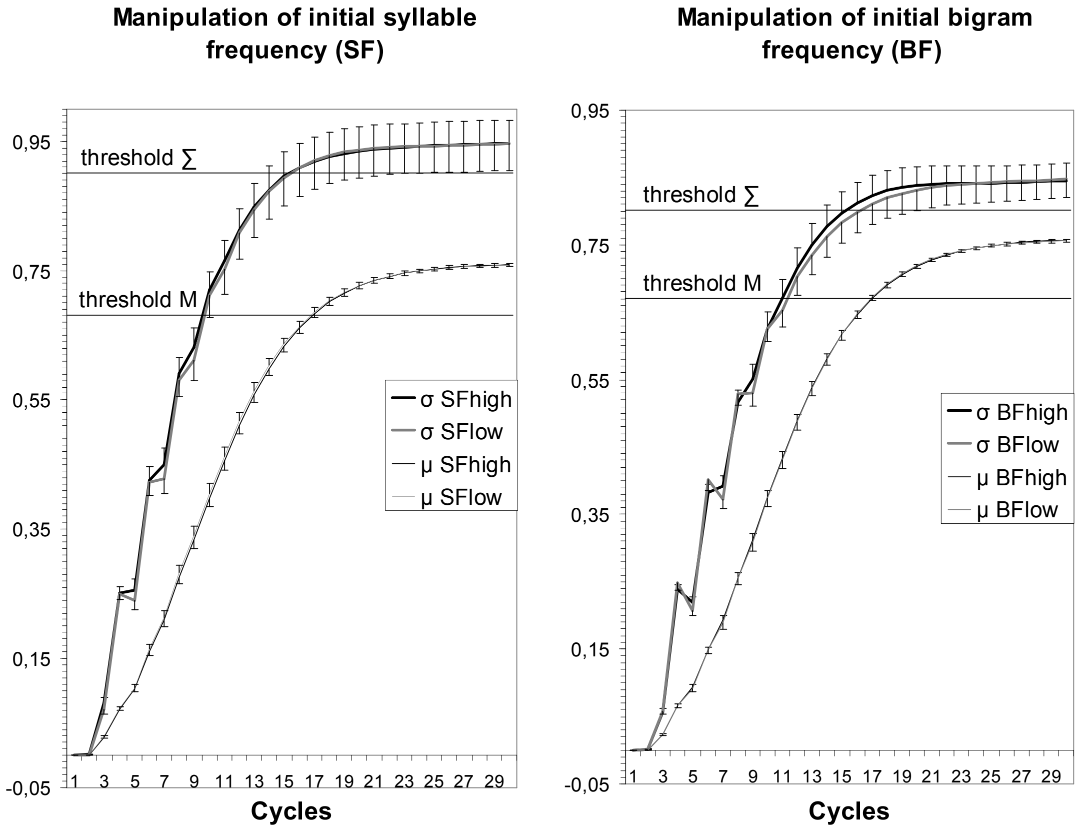

Figure 2

Mean μ and σ activation functions in the MROM according to the manipulations of initial syllable frequency and initial bigram frequency for words in Experiments 2 and 3

Note: Error bars are giving standard errors of means.

This pattern of results is partly compatible with our hypothesis that the σ-process of the MROM might be sensitive to bigram frequency. The possible responses given separately via the two criteria of the model are presented in Figure 3. Whereas the M-threshold for responses via the μ-activation of the model is a fixed value - set at 90% of the asymptotic value of the corresponding mean activation function - the setting of the ∑-threshold is more flexible in order to enable the model to account for task specific effects and to make the probability of a "fast-guess" depend on early processing phases of the stimulus.

Depending on the global lexical activation during cycles two to seven, the ∑-threshold of the model can be shifted up- or downwards. Here, we decided to apply a fixed ∑-threshold because of the slightly oscillating σ-activation functions during these cycles, but the threshold was set at a relatively liberal value of 95% of the corresponding asymptotic value, in order to increase the chance of an effect of bigram frequency to arise in the model's ∑-responses.

As evident from Figure 3, responses corresponding to the ∑-criterion of the model were somewhat faster for words with high than with low initial bigram frequency, but this effect failed to reach statistical significance, F(1,54) = 2.68; p>0.1. Analyses revealed no effect at all regarding responses via the ∑-criterion for the manipulation of syllable frequency, F<1. Furthermore, no effects were obtained for either of the two manipulations on responses via the M-criterion of the MROM, both F<1.

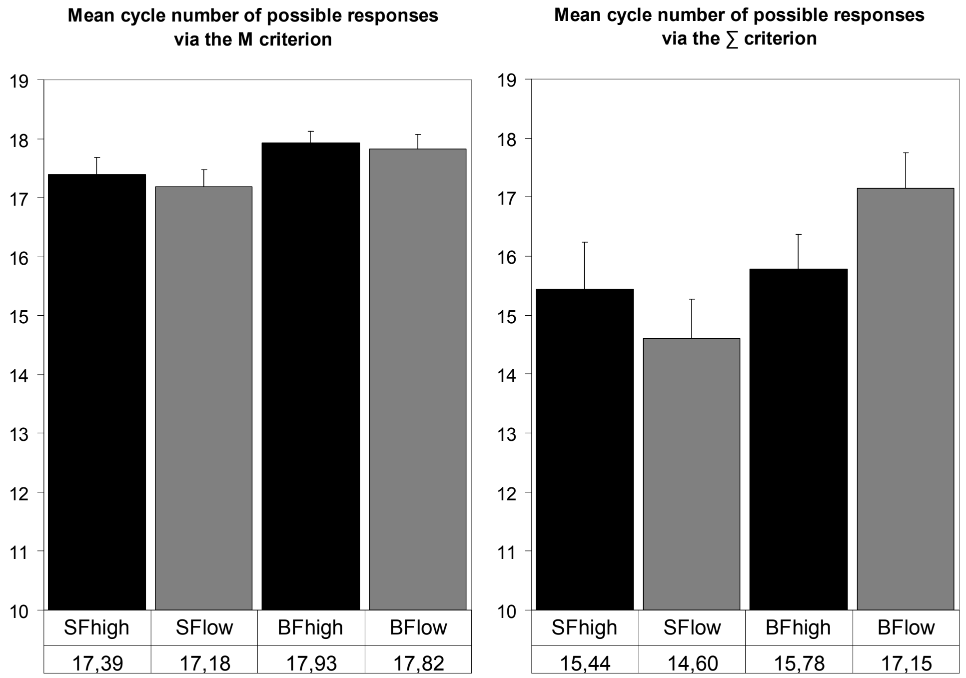

Figure 3

Mean cycle numbers of responses as occurring separately by the two response mechanisms of the MROM according to the manipulations of initial syllable frequency (SF) and initial bigram frequency (BF) for words in Experiments 2 and 3

Note: Error bars are giving standard errors of means.

Finally, even if the tendency of bigram frequency to speed responses via the ∑-criterion can be considered as modest evidence for the hypothesis that the MROM might account for the empirical effect in Experiment 3, this tendency is attenuated when the responses corresponding to the two different criteria are combined (i.e., always choosing the faster of the two).

Even when applying a liberal ∑-criterion, the final output of the MROM only reveals a very small tendency of responses being faster to words with high than with low bigram frequency, F(1,54) = 1.42; p>0.3. Final responses of the model compared to the data of Experiments 2 and 3 are presented in Figure 4[14].

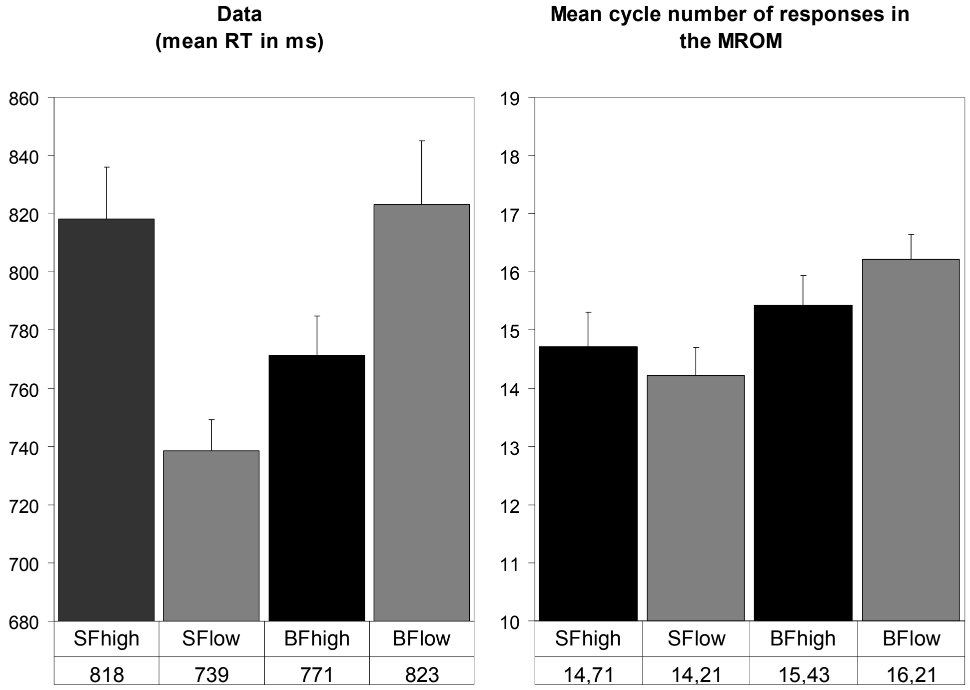

Figure 4

Comparison of the MROM's final output with the experimental data of Experiments 2 and 3
Note: Error bars are giving standard errors of means.

---

[14] The empirical data is based on the same words that were used for the simulations. Both the effects of syllable frequency (79ms) and of bigram frequency (52ms) were statistically significant, F(1,54) = 14.96; p<0.0004; F(1,54) = 4.06; p<0.05

Thus, it appears that the actual MROM is not capable of accounting for an effect of syllable- or bigram frequency in visual word recognition. Whereas the absence of an initial syllable frequency effect – with initial bigram frequency being controlled for - in the simulation data is no surprise, given that the model does not contain syllabic representations, the model's failure to significantly account for the initial bigram frequency effect in Experiment 3 deserves further consideration.

We had hypothesized that such an effect might occur in the model as a function of increasing global lexical activation due to the frequency of initial bigrams in the stimulus words. Note that such an argument is not without problems, because even if the activation of many word representations sharing a high-frequency bigram would certainly lead to an increase in global lexical activation, these word representations would also compete with each other via lateral inhibition. A response via the M-criterion of the MROM could therefore have been delayed or inhibited to the same extend that a response via the ∑-criterion was expected to be speeded by bigram frequency. It is not trivial to predict which of the two processes would prove to be predominant in the model's output. The present simulation data provided no evidence that the μ-process of the MROM is sensitive to bigram frequency, but the observed increase of global lexical activation was not significant either.

In any case, the absence of a significant bigram frequency effect in the simulation data means that the MROM apparently allows for word representations to significantly influence the model's behavior only when these words share more than two letters (in the case of stimuli varying between four and six letters length) with the target (but see Grainger & Jacobs, 1993 for positional letter frequency effects in monosyllabic words).

General Discussion

The experiments of the present study were designed to test for the nature of an effect that has repeatedly been quoted as evidence for automatic syllabic processing during visual word recognition: the syllable frequency effect. Whether this effect can really be attributed to the processing of syllables or whether it could rather be understood as a by-product of purely orthographic processing is the main question addressed in the present study. The present experimental results provide clear evidence that the syllable frequency effect in lexical decision occurs independently of bigram troughs or letter cluster frequency. Experiment 1 showed that the inhibitory effect of initial syllable frequency remains unaffected by the presence or absence of a bigram trough at the syllabic boundary (Seidenberg, 1987, 1989). Therefore, at least for the Spanish language, it can no longer be argued that an apparent syllabic segmentation could occur as a by-product of or would be facilitated by purely orthographic processing that would use a typically low-frequent bigram at the syllabic boundary as a segmentation device.

Experiment 2 shows that the inhibitory effect of syllable frequency can also be obtained when the frequency of the letter cluster forming the syllable (the first bigram in words starting with a two letter CV-syllable) is controlled for. This important finding provides the missing link in the line of argument in favor of syllabic processing in visual word recognition: Previous studies controlled for the confound of syllable frequency with orthographic redundancy by using only words that did not show the bigram trough pattern at the syllable boundary. Yet, the fact that in most cases a high-frequency syllable is also a high-frequency letter cluster remained a critical point of this approach, because it allowed for an alternative interpretation of these results: it might not be the frequency of syllabic units but the frequency of letter clusters, which can be understood as purely orthographical without any reference to syllabic units, that might have triggered the empirical effects attributed to syllable frequency.

The considerable size (62 ms) of the syllable frequency effect when bigram-frequency was controlled for is perfectly in line with the outcome of Experiment 3 where a facilitative effect of initial bigram-frequency was obtained when syllable frequency was held constant.

The main contribution of the present results to a better understanding of polysyllabic word processing lies in the finding that one and the same sublexical unit seems to be functional in opposite ways depending on how it is defined and how, in consequence, its frequency is computed. The frequency of a word's first two letters (the first syllable) had an inhibitory effect in Experiment 2, where the manipulated variable syllable frequency was computed taking into account the frequency of all bisyllabic Spanish words starting with the same two letters as a syllable. In contrast, in Experiment 3, the frequency of the first two letters was computed referring to all bisyllabic words starting with the same two letters regardless of whether they formed the initial syllable or not. This time, response latencies to words decreased with increasing frequency of the first bigram. These findings suggest that syllabic units and orthographic letter clusters affect polysyllabic word reading at different processing levels.

It appears that the activation of lexical candidates competing with each other for identification during polysyllabic word recognition is strongly mediated by syllabic units whereas the frequency of orthographically defined units as bigrams rather seems to enhance early prelexical processing.

Bigram frequency might facilitate prelexical orthographic processing in general (see the outcome of the multiple regression analyses of the data of Experiment 1; see Massaro & Cohen, 1994, for a facilitative bigram-frequency effect in a letter search task; see also Hauk et al., 2006), but the fact that initial bigrams in Experiment 3 always formed the initial syllable of target words leaves open the possibility that this empirical effect could relate to syllabic processing with bigram frequency facilitating the syllabic parsing of orthographically presented words.

This contrast between effects of syllable frequency and letter cluster frequency presents a serious challenge for any model of visual word recognition that is not sensitive to syllabic structure. In our view, a model that aims to account for this contradictory role of the same sublexical unit needs some implemented definitions of how such a sublexical unit can be characterized (syllable and/or bigram) according to which it will be assigned a specific role at different processing stages.

Parallel distributed models (e.g., Seidenberg & McClelland, 1989; Plaut, McClelland, Seidenberg, & Patterson, 1996), in particular, would face some serious difficulties with regard to the present results. In the first place, these models do not comprise a mechanism of lateral inhibition which could account for the competition between candidate words. Instead, they would always predict facilitative effects for the frequency of sublexical units. The inhibitory syllable frequency effect would most probably fall beyond their scope. Furthermore, it is unclear how they could possibly account for the two different effects of the first two letters' frequencies (syllable-frequency and bigram-frequency) without postulating the involvement of different representational units.

With regard to localist connectionist models, simulations run with the MROM (Grainger & Jacobs, 1996), a model containing a mechanism of lateral inhibition between candidate words, have shown that this model cannot simulate the inhibitory syllable frequency effect without containing syllabic representations. Regarding the facilitative effect of bigram frequency in Experiment 3, the architecture of the MROM comprising connections between letter and whole word representations would in principle allow for such an effect of purely orthographic letter cluster frequency to arise in the simulations. Word processing in the model seemed to be sensitive to bigram frequency to some extent: global lexical activation within the model was increased for words with high frequency bigrams during processing cycles thirteen to twenty. But these differences did not reach statistical significance.

Clearly, more empirical work is necessary to examine whether such an empirical effect is independent from syllabic structure. As regards the relatively low degree of sensitivity of the MROM (without syllabic representations) to bigram frequency, this problem might possibly be resolved by the adjustment of parameter weights- provided that the effect would prove to be purely orthographic in nature - without any relation to syllabic units.

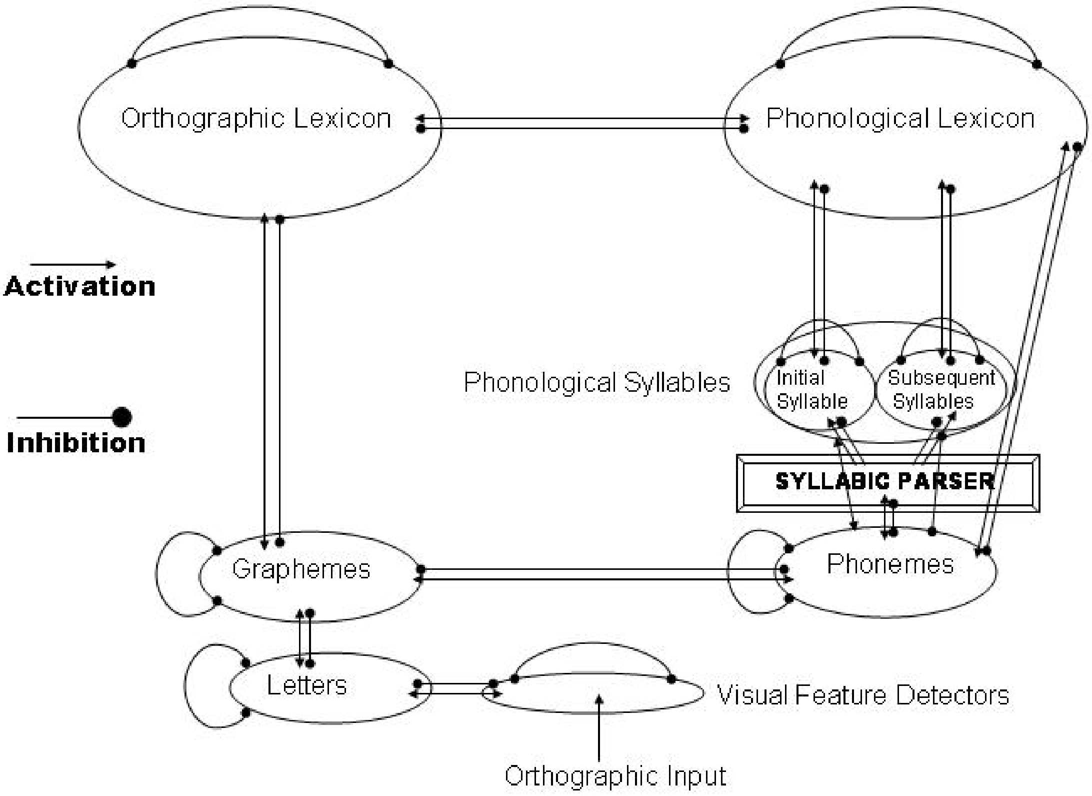

Figure 5

The possible Architecture of an Interactive Activation Model of polysyllabic visual Word Recognition

On the other hand, a localist connectionist model containing several different representation layers – one of them for syllabic units - could in theory deal with such opposite effects of the frequency of the same first two letters, because activation would be sent out from the first two letter units in different ways: letter representations would directly activate whole word representations containing the target letters. They would also activate syllabic representations, which would subsequently send activation to the word level. The possible architecture of such an interactive activation model of polysyllabic visual word recognition is sketched in Figure 5. The model contains both an orthographic and a phonological lexicon and activation spreads from letter representations via grapheme, phoneme and syllabic representations on to whole word representations in the two lexica. A "yes" response in lexical decision would occur when an activation threshold for a single word representation (corresponding to identification of the target) or for global lexical activation (corresponding to a "fast-guess") is reached in one of the two lexica of the model (see Grainger & Jacobs, 1996; Jacobs, Rey, Ziegler, & Grainger, 1998). Syllabic representations are located in the phonological route of the model mediating the activation of phonological word representations (see Mathey, et al., 2006, for a similar proposal). Syllables are generally seen as phonological units and there is evidence for a phonological nature of syllabic processing also in visual word recognition (Álvarez et al., 2004). The fact that within our data syllabic effects were shown to be independent from orthographic redundancy is additional support for this view.

The inhibitory effect of initial syllable frequency would occur in the model, because an initial phonological syllable's representations would activate a cohort of syllabic neighbors' representations in the phonological lexicon that would interfere with the processing of the target by the mechanism of lateral inhibition. The size of this cohort and its inhibitory potential would increase with syllable frequency explaining the processing delay for words with high syllable frequency. We had argued that the failure of the MROM to significantly reproduce an effect of bigram frequency is probably due to the fact that word representations sharing only a small amount of letters with the target do not become sufficiently activated. Regarding syllabic processing in the model, this problem might be resolved by strengthening the connection weights between initial syllabic units and the phonological lexicon (see Álvarez, Carreiras, & de Vega, 2000, for differential effects of first and second syllable frequency). Furthermore, a phonological syllable always represents 50% of a bisyllabic phonological word form. In contrast to bigrams, which are not represented as specific multi-letter units in the model, syllabic units would activate a well-defined cohort of candidate representations – the syllabic neighborhood. Syllable-mediated activation over the phonological lexicon would be less widespread than activation over the orthographic lexicon coming from the representations of all letters of the target. This might ensure sufficient sensitivity of the model to syllable frequency with syllabic neighbors' representations getting sufficiently activated to compete with the target for identification.

For the present study we only used words of relatively low word frequency, but the model makes the prediction that syllabic processing in visual word recognition would become less important with increasing word frequency, because fast access to high frequency word representations would be possible via the orthographic layers of the model, which do not contain syllabic representations.

Phonological processing in the model always requires the previous activation of orthographic representation units and will therefore always be somewhat delayed relative to orthographic processing. This is in line with the finding that syllable frequency effects are always more pronounced for low frequency than for high frequency words (Perea & Carreiras, 1998; Conrad & Jacobs, 2004). It might be argued that an increasing cohort of co-activated candidate representations sharing a phonological syllable would also lead to an increase in global lexical activation and that responses corresponding to a fast guess could foil or contrast the hypothesized delay of identification for high syllable frequency words in a model with a multiple-read-out procedure.

But note that responses according to the ∑-criterion of the MROM are strongly dependent on early processing phases of the model, because ∑-thresholds are adjusted as a function of global lexical activation values during the first seven cycles of the model (see Grainger & Jacobs, 1996). As outlined above, the processing of phonological syllable neighbors within the model would take place at a relative late processing stage and fast-guess responses to high syllable frequency words might therefore not play an important role in the model's output.

Now, even when assuming the existence of automatic syllabic processing in visual word recognition, one crucial question remains to be resolved: how would the reading system achieve a syllabic segmentation of the orthographic input? We could show in Experiment 1 that the presence or absence of a bigram trough at the syllable boundary of Spanish words does not modulate syllabic processing as reflected by the syllable frequency effect. Still, orthographic redundancy might play a role for syllabic processing in that syllables become more salient when being formed of letter clusters with a high orthographic frequency (see Mathey et al., 2006). Within the model we propose, a high frequency bigram's letter representations would receive more feedback activation from the orthographic lexicon than those representing a low- frequency bigram. In consequence, they would more efficiently activate a corresponding syllabic unit at the layer of phonological syllables.

Therefore, the facilitative bigram frequency in Experiment 3 could arise in the model, because high frequency initial bigrams corresponding to a word's initial syllable would facilitate the syllabic parsing process allowing for a faster access to a word's representation in the phonological lexicon (see Conrad et al., 2006, for a discussion on why syllabification is a necessary prerequisite for the processing of phonological word forms). Two recent ERP-studies provide additional evidence for this line of argument regarding the interplay between orthographic and phonological processing during the time course of visual word recognition: These studies reporting syllable frequency effects on ERP-waves during lexical decision consistently obtained significant effects of syllable frequency on two distant time windows. Both Barber et al. (2004) and Hutzler et al. (2004) obtained increased negativity for words with high relative to low initial syllable frequency around the N400 component of the ERP-signal. This relatively late effect was interpreted as to reflect competition between syllabic neighbors at the level of whole word representations (see Perea & Carreiras, 1998; see Holcomb, Grainger, & O'Rourke, 2002, for an N400 effect for words with many orthographic neighbors, see also Goslin, Grainger, & Holcomb, 2006).

But high syllable frequency also produced an early increase of negativity in the ERP-signal between 150-300 ms in the study of Barber et al (2004) and between 190-280 ms in Hutzler et al's (2004) experiment (see Carreiras, Vergara, & Barber, 2005, for a P200 effect of syllabic congruency for words presented in colors that matched or mismatched syllabic structure). The onset of these early syllable frequency effects was prior to typical markers of lexical access as the effects of word frequency in Barber et al. (2004) or of lexicality in Hutzler et al. (2004), which did not start before 350 ms. Therefore, these effects seem to arise during prelexical processing. Initial bigram frequency has been shown to influence the ERP-signal as early as 100 ms after stimulus presentation in visual word recognition (Hauk et al., 2006). Note that there was no control for the confound between syllable- and letter cluster frequency in the studies of Barber et al. (2004) and Hutzler et al. (2004). The early effects of syllable frequency they obtained might reflect the moment when phonological syllables become salient or are identified within the orthographic input and letter cluster frequency might play a crucial role during this process.

In general, given the opposite effects of syllable frequency and bigram frequency and the independence of the syllable frequency effect from bigram troughs at the syllable boundary, our data make a stronger case for the importance of the syllable in visual word recognition with regard to the relation between orthographic redundancy and syllabic processing than recent studies in French (Mathey et al., 2006; Doignon & Zagar, 2005).

Apart from some problems with the material used in these studies, these differences might result from specific properties of the different languages at hand. Whereas the French language is characterized by a considerable degree of inconsistency in particular in the mapping form phonemes to graphemes (see Ziegler, Stone, & Jacobs, 1996), the mutual mapping between phonemes and graphemes in Spanish is very consistent and this has important consequences for the transparency of syllabification in Spanish orthographic word forms.

An analysis of syllabification for all bisyllabic words in the LEXESP database (Sebastián-Gallés et al., 2000) revealed that correct syllabic parsing for all Spanish orthographic word forms is possible following some very simple principles of segmentation (Conrad, Carreiras, & Jacobs, in revision): the Spanish language allows for a very restricted number of consonant clusters within one syllable. The maximum number of consonants at the syllabic onset is two and generally only one consonant is licensed as a syllabic offset[15].

Syllabification in Spanish is perfectly described by the principles of maximum syllabic onset and of a maximum sonority contrast at the syllable boundary: whenever one single consonant grapheme occurs between two vowels in a Spanish word, this consonant forms the onset of a syllable. A pattern of three consonant graphemes is always parsed as follows: the first segment is a syllabic offset and the two subsequent ones form a syllabic onset. The only ambiguity in terms of how to syllabically parse a given number of consonant graphemes between two vowels is given when two consonant graphemes occur together. But even in this case, correct syllabification can always be achieved without the involvement of lexical knowledge, because any given combination of two specific consonant graphemes can only occur either within a Spanish syllable or has to be separated by a syllabic boundary. It never occurs that both possibilities exist for the same two consonants[16].

The regularity of syllabification in Spanish and the simplicity of the principles by which syllable boundaries can be identified within the Spanish orthography make it plausible that Spanish readers would implicitly make use of such principles for the segmentation of polysyllabic word forms.

---

[15] The only exceptions from these rules are syllabic offsets including one consonant plus the consonant “s” which is added to the syllabic offset because it cannot be combined within the letter “t” at the onset of a subsequent syllable. Example words are “instante” (moment) or “obstar” (to hinder).

[16] E.g., “bl” or “br” can only be syllabic onsets like in the words “hablar”, or “abrir” whereas “st” or “rt” will always include a syllable boundary like in words as “hasta” or “huerto”.

This would mean that they would not necessarily need additional information from orthographic redundancy in order to identify and process a word's phonological syllables. A model of visual word recognition might therefore be implemented with a syllabic parsing mechanism that is sensitive to these principles. Hutzler, Ziegler, Perry, Wimmer and Zorzi (2004) as well as Perry, Ziegler and Zorzi (2007) have shown how a computational model can learn such "rules" when presented with an input characterized by specific regularities. In the model presented in Figure 5, this syllabic parser would perform a syllabic segmentation of the target and determine the activation of phonological syllables' representations. In addition, these phonological syllable representations would receive activation from their corresponding letter representations via the principles of interactive activation, but clearly, orthographic redundancy would not be the necessary base for syllabic processing to occur. Using such a syllabic parser in languages with a transparent orthography and regular syllabification and suppressing its activity in languages with less transparent syllabic structure might enable the model to account for language specific differences in syllabic processing. Suppressing the syllabic parser and its "rule-based" unambiguous syllabic segmentation would involve an increased probability for orthographic redundancy to influence the activation of syllabic representations. Stressing the competition between different syllabic representational units based on activation from lower level representational units might assure a better account for syllabic processing in languages with less transparent syllabic structure.

In any case, our results show that the recognition of polysyllabic words in visual word recognition cannot be fully understood without taking into account the involvement of syllabic processing. Adding to the already vast literature showing phonological influences on visual word recognition (e.g., Carreiras, Ferrand, Grainger, & Perea, 2005; Ferrand & Grainger, 1992; Frost, 1998; Lukatela & Turvey, 1994; Grainger & Ferrand, 1994; Lukatela, Eaton, Lee, Carello, & Turvey, 2002; Lukatela, Frost, & Turvey, 1998; Perfetti & Bell, 1991; Pollatsek, Perea & Carreiras, 2005; Pollatsek, Lesch, Morris, & Rayner, 1992; Van Orden, 1987; Van Orden; Johnston, & Hale, 1988), the present findings suggest that during visual word recognition, phonological rather than orthographic processing involves the emergence of clusters at an intermediate level between basic sublexical units (letters, graphemes and phonemes) and whole word forms. These phonological clusters – a word's syllables – seem to have an important role for the activation of word candidates.

Chapter 4

Phonology as the source of syllable frequency effects in visual word recognition: Evidence from French[17]

Markus Conrad, Jonathan Grainger, & Arthur M. Jacobs

Abstract

We report one Experiment designed to allow six critical comparisons in order to investigate whether syllable frequency effects in visual word recognition can be attributed to phonological or orthographically defined syllables. Whereas only a weak effect was obtained when both orthographic and phonological syllable frequency were conjointly manipulated in Comparison 1, robust effects for phonological and null effects for orthographic syllable frequency were found in Comparisons 2 and 3. Comparisons 4 and 5 showed that the syllable frequency effect does not result from a confound with the frequency of letter or phoneme clusters at the beginning of words. The syllable frequency effect was shown to diminish with increasing word frequency in Comparison 6. These results suggest that visually presented polysyllabic words are parsed into phonologically defined syllables during visual word recognition.

---

[17] Published (2007) in Memory & Cognition, 35 (5), 974-983.

Introduction

The syllable has enjoyed a privileged status in many accounts of how humans recognize both spoken (e.g., Cutler, Mehler, Norris, & Seguí, 1986; Mehler, Dommergues, Frauenfelder, & Seguí, 1981; Morais, Content, Cary, Mehler, & Seguí, 1989) and printed words (Lima & Pollatsek, 1983; Millis, 1986; Prinzmetal, Treiman, & Rho, 1986; Spoehr & Smith, 1973; Taft & Forster, 1976; Tousman & Inhoff, 1992). Initial support for the hypothesized role of the syllable during visual word recognition was provided by Carreiras, Álvarez, and de Vega (1993) who found an effect of syllable frequency on lexical decision latencies to visually presented Spanish words. More precisely, lexical decision was sensitive to the frequency of the first syllable of disyllabic words, with longer latencies to words with high initial syllable frequency. Carreiras et al. (1993) interpreted the observed processing cost for words with high frequency first syllables as the result of interference caused by the representations of other words sharing the same initial syllable (in analogy with accounts of the interfering effects of orthographic neighbors - Grainger, O'Regan, Jacobs, & Seguí, 1989).

The inhibitory effect of syllable frequency in Spanish (Carreiras et al., 1993) has been replicated in a number of studies (e. g., Álvarez, Carreiras, & Taft, 2001; Perea & Carreiras, 1998) and has also been found in other languages: French (Mathey & Zagar, 2002), another Romance language but also German (Conrad & Jacobs, 2004), a non Romance language. This research has allowed several alternative explanations, not related to syllabic representations, to be discarded. The syllable frequency effect proved not to be confounded with orthographic neighborhood (Perea & Carreiras, 1998), nor with morpheme frequency (Álvarez et al., 2001). Furthermore, syllable frequency effects have also been in found in electrophysiological investigations measuring ERPs (Barber, Vergara, & Carreiras, 2004; Hutzler, Bergmann, Conrad, Kronbichler, Stenneken, & Jacobs, 2004) and eye movements (Carreiras & Perea, 2004b; Hutzler, Conrad, & Jacobs, 2005). Nevertheless, two outstanding questions remain concerning the interpretation of such syllable frequency effects. These questions are the focus of the present study.

First, all studies reporting an inhibitory effect of syllable frequency to date have confounded the influence of orthographically and phonologically defined syllables. This is because in many languages, including Spanish and German, it is not easy to disentangle the two. Spanish is almost perfectly consistent regarding the relation of spelling and sound. The graphemes V and B as well as the graphemes Y and LL which are pronounced in the same way, or the graphemes C and G the pronunciation of which is determined by the following vowel are rare examples of inconsistency. Also in German an inconsistent transcription of graphemes into phonemes and of phonemes into graphemes is rather the exception than the rule. Inconsistency in German is mainly related to the issues of vowel length and terminal devoicing, but this inconsistency is typically resolved by the surrounding context at least regarding the transcription of graphemes into phonemes. E.g., a vowel sound in German words is short when followed by two consonants and it is long when followed by a single consonant or when the letter H is present between the vowel and subsequent consonants - the letter D is pronounced in a similar way as the letter T only when occurring in final position.

Theoretically, it is important to distinguish the influence of orthographically and phonologically defined syllables since this will provide important constraints concerning the possible locus of this effect within a general architecture for word recognition. For example, Taft (1979) has proposed an account of visual word recognition in which orthographically defined syllables play a key role, whereas in Ferrand, Seguí, and Grainger's (1996) model, it is phonologically defined syllables that have functional significance (see also, Colé, Magnan, & Grainger, 1999).

Second, all studies to date reporting an inhibitory effect of syllable frequency have confounded syllable frequency with initial segment frequency (letter and/or phoneme clusters). Words with a higher first syllable frequency will also tend to have higher initial letter and phoneme frequencies, independently of whether or not these initial letter or phoneme clusters form a syllable. Thus, what researchers have called a "syllable" frequency effect could in fact be an effect of initial cluster frequency (Schiller, 1998, 2000). Furthermore, the way cluster frequencies vary within and across syllable boundaries, has also been proposed as a possible confounding variable (Seidenberg, 1987, 1989; but see also Rapp, 1992).

Thus, for example bigram frequency is typically greater within a given syllable than at the boundary of two syllables, creating what Seidenberg referred to as a "bigram trough". Carreiras et al. (1993) had tried to rule out an alternative explanation for their empirical effects by assuring that the word stimuli they used did not show the bigram trough pattern.

However, the confound with initial cluster frequency still remains, and no attempt has been made to remove this confound in prior experimentation.

The present study uses the French language in an attempt to answer these two key questions. The French orthography has some inconsistency regarding its transcription of graphemes into phonemes, e.g., the first syllable "de" is pronounced as /de/ in "dessin" (drawing) and as /d*/ in "dessous" (beneath), but French can be considered highly inconsistent in the way phonemes can be represented by graphemes. Ziegler, Jacobs, and Stone (1996) presented a statistical analysis of the spelling to sound consistency for the bodies of monosyllabic French words showing 12% inconsistency for the spelling to sound mapping and 79% inconsistency for the mapping of sound to spelling. As a consequence, the fact that a specific phonological syllable can be written in different ways is a common feature of the French language (an example in English would be the initial syllable /si/ in "ceiling" and "seaman". Examples of French words sharing the same phonological syllable are "cigare", "cyclone" and "sirène").

Therefore in French it is possible to experimentally disentangle the frequencies of orthographically and phonologically defined syllables and also to distinguish syllable frequency from letter and phoneme cluster frequency. In the present study we designed a single experiment that included all the appropriate comparisons to allow us to address these two key questions.

We first attempted to replicate the general effect of syllable frequency in French. Then we examine the orthographic versus phonological nature of syllable frequency effects in two comparisons involving i) the cumulated word frequency of first syllable neighbors, and ii) the number of higher frequency first syllable neighbors. We examine the true syllabic nature of syllable frequency effects in two further comparisons involving i) a control for initial cluster frequency while syllable frequency is varied and ii) a manipulation of initial cluster frequency while syllable frequency is controlled. Finally, the question of the mandatory character of syllabic processing is addressed in a comparison manipulating syllable frequency within different ranges of word frequency.

The Experiment

Method

Participants

Forty-one students from the University of Provence participated in the experiment. Their participation was rewarded with course credits. All were native speakers of French and had normal or corrected-to-normal vision.

Design and Stimuli.

The words tested in this experiment were all bisyllabic with initial CV syllables (except for some words in comparison 2 that started with a different syllable structure), and all carefully controlled for bigram frequency profile (the frequency of the bigram straddling the word's two syllables was always as least as high as the mean frequency of the other bigrams, such that none contained a bigram trough pattern at the syllable boundary). The LEXIQUE Database (New, Pallier, Brysbaert, & Ferrand, 2004) for the French language includes about 40000 bisyllabic words for which the phonological syllables but not orthographic syllables are listed. Combining this database with an additional list giving orthographic syllables for French words[18], we obtained 9673 bisyllabic words for which both phonological and orthographic syllables were available. Applying the above mentioned selection criteria (bigram troughs and syllabic structure) and considering only nouns and adjectives of length 4-8 letters and with a printed frequency of at least 0.5 per million of occurrences, the number of words that could possibly enter any experiment examining syllabic effects was reduced to 579. When trying to experimentally disentangle several statistical measures that are highly correlated (e.g., phonological and orthographic syllable frequency, the frequencies of the first bigram and of the first two phonemes) it was impossible to find enough words that could serve as items in several completely independent experiments without any overlap of items between them.

---

[18] We are grateful to Ronald Peereman, Université de Bourgogne, for providing this database.

Therefore, instead of performing 6 different experiments with overlapping sets of stimuli, we decided to perform a single experiment containing the complete set of stimuli that would have been tested in the 6 different experiments, but without stimulus repetition. We then performed 6 different analyses on 6 distinct but overlapping subsets of stimuli drawn from the total set of stimuli that were tested. A total of 278 different words were tested in the Experiment, and the total number of words involved in all 5 analyses was 490. Prior to the presentation of each of the 6 analyses (Comparisons 1-6) we describe the stimulus characteristics relative to the particular subset of stimuli involved.

This experimental procedure has the following advantages. When comparing the effects of closely related measures, it may be of interest to directly compare the strength of the corresponding empirical effects. With the present experimental approach, these effect sizes are directly comparable, because they are based on the performance of the same group of participants. Furthermore, the greater number of words within one experimental session including several experimental comparisons will result in a more natural reading context. Nonwords were orthographically legal, pronounceable bi-syllabic letters strings in French, and had at least one orthographic neighbor amongst existing French words. About five percent of the nonwords were pseudohomophones.

Apparatus and Procedure

Stimuli were presented in uppercase letters using Courier 24 type font on a 17'' ProNitron color monitor (resolution 1024x768 pixel, 75 Hz) driven by an Umax Pulsar computer. Stimulus presentation and response recording was controlled by PsyScope software (V. 1.2.4 PPC; Cohen, MacWhinney, Flatt, & Provost, 1993). At the utilized viewing distance of 50 cm the stimuli subtended a visual angle of approximately 1.7 degrees. Each trial was initiated by a fixation point appearing at the center of the screen for 500 ms. The fixation point was then replaced by a blank screen (0 ms), followed by the word or nonword stimulus that remained visible until participants pressed a button indicating their decision concerning the lexicality ("yes"-button for a word; "no"-button for a nonword) of the stimulus. The time between the onset of stimulus presentation and the response was measured as the dependent variable. There were also ten initial training trials. Participants were tested individually in a quiet room. The stimulus list contained 278 words and 278 nonwords. Order of appearance of items was randomized for each participant.

Comparison 1: General syllable frequency

The first comparison was designed to verify that the inhibitory effect of syllable frequency is reliable in French. Prior reports of such an effect (Mathey & Zagar, 2002) had manipulated number of higher frequency syllabic neighbors rather than the traditional syllable frequency manipulation. Number of higher frequency syllabic neighbors had been proposed by Perea and Carreiras (1998) as the strongest predictor of inhibitory effects related to syllable frequency. Therefore it might be the case that a standard manipulation of syllable frequency (e.g., Carreiras et al., 1993) would be less reliable in French.

Stimuli and Design

100 words were selected in order to manipulate the positional frequency (high vs. low) of the first syllable. Syllable frequency was computed as the cumulated word frequency (i.e., a token count) of all bisyllabic words sharing the initial syllable of the target word (see Conrad, Carreiras, & Jacobs, submitted, for differential effects of type and token measures of syllable frequency in lexical decision). Syllable frequency was computed separately for both the orthographic and the phonological realization of any given syllable. A word was considered of high syllable frequency when its syllable frequency was at least 600 per 1 million of occurrence in both the orthographic and the phonological syllable frequency count, e.g., the word “parrain” (godfather), and of low syllable frequency with less than 200 per million occurrences in both counts, e.g., the word “neveu” (nephew)[19].

Words were matched across conditions for the following variables: word frequency, word length, length of the first syllable, orthographic and phonological neighborhood (density and number of higher frequency neighbors), positional frequency of the second syllable (orthographic and phonological). All words were of low word frequency (less than 10 occurrences per million). Characteristics for words used in Comparison 1 are presented in Table 4.1.

---

[19] All examples words for the different Comparisons in this study are taken from the stimulus material of the corresponding Comparison.

Table 4.1

Characteristics of Words used in Comparison 1
Means and Ranges of the Independent Variable (IV): orthographic and phonological Frequency of the first Syllable (SF1orth; SF1phon).
Means and Ranges of Control Variables: Word Frequency (WF), Word Length (L), Length of the first Syllable (SL1), Density of orthographic and phonological Neighborhood (North, Nphon), Number of higher Frequency orthographic and phonological Neighbors (HFNorth, HFNphon), orthographic and phonological Frequency of the second Syllable (SF2orth, SF2phon).

		Syllable Frequency (orthographic and phonological)			
		High		Low	
		Mean	Range	Mean	Range
SF1orth	IV	992	622-1744	126	9-186
Sf1phon	IV	1000	632-1509	130	9-195
WF		3.11	0.5-9	3.16	0.5-9
L		6.52	5-8	6.42	5-8
SL1		2.04	2-3	2.04	2-3
North		1.52	0-7	1.42	0-6
HFNorth		0.66	0-4	0.56	0-5
Nphon		4.80	0-18	5.20	0-19
HFNphon		1.80	0-10	1.64	0-12
SF2orth		19	1-152	22	1-140
SF2phon		53	1-381	59	1-254

Note: Frequency counts are given per million occurrences

Results and Discussion

In this and the following analyses, mean correct response latencies and error percentages (see Table 4.2) were submitted to separate analyses of variance (ANOVAs) by participants and by items (F1 and F2, respectively). For all comparisons reported in this study, response latencies differing more than two standard deviations from the mean for each participant and experimental condition were excluded from the analyses. This led to the exclusion of 3.8% of the data of Comparison 1. Thirteen of the word stimuli in Comparison 1 had to be excluded from the analysis, because their corresponding mean error rates were higher than 45 percent (the same exclusion criterion was applied in all reported comparisons).

Analyses revealed an effect of syllable frequency on response latencies that was significant in the analysis over participants: Words were responded to 23ms slower when their first syllable was of high frequency than when it was of low frequency, significant in the participant analysis, F1 (1,40) = 7.96, p <.008; F2 (1,85) = 2.54, p >.1.

Error rates also increased with syllable frequency – 13.5% vs. 11.8% for high syllable frequency vs. low syllable frequency words- although this effect did not reach statistical significance, F1 (1,40) = 3.72, p <.07; F2 (1,85) <1.

Table 4.2

Mean Reaction Times (RT; in Milliseconds). Standard Deviation of Reaction Times (Std. Dev.; in Milliseconds) and Percentage of Errors for Words in Comparison 1

	Syllable Frequency (orthographic and phonological)	
	High	Low
RT	754	731
Std. Dev.	139	122
% error	13.5	11.8

Comparison 1 has established a standard syllable frequency effect in French, that is somewhat weaker than the effect of higher frequency syllabic neighbors reported by Mathey and Zagar (2002), and less reliable than prior reports of syllable frequency effects in Spanish and German. However, our count of first syllable frequency explicitly applied to both orthographic and phonological syllable frequency. These two frequencies converge automatically in a consistent orthography like Spanish or German, but they differ to some degree in an orthography with as inconsistent phoneme to grapheme mapping as French. The question of whether the standard effect of syllable frequency is mediated by orthographic and phonological syllable frequency in the same way is an open question of theoretical interest. On the hypothesis that orthographic and phonological syllables influence visual word recognition in different ways, then the strength of the empirical effect in Comparison 1 might have suffered from the fact that orthographic and phonological syllable frequency were conjointly manipulated in this comparison. Comparison 2 was designed to examine the influence of phonological and orthographic syllable neighborhood separately.

Comparison 2: Orthographic vs. phonological syllables

Stimuli and Design

Comparison 2 A. 60 words were selected in order to manipulate the positional frequency (high vs. low) of the first syllable, realized as orthographic syllable frequency. Orthographic syllables were considered high-frequency when having a frequency of at least 530, and were considered low-frequency when having a frequency of less than 245 per million of occurrences. The frequency of the phonological first syllable was held constant across the two cells of the design. Example words are "canal" (canal) and "kayak" (kayak) which share their initial phonological syllable, but the orthographic syllable "ca" is of high frequency (573 per million occurrences) whereas "ka" is of low frequency (7 p.m.o.).

Comparison 2 B. 60 words were selected in order to manipulate the positional frequency (high vs. low) of the first syllable, realized as phonological syllable frequency. Ranges set for the manipulation of phonological syllable frequency where the same as for orthographic syllable frequency in Comparison 2A. The frequency of the orthographic first syllable was held constant across the two cells of the design. Example words are "cigogne" (swan) and "tomate" (tomato) which have initial orthographic syllables of comparable frequency (173 vs. 177 p.m.o.), but differ in phonological syllable frequency, because the phonological syllable /si/ of "cigogne" increases much in frequency (653 p.m.o.) due to words like "sirop" (syrup) which share this phonological syllable, whereas the contribution of alternative orthographic realizations to the frequency of the phonological syllable /tO/ of "tomate" (195 p.m.o.) is less important.

Words in both Comparisons 2 A and B were equated on the same variables as words in Comparison 1 across the two cells of the factor syllable frequency (see Table 4.3). None of the words was of high printed frequency (100 or more per 1 million of occurrences).

Results and Discussion

Outlier rejection led to a loss of 5% of the data in each Comparisons 2 A and B. Three words out of the stimuli of Comparison 2 A and two word stimuli out of Comparison 2 B had to be excluded because of excessive error rates. Mean response latencies and error rates for words in Comparison 2A and B are shown in Table 4.4.

Table 4.3

Characteristics of Words used in Comparison 2
Means and Ranges of the Independent Variable (IV): orthographic Frequency of the first Syllable (SF1orth) in Comparison 2A - phonological Frequency of the first Syllable (SF1phon) in Comparison 2B.
Means and Ranges of Control Variables: phonological Frequency of the first Syllable (SF1phon) in Comparison 2A - orthographic Frequency of the first Syllable (SF1orth) in Comparison 2B, Word Frequency (WF), Word Length (L), Length of the first Syllable (SL1), Density of orthographic and phonological Neighborhood (North, Nphon), Number of higher Frequency orthographic and phonological Neighbors (HFNorth, HFNphon), orthographic and phonological Frequency of the second Syllable (SF2orth, SF2phon).

Comparison 2A

	Orthographic Syllable Frequency			
	High		Low	
	Mean	Range	Mean	Range
SF1orth IV	608	530-908	174	7-240
SF1phon*	595	49-689	1011	218-10036
WF	14.26	1-86	13.98	0.5-72
L	6.00	5-7	6.00	5-7
SL1	2.00	2-2	2.07	2-3
North	2.10	0-9	1.70	0-7
HFNorth	0.97	0-9	0.53	0-4
Nphon	6.87	0-19	6.60	0-17
HFNphon	1.30	0-10	1.80	0-11
SF2orth	51	1-279	72	0.5-715
SF2phon	92	1-1031	155	1-815

Comparison 2B

	Phonological Syllable Frequency			
	High		Low	
	Mean	Range	Mean	Range
SF1phon IV	1308	532-10036	168	5-241
SF1orth	311	3-574	289	174-908
WF	12.15	0.5-86	11.04	0.5-62
L	6.27	5-7	6.27	5-7
SL1	2.20	2-4	2.17	2-3
North	1.40	0-6	1.67	0-7
HFNorth	0.43	0-5	0.40	0-4
Nphon	7.93	1-21	5.77	0-14
HFNphon	2.10	0-8	1.73	0-11
SF2orth	113	1-1764	76	0.5-715
SF2phon	189	1-2544	146	0.5-815

Note: Frequency counts are given per million occurrences
* The relatively high numerical mean difference for this variable between the two conditions of the factor orthographic syllable frequency is due to one outlier. It is not statistically significant, p>.2

<u>Comparison 2 A.</u> For orthographic syllable frequency analyses revealed no effect on response latencies. Words were responded to 6 ms slower when their first syllable was of high orthographic frequency than when it was of low orthographic frequency,

but this mean difference was far from significance, p>.4. No significant effect of orthographic syllable frequency on error rates was obtained either, p >.1.

Comparison 2 B. For phonological syllable frequency there was a significant effect of syllable frequency on response latencies: Words were responded to 42 ms slower when their first syllable was of high phonological frequency compared to low phonological syllable frequency, F1 (1,40) = 14.69, p ≤.0004; F2 (1,56) = 5.29, p <.03. This inhibitory effect of phonological syllable frequency was also present in the error data where it reached statistical significance in the analysis over participants, F1 (1,40) = 6.57, p <.02; F2 (1,56) = 1.31, p >.2. Words with high frequency phonological first syllables provoked more errors than words with low frequency phonological syllables, 11.2% vs. 7.9% respectively.

Table 4.4

Mean Reaction Times (RT; in Milliseconds). Standard Deviation of Reaction Times (Std. Dev.; in Milliseconds) and Percentage of Errors for Words in Comparison 2 A and B

Comparison 2 A

Orthographic Syllable Frequency

	High	Low
RT	695	689
Std. Dev.	117	107
% error	10.8	9.0

Comparison 2 B

Phonological Syllable Frequency

	High	Low
RT	712	670
Std. Dev.	131	97
% error	11.2	7.9

Comparison 2 has shown a robust inhibitory effect of syllable frequency on response latencies only when phonological syllable frequency is manipulated and not for orthographic syllable frequency. These results strongly suggest that phonologically defined syllables are the basis of syllable frequency effects.

Comparison 3 provides a further examination of orthographic versus phonological syllable frequency effects, but this time defined in terms of the number of higher frequency syllabic neighbors. As noted before, Perea and Carreiras (1998) found that number of higher frequency syllabic neighbors was a better predictor of response latencies than the standard syllable frequency measure.

Comparison 3: Number of higher frequency syllabic neighbors

Stimuli and Design

Comparison 3 A. 76 words were selected in order to manipulate the number of higher frequency orthographic syllabic neighbors ((high (> 17) vs. low (< 15)) of the first syllable. The number of higher frequency phonological syllabic neighbors of the first syllable was held constant across the two cells of the design. For example, “famine” (famine) and “sauveur” (savior) have a comparable number of higher frequency phonological syllabic neighbors (18 vs. 19) but differ in the number of higher frequency orthographic syllabic neighbors (18 vs. 4). This is because of high frequency words as “social” (social) that share the phonological but not the orthographic first syllable with “sauveur”.

Comparison 3 B. 78 words were selected in order to manipulate the number of higher frequency phonological syllabic neighbors ((high (> 17) vs. low (< 15)) of the first syllable. The number of higher frequency orthographic syllabic neighbors of the first syllable was held constant across the two cells of the design. Example words are “ciseau” (chisel) and “dilemme” (dilemma) with respectively ten and eleven higher frequency orthographic syllabic neighbors. The phonological syllable /si/ is shared by many relatively high frequency words with an orthographic syllable other than “ci”, e.g., “silence” (silence) which is not the case for the phonological syllable /di/. In consequence, there are thirty-five vs. twelve higher frequency phonological syllabic neighbors for the words “ciseau” and “dilemme”.

Words in both Comparisons 3 A and B were equated on the same variables as words in Comparison 1 across the two cells of the experimental factor (see Table 4.5). None of the words was of high word frequency (100 or more per 1 Million of occurrence).

Table 4.5

Characteristics of Words used in Comparison 3

Means and Ranges of the Independent Variable (IV): Number of higher Frequency Syllabic Neighbors of the first orthographic Syllable (HFSN1orth) in Comparison 3A - Number of higher Frequency Syllabic Neighbors of the first phonological Syllable (HFSN1phon) in Comparison 3B.

Means and Ranges of Control Variables: Number of higher Frequency Syllabic Neighbors of the first phonological Syllable (HFSN1phon) in Comparison 3A - Number of higher Frequency Syllabic Neighbors of the first orthographic Syllable (HFSN1orth) in Comparison 3B; Word Frequency (WF), Word Length (L), Length of the first Syllable (SL1), Density of orthographic and phonological Neighborhood (North, Nphon), Number of higher Frequency orthographic and phonological Neighbors (HFNorth, HFNphon), orthographic and phonological Frequency of the second Syllable (SF2orth, SF2phon).

Comparison 3A

	Number of orthographic higher Frequency Syllabic Neighbors			
	High		Low	
	Mean	Range	Mean	Range
HFSN1orth IV	20.79	18-38	10.79	1-14
HFSN1phon	20.29	10-36	20.03	13-88
WF	4.01	0.5-17	4.20	0.5-18
L	6.39	5-8	6.26	5-8
SL1	2.05	2-3	2.13	2-3
North	2.24	0-7	2.29	0-10
HFNorth	0.97	0-4	0.68	0-4
Nphon	6.03	0-30	7.00	0-20
HFNphon	1.79	0-6	2.11	0-9
SF2orth	53	0.5-325	53	0.5-204
SF2phon	103	0.5-731	146	1-1031

Comparison 3B

	Number of phonological higher Frequency Syllabic Neighbors			
	High		Low	
	Mean	Range	Mean	Range
HFSN1phon IV	25.46	18-88	10.92	4-14
HFSN1orth	14.15	1-20	12.90	10-19
WF	2.89	0.5-10	2.99	0.5-16
L	2.21	2-3	2.08	2-3
North	1.90	0-7	2.36	0-6
HFNorth	0.90	0-4	0.97	0-4
Nphon	7.36	0-30	6.59	0-19
HFNphon	2.18	0-6	2.28	0-10
SF2orth	54	0.5-325	48	0.5-241
SF2phon	156	1-1804	134	0.5-596

Note: Frequency counts are given per million occurrences

Results and Discussion

Outlier rejection led to a loss of 3.8% of the data in Comparison 3 A and of 3.4% in Comparison 3 B. Eight words out of the stimuli of Comparison 3 A had to be excluded because of excessive error rates. The same was the case for ten words in Comparison 3 B. Mean response latencies and error rates for words in Comparison 3 A and B are shown in Table 4.6.

Comparison 3 A. Mean response latencies did not differ for words with many or few higher frequency orthographic syllabic neighbors. Error rates slightly increased with the number of higher frequency orthographic syllabic neighbors, 14.1% vs. 12.2%, but this difference was not statistically significant, F1 (1,40) = 3.41, p <.08; F2 (1,66) <1.

Comparison 3 B. Analyses revealed a significant inhibitory effect on response latencies: responses were 32 ms slower to words with many than to those with few higher frequency phonological syllabic neighbors, F1 (1,40) = 12.73, p <.002; F2 (1,66) = 4.69, p <.04. There was also an inhibitory effect –significant in the analysis over participants- in the error data, 14.2% vs. 9.5% errors for words with many vs. few higher frequency phonological syllabic neighbors, F1 (1,40) = 15.68, p <.0003; F2 (1,66) = 3.16, p <.09.

Table 4.6

Mean Reaction Times (RT; in Milliseconds). Standard Deviation of Reaction Times (Std. Dev.; in Milliseconds) and Percentage of Errors for Words in Comparison 3 A and B

Comparison3 A		
	Number of higher Frequency orthographic syllabic Neighbors	
	High	Low
RT	743	744
Std. Dev.	131	143
% error	14.1	12.2
Comparison 3 B		
	Number of higher Frequency phonological syllabic Neighbors	
	High	Low
RT	747	715
Std. Dev.	136	135
% error	14.2	9.5

The differential effects of orthographic and phonological syllable frequency found in Comparison 2 are even more clear-cut in Comparison 3. In the response latencies there was an inhibitory effect of the number of higher frequency phonological syllabic neighbors but no hint of an effect for the number of higher frequency orthographic syllabic neighbors. Thus, again we have clear evidence that it is phonologically defined syllables that are driving syllable frequency effects in visual word recognition (for effects of phonological syllable frequency in speech production see Cholin, Levelt, & Schiller, 2006).

However, as noted in the introduction, there is one remaining issue that must be addressed before one can safely interpret syllable frequency effects as evidence for syllabic processing. Words that have a high first syllable frequency also have high initial letter/phoneme cluster frequencies. Comparison 4 was designed to examine effects of phonological syllable frequency while controlling for initial letter cluster frequency.

Comparison 4: Effects of phonological syllable frequency with letter cluster frequency controlled for

Stimuli and Design

70 words were selected in order to manipulate the phonological frequency (high vs. low) of the first syllable. Phonological syllables were considered high-frequency when having a frequency of at least 570, and were considered low-frequency when having a frequency of less than 45 per million occurrences. The following frequency measures were held constant across the two cells of the experimental design: the frequencies of the first bigram, the first trigram, the first quadrigram, and the frequency of the letter cluster representing the first syllable. The frequencies of these letter clusters were computed in a similar way as it had been described for syllable frequency in order to assure that the numerical correlations of these alternative variables with the syllable frequency measures used in this study were as close as possible. This should guarantee a most valid control for these alternative variables in this Comparison. The frequency of the first bigram was computed as the cumulated frequency of all bisyllabic words sharing this bigram in initial position. This was done independently of whether this first bigram was the word’s first syllable or not. The same procedure was applied to compute the frequency of a words’ first initial three or four letters (the first trigram or quadrigram). Similarly, the frequency of the letters representing the initial syllable was computed as follows: the cumulated frequency of all bisyllabic words starting with these letters regardless of whether they represent the first syllable or not. Given that the initial syllables of words used in the experiment differed in orthographic length, this last variable might be an important one to control for because it reflects the pure orthographic non-syllabic frequency of the first syllable in a more flexible way than initial bigram or trigram frequency.

Words were also equated on the same variables as words in Comparison 1 across the two cells of the experimental factor (see Table 4.7). None of the words was of high word frequency (100 or more per 1 Million of occurrence).

Table 4.7

Characteristics of Words used in Comparison 4
Means and Ranges of the Independent Variable (IV): phonological Frequency of the first Syllable (SF1phon).
Means and Ranges of Control Variables: Word Frequency (WF), Word Length (L), Length of the first Syllable (SL1), Density of orthographic and phonological Neighborhood (North, Nphon), Number of higher Frequency orthographic and phonological Neighbors (HFNorth, HFNphon), orthographic and phonological Frequency of the second Syllable (SF2orth, SF2phon), Frequency of the first Bigram (Ffirst2L), Frequency of the first Trigram (Ffirst3L), Frequency of the first Quadrigram (Ffirst4L) and Frequency of the Letter Cluster forming the first Syllable (FsyllL).

	Phonological Syllable Frequency			
	High		Low	
	Mean	Range	Mean	Range
SF1phon IV	651	574-1410	169	42-242
WF	10.86	0.5-86	12.81	1-93
L	6.09	5-7	6.09	5-7
SL1	2.06	2-3	2.03	2-3
North	1.94	0-9	1.89	0-6
HFNorth	0.89	0-9	0.66	0-5
Nphon	6.69	0-19	7.91	0-30
HFNphon	2.11	0-15	1.54	0-8
SF2orth	45	0.5-279	42	2-279
SF2phon	85	1-596	100	2-571
Ffirst2L	666	8-1866	659	267-1477
Ffirst3L	117	0.5-269	120	2-412
Ffirst4L	32	0.5-218	38	1-133
FsyllL	593	8-919	647	267-1477

Note: Frequency counts are given per million occurrences

Example words are “cigogne” (swan) with a high (653 p.m.o.) and “piscine” (swimming-pool) with a low (160 p.m.o.) phonological syllable frequency. For these two words there is no relevant difference for the frequencies of the letter cluster forming the initial syllable, the first bigram in this case (277 vs. 284 p.m.o.). This is because of the inconsistent phonological first syllable /si/ of “cigogne” but also because of the fact that for forty percent of bisyllabic words starting with the bigram “pi” this bigram is not the first syllable, e.g. “pincée” (pinch). In contrast, “ci” is the initial syllable of seventy-six percent of bisyllabic words starting with the bigram “ci”.

Results and Discussion

Outlier rejection led to a loss of 4.7% of the data in Comparison 4. Five words out of the stimuli of Comparison 4 had to be excluded because of excessive error rates. Mean response latencies and error rates for words in Comparison 4 are shown in Table 4.8.

Table 4.8

Mean Reaction Times (RT; in Milliseconds). Standard Deviation of Reaction Times (Std. Dev.; in Milliseconds) and Percentage of Errors for Words in Comparison 4

	Phonological Syllable Frequency (Letter Cluster Frequencies controlled for)	
	High	Low
RT	723	667
Std. Dev.	118	95
% error	12.4	8.6

Words with a high phonological syllable frequency were responded to 56ms slower, F1 (1,40) = 48.313, p ≤.0001; F2 (1,63) = 11.87, p <.002, and less accurately, F1 (1,40) = 14.81, p <.0004; F2 (1,63) = 2.03, p >.1, than words with a low phonological syllable frequency (12.4% vs. 8.6% errors). The effect on error rates was significant in the analysis over participants.

Comparison 4 shows that even if syllable frequency correlates systematically with the frequency of the letter cluster forming the orthographic syllable, the effect of syllable frequency in lexical decision proved to be independent of the frequencies of any letter cluster at the beginning of a word. Therefore, what had already been suggested by Comparisons 2 and 3 could again be confirmed: the syllable frequency effect in lexical decision seems to have its base in phonological processing where phonological syllables are used as sublexical units mediating the segmentation of polysyllabic words.

However, given that it is phonological and not orthographic syllables that are driving the syllable frequency effects obtained in the present study, it could well be argued that it is initial phoneme cluster frequency, and not bigram or trigram frequency that is the potential confounding variable. Comparison 5 was therefore designed to test for effects of initial phoneme frequency while controlling for the frequency of the first phonological syllable.

Comparison 5: Effects of phoneme cluster frequency with syllable frequency held constant

Stimuli and Design

46 words were selected in order to manipulate the frequency of the first two phonemes (high vs. low). Initial biphone frequency was computed in the same way as the frequency of the first bigram in Comparison 4. Initial biphones were considered high-frequency when having a frequency of at least 325, and were considered low-frequency when having a frequency of less than 215 per million occurrences. The frequency of the first syllable was held constant across the two cells of the experimental design. Example words are "garant" (guarantor) and "rivage" (coastline) that differ in initial biphone frequency (424 vs. 224 p.m.o.) but do not differ considerably in initial phonological syllable frequency (193 vs. 202 p.m.o.), because the first two phonemes of "garant" more often form the beginning of other bisyllabic words without forming their initial syllable, e.g., "gardien" (guard) than is the case for the first two phonemes of the word "rivage". Words were equated on syllable frequency according to all of the following realizations of syllable frequency: orthographic and phonological first syllable frequency, number of higher frequency syllabic neighbors of both the orthographic and the phonological syllable. Words were also equated on the same variables as words in Comparison 1 across the two cells of the experimental factor (see Table 4.9). None of the words was of high word frequency (100 or more occurrences per million).

Results and Discussion

Outlier rejection led to a loss of 4.5% of the data. Three words out of the stimuli of Comparison 5 had to be excluded because of excessive error rates. Mean response latencies and error rates for words in Comparison 5 are shown in Table 4.10. Responses were 13ms faster to words with high frequency initial biphones. This difference was not statistically significant, $p>.4$. No effect was obtained for the error data, $F<1$.

Table 4.9

Characteristics of Words used in Comparison 5
Means and Ranges of the Independent Variable (IV): Frequency of the initial Biphone (Ffirst2PH).
Means and Ranges of Control Variables: orthographic and phonological Frequency of the first Syllable (SF1orth, SF1phon), Number of higher frequency syllabic Neighbors of the orthographic and of the phonological first Syllable (HFSN1orth, HFSN1phon), Word Frequency (WF), Word Length (L), Length of the first Syllable (SL1), Density of orthographic and phonological Neighborhood (North, Nphon), Number of higher Frequency orthographic and phonological Neighbors (HFNorth, HFNphon), orthographic and phonological Frequency of the second Syllable (SF2orth, SF2phon).

		Frequency of the first Biphone			
		High		Low	
		Mean	Range	Mean	Range
Ffirst2PH	IV	425	327-871	231	212-244
SF1phon		239	126-344	222	202-241
SF1orth		226	73-401	212	202-233
HFSN1orth		10.04	1-25	9.7	1-27
HFSN1phon		11.74	1-29	10.48	1-30
WF		7.47	1-33.	6.76	0.5-30
L		6.26	5-8	6.13	5-8
SL1		2.17	2-3	2.00	2-2
North		2.52	0-6	1.91	0-6
HFNorth		0.91	0-5	0.65	0-4
Nphon		8.78	0-20	6.65	0-13
HFNphon		1.96	0-7	2.26	0-11
SF2orth		89	1-715	75	0.5-715
SF2phon		171	1-731	126	0.5-695

Note: Frequency counts are given per million occurrences

Comparison 5 showed that initial biphone frequency did not significantly affect lexical decision latencies when initial syllable frequency was controlled. Therefore, we have successfully excluded the role of both initial orthographic and phonological cluster frequency as potential sources of syllable frequency effects.

Table 4.10

Mean Reaction Times (RT; in Milliseconds). Standard Deviation of Reaction Times (Std. Dev.; in Milliseconds) and Percentage of Errors for Words in Comparison 5

	Frequency of the first Biphone	
	High	Low
RT	712	725
Std. Dev.	100	135
% error	13.5	13.0

The conjoined output of Comparisons 1 to 5 indicates that syllables are functional units during visual word recognition and that syllabic processing is phonological in nature. However, it remains to be seen whether or not this type of phonological processing based on the syllabic structure of polysyllabic words is an obligatory feature of silent reading, occurring independently of word frequency. Previous studies have reported an interaction between effects of word frequency and syllable frequency, with syllable frequency effects being stronger for low frequency words (for error rates in Experiment 1 and for response latencies in lexical decision in Experiment 3 of Perea & Carreiras, 1998; for both dependent variables: Conrad & Jacobs, 2004). Comparison 6 was therefore designed to test whether the syllable frequency effect is modulated by word frequency.

Comparison 6: Effects of phonological syllable frequency as a function of word frequency

Stimuli and Design

96 words were selected according to the orthogonal manipulation of the factors word frequency and initial phonological syllable frequency. A word was considered low-frequency when it had a frequency of less than four per million occurrences. Words with a frequency between five and one hundred per million occurrences were placed in the high-frequency category. The ranges of initial syllable frequency were above 570 for high syllable frequency words and below 225 per million occurrences for low syllable frequency words. “Salive” (saliva) and “museau” (muzzle) are examples for high frequency words with high respectively low syllable frequency. “Microbe” (germ) and “tisane” (herb tea) are examples for this syllable frequency manipulation within low frequency words. Across the four cells of the experimental design the following variables were held constant (see Table 4.11): Word length, length of the initial syllable, orthographic and phonological neighborhood (density and number of higher frequency neighbors), positional frequency of the second syllable (orthographic and phonological). All words started with a CV-syllable.

Table 4.11

Characteristics of Words used in Comparison 6
Means of the Independent Variables (IV): Word Frequency (WF) and phonological Frequency of the first Syllable (SF1phon).
Means and Ranges of Control Variables: Word Length (L), Length of the first Syllable (SL1), Density of orthographic and phonological Neighborhood (North, Nphon), Number of higher Frequency orthographic and phonological Neighbors (HFNorth, HFNphon), orthographic and phonological Frequency of the second Syllable (SF2orth, SF2phon).

	Word Frequency							
	High				Low			
	Syllable Frequency				Syllable Frequency			
	High		Low		High		Low	
	Mean	Range	Mean	Range	Mean	Range	Mean	Range
WF IV	15.59	5-86	17.6	5-93	2.26	1-4	2.28	1-4
SF1phon IV	909	574-1509	158	13-218	906	574-1509	163	42-223
L	6.63	5-8	6.5	5-8	6.42	5-8	6.42	5-8
SL1	2.00	2-2	2.04	2-3	2.13	2-3	2.08	2-3
North	1.67	0-5	1.71	0-5	1.58	0-7	1.42	0-3
HFNorth	0.25	0-3	0.17	0-2	0.50	0-3	0.63	0-2
Nphon	5.17	0-17	5.04	0-19	4.50	0-11	5.08	0-15
HFNphon	0.38	0-3	0.42	0-3	1.46	0-4	1.42	0-5
SF2orth	36	5-143	50	7-241	31	1-241	30	1-187
SF2phon	69	5-252	80	8-394	84	1-394	93	2-360

Note: Frequency counts are given per million occurrences

Results and Discussion

Outlier rejection led to a loss of 4.8% of the data. Mean response latencies and error rates for words in Comparison 6 are shown in Table 4.12. Analyses revealed a significant effect of word frequency with high frequency words being responded to 83ms faster than low frequency words, F1 (1,40) = 73.99, p ≤.0001; F2 (1,92) = 52.60, p ≤.0001. Error rates also decreased with word frequency, 14.4% errors occurred for low frequency words vs. 5.0% for high frequency words, F1 (1,40) = 55.26, p ≤.0001; F2 (1,92) = 33.74, p ≤.0001. A significant inhibitory effect was obtained for the factor syllable frequency. Responses were 35ms slower to words starting with a high frequency syllable than to those with low frequency initial syllables, F1 (1,40) = 15.54, p ≤.0003; F2 (1,92) = 10.67, p <.002. More errors (11.2% vs. 8.1%) were provoked by high syllable frequency than by low syllable frequency words, the effect was significant in the participant analysis, F1 (1,40) = 9.97, p <.004; F2 (1,92) = 3.67, p <.06.

There was a significant interaction between the two factors word frequency and syllable frequency in both the analyses on response latencies and error rates. The syllable frequency effect on response latencies was stronger for low frequency words than for high frequency words (63ms vs. 7ms), F1 (1,40) = 19.43, p ≤.0001; F2 (1,92) = 6.57, p <.02. Syllable frequency led to increased error rates only for low frequency words, F1 (1,40) = 21.05, p ≤.0001; F2 (1,92) = 5.84, p <.02.

Table 4.12

Mean Reaction Times (RT; in Milliseconds). Standard Deviation of Reaction Times (Std. Dev.; in Milliseconds) and Percentage of Errors for Words in Comparison 6

	Word Frequency					
	High			Low		
Syllable Frequency	RT	Std. Dev.	% error	RT	Std. Dev.	% error
High	670	124	4.6	782	163	17.9
Low	663	104	5.4	719	125	10.9

The results of Comparison 6 show that the syllable frequency effect interacts with word frequency, and is only robust in low frequency words. This fits with the results of previous studies (Conrad & Jacobs, 2004; Perea & Carreiras, 1998) showing a greater sensitivity to syllabic processing as word frequency diminishes.

General Discussion

The results of the present study provide an innovative perspective on the role of syllables in visual word recognition, and more generally on the role of phonology in reading. Our study is based on a finding known as the syllable frequency effect, a phenomenon that has been replicated in several studies now in both Spanish and German (Álvarez et al., 2001; Carreiras et al., 1993; Conrad & Jacobs, 2004; Conrad, Stenneken, & Jacobs, 2006; Perea & Carreiras, 1998). It refers to the finding that polysyllabic words that have an initial syllable that is shared by many other polysyllabic words (i.e., a high syllable frequency) are harder to recognize than polysyllabic words that have initial syllables of low frequency. Comparison 1 of the present study showed that syllable frequency effects in French are also apparent when applying this standard manipulation of syllable frequency (the only previous study of syllable frequency effects in French had used a higher frequency syllabic neighbor manipulation, Mathey & Zagar, 2002). Having established a basic syllable frequency effect in French, analogous to the effects previously reported for Spanish and German, Comparisons 2-5 were designed to examine two outstanding issues concerning such effects:

1) are they driven by orthographically defined or phonologically defined syllables?
2) are they true syllabic effects and not simply the result of correlated changes in initial cluster (orthographic or phonological) frequency?

Comparison 2 demonstrated a robust inhibitory effect for phonological syllable frequency in contrast with a null effect (a small trend to inhibition) on response latencies for orthographic syllable frequency. Comparison 3 confirmed this pattern applying a manipulation of the number of higher frequency syllabic neighbors. Again, syllable frequency only affected response latencies when the syllable was defined phonologically, and not when it was defined orthographically. Comparisons 4 and 5 allowed us to rule out the possibility that syllable frequency effects are in fact effects of initial letter or phoneme cluster frequency and nothing to do with syllables.

Comparison 4 found a robust effect of syllable frequency when the frequency of word initial letter clusters (bigrams and trigrams) was held constant.

Comparison 5 showed that the frequency of a word's two initial phonemes (biphone frequency), a variable that is strongly correlated with phonological syllable frequency especially for CV syllables, did not produce a significant effect on response latencies when syllable frequency was controlled for. Finally, Comparison 6 showed that syllable frequency effects were only robust in low frequency words. Therefore, the results of the present study suggest that syllable frequency effects indeed reflect processing of syllable-sized units during visual word recognition, and also suggest that these syllable-sized units are defined phonologically. The influence of such syllabically structured phonological processing is most evident during the recognition of low frequency words.

A recent masked priming study by Álvarez, Carreiras, and Perea (2004) also provided evidence that syllable effects in visual word recognition are phonological rather than orthographic effects. Primes that shared their initial syllable with target words facilitated target word recognition even when the syllable has a different orthographic realization (e.g., the pronunciation of the Spanish orthographic syllables BI and VI is the same).

Thus, the effects of syllabic manipulations with polysyllabic words add to the already vast literature showing phonological influences on visual word recognition (e.g., Ferrand & Grainger, 1992, 1994; Frost, 1998; Grainger & Ferrand, 1994; Lukatela, Eaton, Lee, Carello, & Turvey, 2002; Lukatela, Frost, & Turvey, 1998; Lukatela & Turvey, 1994; Perfetti & Bell, 1991; Pollatsek, Lesch, Morris, & Rayner, 1992; Van Orden, 1987; Van Orden; Johnston, & Hale, 1988). These phonological influences can be accommodated by a model in which sublexical orthographic representations (i.e., letters, graphemes) are immediately converted into sublexical phonological representations (i.e., phonemes) during the processing of a printed word (Ferrand et al., 1996; Grainger & Ferrand, 1994; Jacobs, Rey, Ziegler, & Grainger, 1998).

What the present results tell us is that this process of sublexical conversion from orthography to phonology also involves syllable-sized representations. The conversion of graphemes into phonological syllable representations could easily be achieved for most polysyllabic words in a language like French where inconsistency in the mapping of graphemes into phonemes is rather the exception than the rule (see Ziegler et al., 1996) and where syllabic boundaries are clearly defined (see Ferrand et al., 1996; Kaye, & Lowestamm, 1984; for syllabification algorithms in French, see Dell, 1995; Laporte, 1993).

Thus, on presentation of a printed word, a sublexical orthographic code generates activation in the appropriate set of phoneme representations that then converge on syllabic representations. These syllable-sized units only receive bottom-up input via phoneme representations, and are therefore phonologically defined syllables. The syllable representations then control activation at the level of whole-word orthographic and phonological representations. On presentation of a polysyllabic word, all whole-word representations that are connected with the first syllable of the target word will therefore receive activation from that syllable representation and compete with the target word for recognition. This is how inhibitory effects of syllable frequency arise.

Comparison 6 of the present study examined whether or not syllable frequency effects are influenced by word frequency. The results showed that the effect of phonological syllable frequency diminished with increasing word frequency. This finding fits with our phonological interpretation of syllable frequency effects. In models of visual word recognition that postulate a direct orthographic route to meaning and an indirect phonological route (e.g., Ferrand et al., 1996; Grainger & Ferrand, 1994; Jacobs, et al., 1998), it is clear that phonological influences will depend on speed of processing in the direct route. Orthographic processing may be too fast in high frequency words for the sublexical computation of phonology (including phonological syllables) to significantly influence a lexical decision response based on activity in whole-word representations (Grainger & Jacobs, 1996).

Finally, to end on a methodological note, the present study tested a relatively large set of pre-planned orthogonal contrasts in a single experiment. This has the advantage of allowing comparisons of different experimental manipulations on the basis of data obtained from the same set of participants in the same testing conditions. It also has the advantage of examining effects involving quite small numbers of stimuli (due to the massive constraints on stimulus selection) embedded in a larger more heterogeneous stimulus set.

Given the evidence for effects of list composition on performance in standard word recognition tasks (e.g., Gordon, 1983; Lupker, Brown, & Colombo, 1997; Perea, Carreiras, & Grainger, 2004), large heterogeneous lists of stimuli have the advantage of reducing effects that are uniquely due to the repetition of stimuli from a particular experimental condition (via trial-to-trial adjustments in response criteria – Perea et al., 2004). It is obvious that "normal" extra-laboratory reading rarely involves the successive presentation of stimuli fulfilling the highly specific stimulus selection criteria that we typically apply in laboratory experiments.

In conclusion, the present study provides further support in favor of a model of visual word recognition in which the rapid sublexical computation of phonology from orthography involves phonologically defined syllable-sized representations. These syllabic representations control activation at the level of whole-word representations such that high frequency initial syllables activate many such whole-word representations which then compete with the target word for identification

Outlook

The question of whether a syllabic segmentation of orthographic word forms during visual word recognition was an automatic feature of visual word recognition was the most important motivation for the experimental work presented in this thesis.

An inhibitory effect of syllable frequency in the lexical decision task obtained for several orthographies (Spanish, Carreiras et al., 1993, French, Mathey & Zagar, 2002, and German, Conrad & Jacobs, 2004) had suggested that this might be the case, but a reliable attribution of these empirical effects had remained difficult, because these studies had not allowed for a clear distinction between purely orthographic (without relation to syllabic structure) and truly syllabic processing as possibly underlying the empirical results. Furthermore, the question of whether an assumed syllabic processing would relate to phonological or orthographic syllables couldn't either be answered by these studies.

Several experiments presented in this dissertation were designed to further examine the nature of the syllable frequency effect during the process of silent reading and they provide clear evidence regarding these two outstanding questions:

1. Data obtained for the Spanish and French orthography showed that the inhibitory initial syllable frequency effect in lexical decision can be obtained when controlling for the frequency of the letter cluster forming the initial syllable (see Experiment 2 of Chapter 3 and Comparison 4 of Chapter 4). The effect, therefore, has to relate to the processing of syllabic units. The facilitative effect of initial bigram frequency controlling for initial syllable frequency obtained for the Spanish orthography (see Experiment 3 of Chapter 3) underlines the distinctive character of purely orthographic processing on the one hand and syllabic processing on the other.

It appears that syllabic units in contrast to orthographically defined letter clusters as bigrams strongly mediate the activation of word candidates competing with each other during visual word recognition. The processing of bigrams rather appears to be an inherent feature of prelexical processing.

2. Data obtained for the French orthography where particular phonological syllables can have different spelling realizations allows attributing the syllable frequency effect in lexical decision to the processing of phonological syllables (see Comparisons 2 and 3 of Chapter 4). Comparison 6 of Chapter 4 revealed that syllabic processing as reflected by the syllable frequency effect diminishes with increasing word frequency.

Taken together, these empirical results seem to offer the following conclusion:

Phonological encoding during the process of silent reading involves an automatic syllabic segmentation of orthographic word forms into their phonological syllables - at least when a fast and direct access to a high frequency orthographic word form via purely orthographic processing is not sufficient for lexical access.

I am tempted to state that the experiments presented in this dissertation therefore provide an affirmative answer to the question of whether phonological syllabic segmentation is an important feature of visual word recognition. Yet, what is far less clear is how this syllabic segmentation is achieved by the reading system.

Event related potential studies revealing the time course of visual word recognition could offer useful evidence regarding the relation between orthographic and syllabic processing. Two recent ERP-studies distinguished between an early (prelexical) effect of initial syllable frequency at around 200 ms and a late (lexical) effect around 400 ms (Barber et al., 2004; Hutzler et al., 2004). An even earlier effect of initial bigram frequency with an onset at 100 ms was reported by Hauk et al. (2006). Whether the early “syllabic” effects in the studies of Barber et al. (2004) and Hutzler et al. (2004) can really be attributed to prelexical processing of syllables or whether they rather have to be seen as resulting from purely orthographic (non syllabic) processing, is difficult to determine, because the natural confound between syllable- and letter cluster frequency had not been controlled for in these studies.

On the other hand, it is also unclear whether the effect of initial bigram frequency with initial syllable frequency controlled for reported in Chapter 3A where initial bigrams always formed the initial syllables of targets has a relation to syllabic processing – with high frequency bigrams facilitating the syllabic parsing process – or whether it is best understood as a phenomenon of purely orthographic processing in a more restricted way.

A differential examination of the respective onsets of effects of

a) general orthographic prelexical processing,

b) encoding of basic phonological units, and

c) encoding of phonological syllabic units

and the respective durations of these phenomena during the time course of visual word recognition as reflected by the ERP-signal would be a useful aim for future research.

Another main research goal is the implementation of a functional computational model that could account for the processing of polysyllabic words.

The evidence for syllabic processing in visual word recognition presented in this dissertation shows that the simple extension of the principles of modelling monosyllabic word processing to the processing of words of increased length would not be sufficient to account for the processing of polysyllabic words - differing qualitatively from monosyllabic word processing. A theoretical proposal on how the inhibitory effect of syllable frequency could arise in an interactive activation model of visual word recognition has already been made by Carreiras et al. (1993) and Perea and Carreiras (1998) and some specific implications for computational modelling arising from the new empirical evidence presented have been outlined in this dissertation (see Chapters 2-4). However, the basic problem regarding a successful simulation of syllabic processing does not consist in implementing an interactive activation model with a layer of syllabic representation units. The crucial question, instead, is how these syllabic units would become activated as a function of the model's processing of the orthographic input. In other words, what would be the syllabic parsing mechanism of such a model?

Seidenberg (1987; 1989) had made a straightforward proposal on how syllabic units could emerge out of the orthographic input via orthographic processing: whenever a very low frequency bigram (relative to the surrounding bigrams) would be found, this could be "interpreted" as the boundary between two sublexical units.

But it was shown in Experiment 1 of Chapter 3 that the presence or absence of a bigram trough at the syllable boundary did not have any influence on syllabic processing as reflected by the strength of the syllable frequency effect – at least in Spanish (but see Doignon & Zagar, 2005; Mathey et al., 2006, for different proposal regarding the French orthography).

Based on an extensive analysis of all bisyllabic words included in the database for the Spanish language (Sebastián-Gallés et al., 2000), I have formulated an alternative proposal on how a correct syllabic segmentation in this language could be achieved relying on a basic encoding of letters or graphemes as consonants and vowels on the one hand and phonotactic regularities on the other (see Chapter 4, see also Conrad et al., submitted). According to the principles of sonority hierarchy and of a maximum sonority contrast at the syllable boundary, which perfectly describe the syllabification of bisyllabic Spanish words, assigning a single consonant occurring between two vowels to a syllabic onset and analyzing the sonority relation within a multiple consonant cluster would suffice for a correct syllabification of all bisyllabic Spanish word forms.

Even if some empirical data comparing lexical decision latencies for words differing in the complexity of syllabic structure seems to support this assumption (see Conrad et al, submitted manuscript), clearly more experiments have to be conducted in order to verify if and to what extent readers do in fact rely on these principles of syllabification when processing polysyllabic Spanish words. The outcome of such experiments could be used for implementing a computational model with a syllabic parsing mechanism. Such a model might well be able to account for polysyllabic word processing in an orthography with such transparent syllabic structure as Spanish. But the question arises of whether such a model would also prove to be capable of sufficiently simulating empirical affects obtained in other orthographies with more complex and less transparent syllabic structure?

Extensive analyses of the respective databases would be a first necessary step for establishing potential regularities – including their limitations - of syllabification in these languages. For instance, it is evident that – even if the principle of sonority hierarchy characterizing syllabification can be seen as universal – the simple and transparent rules characterising syllabification of bisyllabic Spanish orthographic word forms will not sufficiently describe syllabification in other orthographies.

E.g., encoding the letter N as a consonant and assigning it accordingly to syllable onset or coda would often be misleading in French, where this letter can belong to a nasal vowel's orthographic representation. In German, assigning a single consonant letter occurring between to vowels within a bisyllabic word automatically to a syllabic onset, would result in a syllabic parsing error for many morphologically complex bisyllabic words, even if this letter represents a single consonant grapheme, because morphological structure of bisyllabic German words predominantly affects whole words' syllabification even if this results in a violation of syllabic sonority hierarchy.

A roadmap towards developing a computational interactive activation model that might successfully account for syllabic processing in several orthographies should include the following steps:

1.) Implementation of a Null-model - enabled to process orthographic word forms of different (and increased) word lengths but not containing syllabic representations (see the extension of the MROM used for simulating the empirical results presented in Chapter 3). Such a model should probably fail to account for any effects specifically related to syllable frequency or syllabic structure.
2.) Implementation of different model variants containing syllabic representations. These model variants would allow comparing the outcome of different types of syllabic processing – distinctively operationalized within the architecture of a localist-connectionist model - corresponding to different theoretical views on the nature of syllabic processing as arising
    a) via top down activation of syllabic units from phonological whole word representations (see Levelt, Roelofs, & Meyer, 1999).
    b) via bottom up activation of syllabic units from lower level representations of graphemes and phonemes following the principles of interactive activation.
    c) via a rule base syllabic parsing mechanism reflecting either global principles of syllabification (sonority hierarchy) or language specific regularities of syllabification and phonotactics.
3.) Parameter-tuning and comparison of the different model variants with regard to the outcome of empirical studies.

4.) Cross validation of the optimal model variant with classical findings of visual word recognition. Before proposing a new powerful model for the processing of polysyllabic words, it would be necessary to show that such a model would still be able to account for more basic effects of visual word recognition, effects that existing models have already successfully simulated. E.g., the word superiority effect (Grainger & Jacobs, 1994), the word frequency effect (Grainger & Jacobs, 1996), effects of neighbourhood density and frequency (Grainger & Jacobs, 1996) or the pseudohomophone effect (Ziegler et al., 2001).

A coordinated procedure within a cross linguistic computational modelling approach investigating language specific features of syllabic processing would offer the interesting perspective to use a specific model variant that has proven to offer a satisfying account of syllabic processing in a particular language as a Null-model for syllabic processing in another language. For instance, assigning syllabic representations with a resting level of activation corresponding to syllable frequency might enhance syllabic parsing in orthographies with less transparent syllabic structure.

With regard to the languages used for the experiments presented in this dissertation, another specific prediction for the German orthography would be the following: A model with a phonology-based syllabic parsing mechanism but no morphological representation units could most probably not sufficiently account for the processing of morphologically complex bisyllabic German words. Generally, and in contrast to the relation between orthographic and syllabic processing, the relation between morphological and syllabic processing has not been examined in the experiments contained in this dissertation. This does not present a problem for the Spanish and French data, because bisyllabic words – exclusively being used in all of the presented experiments - in these languages do generally not show a high degree of morphological complexity and syllable boundaries in these languages generally less often coincide with morpheme boundaries than in German. And they almost never do so in the case of bisyllabic words. In Spanish, for instance, an "o" or an "a" is regularly added to a noun or adjective's stem indicating a word's grammatical gender. Therefore, – besides a few monosyllabic exception words like PAN (bread) – all Spanish nouns and adjectives are at least bisyllabic. Prefixed Spanish words therefore have to comprise at least three syllables.

All regular Spanish verb forms are at least bisyllabic and typically a Spanish word's stem is the initial syllable plus one letter (in the case of non prefixed words). The same is true – although to a lesser extent - for the French orthography. In any case, prefixed bisyllabic French words had not been used as stimuli for the experiments presented in Chapter 4. Therefore a confound between syllabic and morphological processing can be excluded for the experiments presented in this dissertation that were conducted using the Spanish or French language (see also Álvarez et al., 2001, for contrasting effects of syllable frequency and effects of the frequency of the BOSS in Spanish, see as well Domínguez, Alija, Cuetos, & de Vega, 2006, for differential effects of prefixes and other initial syllables without specific morphological status).

Also for German, where syllable boundaries in bisyllabic words often coincide with morpheme boundaries, an inhibitory effect of initial syllable frequency has already been obtained using stimulus material where initial syllables never coincided with morphemes (Conrad & Jacobs, manuscript in preparation). This shows that syllabic processing in German cannot be understood as a by product of morphological processing, but the general structure of the German language allowing for an – in principle – indefinite creation of new words via the combination of single morphemes makes an important role of morphological processing in visual word recognition in German very plausible (see Schriefers, Jescheniak, & Hantsch, 2005; Zwitserlood, 2004; Zwitserlood, Bölte, & Dohmes, 2000, Dohmes et al., 2004, for evidence of morphological processing in German speech perception and production). Note that the construction of compound words like the German words HAUSTÜR (front door), BRIEFKASTEN (mailbox) is not used to express the same relation between two concepts in Roman languages; the corresponding expressions in French or Spanish would connect single words via a preposition: e.g., "PORTE DE LA MAISON, BOITE AUX LETTRES; or PUERTA DE LA CASA (BUZON, the Spanish translation of mailbox is a single bisyllabic word, but not a compound).

From a long term perspective, a comprehensive future model of polysyllabic word recognition would never be complete without taking into account the role of morphological processing (see Giraudo & Grainger, 2003; Reichle & Perfetti, 2003; Schreuder & Baayen, 1995, see also Gonnerman, et al., 2007, for computational models including morphological processing).

But even when trying to simulate only syllabic effects arising during the processing of bisyllabic words - which seems to be the next logical step for developing a computational model of polysyllabic word processing - the scope of such a model for the German language would most probably be limited, if such a model would not include a processing device for the specific interplay between syllabic and morphological processing in the case of syllables coinciding with morphemes.

References

Álvarez, C. J., Carreiras, M., & de Vega, M. (2000). Syllable frequency effect in visual word recognition: Evidence of sequential type-processing. *Psicológica, 21*, 341-374.

Álvarez, C. J., Carreiras, M., & Perea, M. (2004). Are syllables phonological units in visual word recognition? *Language and Cognitive Processes, 19*, 427–452.

Álvarez, C. J., Carreiras, M., & Taft, M. (2001). Syllables and morphemes: contrasting frequency effects in Spanish. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 27*, 545-555.

Andrews, S. (1997). The effect of orthographic similarity on lexical retrieval: Resolving neighborhood conflicts. *Psychonomic Bulletin & Review, 4*(4), 439-461.

Ans, B., Carbonnel, S., Valdois, S. (1998). A connectionist multiple-trace model for polysyllabic word reading. *Psychological Review, 105*, 678-723.

Baayen, R. H., Piepenbrock, R., & van Rijn, H. (1993). *The CELEX Lexical Database (CD-ROM)*. Philadelphia, PA: Linguistic Data Consortium, University of Pennsylvania.

Bailey, T. M., & Hahn, U. (2001). Determinants of Wordlikeliness: Phonotactics or Lexical Neighborhoods? *Journal of Memory and Language, 44*, 568-591.

Balota, D. A., Chumbley, J. I. (1985). The locus of word-frequency effects in the pronunciation tasks: Lexical access and/or production? *Journal of Memory and Language, 24*, 89-106.

Barber, H. A., & Kutas, M. (2007). Interplay between computational models and cognitive electrophysiology in visual word recognition. *Brain Research Reviews, 53* (1), 98-123.

Barber, H., Vergara, M., & Carreiras, M. (2004). Syllable-frequency effects in visual word recognition: evidence from ERPs, *Neuroreport, 15*, 545-548.

Bowers, J., Davis, C. J., Hanley, D. A. (2005). Interfering neighbours: The impact of novel word learning on the identification of visually similar words. *Cognition*, B45-B54.

Brand, M., Rey, A., & Peereman, R. (2003). Where is the syllable priming effect in visual word recognition? *Journal of Memory and Language, 48* (2), 435-443.

Brand, M., Rey, A., Peereman, R., & Spieler, D. (2001). Disyllabic word naming a large scale study. In Proceedings of the 43rd annual meeting of the psychonomic society, Kansas City, MO.

Buchanan, L., Westbury, C., & Burgess, C. (2001). Characterizing semantic space: Neighborhood effects in word recognition. Psychonomic Bulletin & Review, 8 (3), 531-544.

Carreiras, M., & Marín, A. (submitted). Early syllabic effects in printed words revealed through perceptual tasks.

Carreiras, M., & Perea, M. (2004a). Naming pseudowords in Spanish: Effects of syllable-frequency in production. *Brain and Language, 90*(1-3), 393-400.

Carreiras, M., & Perea, M. (2004b) Effects of syllable neighbourhood frequency in visual word recognition and reading: Cross-task comparisons. In L. Ferrand & J. Grainger (Eds.) *Psycholinguistique Cognitive*. Bruxelles : De Broeck Université

Carreiras, M., Ferrand, L., Grainger, J. & Perea, M. (2005). Sequential effects of phonological priming in visual word recognition. *Psychological Science, 16* (8), 585- 589.

Carreiras, M., Mechelli, A., & Price, C. (2006). The effect of word and syllable frequency on activation during lexical decision and reading aloud. *Human Brain Mapping, 27*, 963-72.

Carreiras, M., Perea, M., Grainger, J. (1997). Orthographic neighborhood effects on visual word recognition in Spanish: Cross-task comparisons. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 23*, 857-871.

Carreiras, M., Vergara, M., Barber, H. (2005). Early event-related potential effects of syllabic processing during visual word recognition. *Journal of Cognitive Neuroscience, 17*, 1803-1817.

Carreiras, M., Álvarez, C. J., & De Vega, M. (1993). Syllable-frequency and visual word recognition in Spanish. *Journal of Memory and Language, 32*, 766-780.

Cholin, J., Levelt, W. J., & Schiller, N.O. (2006). Effects of syllable frequency in speech production. *Cognition, 99*(2), 205-35.

Cohen, J. D., MacWhinney, B., Flatt, M., & Provost, J. (1993). PsyScope: A new graphic interactive environment for designing psychology experiments. *Behavioral Research Methods, Instruments & Computers, 25*, 2, 257-271.

Coltheart, M., Davelaar, E., Jonasson, J.T., & Besner, D. (1977). Access to the internal lexicon. In S. Domic (Ed.), *Attention and performance* (Vol. VI, pp. 535-555). Hillsdale, NJ: Erlbaum.

Coltheart, M., Rastle, K., Perry, C., Langdon, R., & Ziegler, J. C. (2001). DRC: A dual route model of visual word recognition and reading aloud. *Psychological Review, 108*, 204-256.

Colé, P., Magnan, A., & Grainger, J. (1999). Syllable-sized units in visual word recognition: Evidence from beginning and skilled readers of French. *Applied Psycholinguistics, 20*, 507-532

Conrad, M., & Jacobs, A. M. (2004). Replicating syllable frequency effects in Spanish in German: One more challenge to computational models of visual word recognition. *Language and Cognitive Processes, 19*, 3, 369-390.

Conrad, M., Carreiras, M., & Jacobs, A. M. (2008). Contrasting effects of token and type syllable frequency in lexical decision. *Language and Cognitive Processes*, *2*, available online since September 2007.

Conrad, M., Carreiras, M., & Jacobs, A. M. (in revision). Effects of syllable structure and syllable frequency in lexical decision.

Conrad, M., Grainger, J., & Jacobs, A. M. (2007). Phonology as the source of syllable frequency effects in visual word recognition: Evidence from French. *Memory & Cognition, 35* (5), 974-983.

Conrad, M., Stenneken, P., & Jacobs, A. M. (2006). Associated or dissociated effects of syllable-frequency in lexical decision and naming. *Psychonomic Bulletin & Review, 13*, 339-345.

Cutler, A., Mehler, J., Norris, D., & Seguí, J. (1986). The syllables's differing role in the segmentation of French and English. *Journal of Memory & Language, 25*, 385-400.

Dambacher, M., & Kliegl, R. (2007). Synchronizing timelines: Relations between fixation durations and N400 amplitudes during sentence reading. *Brain Research, 1155*, 147-162.

Dambacher, M., Kliegl, R., Hofmann, M., & Jacobs, A. (2006). Frequency and predictability effects on event-related potentials during reading. *Brain Research, 1084,* 89-103.

Davis, C. J. (2005). N-Watch: A program for deriving neighborhood size and other psycholinguistic statistics. *Behavior Research Methods, 37*, 65-70

Davis, C. J., & Bowers, J. S. (2006). Contrasting five different theories of letter position coding: Evidence from orthographic similarity effects. *Journal of Experimental Psychology: Human Perception and Performance, 32* (3), 535-557.

Davis, C. J., & Perea, M. (2005). BuscaPalabras: A program for deriving orthographic and phonological neighborhood statistics and other psycholinguistic indices in Spanish. *Behavior Research Methods, 37*, 665-671.

De Jong, N. H., Schreuder, R., & Baayen, R. H. (2000). The morphological family size effect and morphology. *Language and Cognitive Processes, 15*, 329-365.

Dell, F. (1995). Consonant clusters and phonological syllables in French. Lingua, 95, 5-26.

Dohmes, P., Zwitserlood, P., & Bölte, J. (2004). The impact of semantic transparency of morphologically complex words on picture naming. *Brain and Language, 90*, 203–212.

Doignon, N., & Zagar, D. (2005). Illusory conjunctions in French: The nature of sublexical units in visual word recognition. *Language and Cognitive Processes, 20*(3), 443-464.

Domínguez, A., Alija, M., Cuetos, F., & de Vega, M. (2006). Event related potentials reveal differences between morphological (prefixes) and phonological (syllables) processing of words. *Neuroscience Letters, 408*, 10–15.

Drews, E., & Zwitserlood, P. (1995). Morphological and Orthographic Similarity in Visual Word Recognition. *Journal of Experimental Psychology: Human Perception and Performance , 21*(5), 1098-1116.

Ernestus, M., & Baayen, R. H. (2001). Choosing between the Dutch past-tense suffixes –te and –de. In T. van der Wouden & H. de Hoop (Eds.), *Linguistics in the Netherlands* (pp.81-93). Amsterdam: Benjamins.

Ernestus, M., & Baayen, R. H. (2003). Predicting the unpredictable: Interpreting neutralized segments in Dutch. *Language, 79*(1), 5-38.

Ferrand, L., & Grainger, J. (1992). Phonology and orthography in visual word recognition: Evidence from masked nonword priming. *Quarterly Journal of Experimental Psychology, 45A*, 353-372.

Ferrand, L., & Grainger, J. (1994). Effects of orthography are independent of phonology in masked form priming. *Quarterly Journal of Experimental Psychology , 47A*, 365-382.

Ferrand, L., Grainger, J., & Seguí, J. (1994). A study of masked form priming in picture and word naming. *Memory & Cognition, 22*, 431-441.

Ferrand, L., Seguí, J., & Grainger, J. (1996). Masked priming of word and picture naming: the role of syllabic units. *Journal of Memory and Language, 35*, 708-723.

Friederici, A. D. (1995). The time course of syntactic activation during language processing – a model based on neuropsychological and neurophysiological data. *Brain and Language, 50* (3), 259-281.

Frost, R. (1998). Towards a strong phonological theory of visual word recognition: True issues and false trails. *Psychological Bulletin, 123*, 71–99.

Giraudo, H., & Grainger, J. (2003). A supralexical model for French derivational morphology. In D., Sandra, & A. Assink (Eds.) *Reading complex words*. Amsterdam, Kluwer.

Gold, B. T., & Rastle, K. (2007). Neural correlates of morphological decomposition during visual word recognition. *Journal of Cognitive Neuroscience, 19* (12), 1983-1993.

Gold, B. T., Balota, D. A., Jones, S. J., Powell, D. K., Smith, C. D., & Andersen, A. H. (2006). Dissociation of automatic and strategic lexical-semantics: Functional magnetic resonance imaging evidence for differing roles of multiple frontotemporal regions. *Journal of Neuroscience, 26* (24), 6523-6532.

Gonnerman, L. M., Seidenberg, M. S., & Andersen, E. S. (2007). Graded Semantic and Phonological Similarity Effects in Priming: Evidence for a Distributed Connectionist Approach to Morphology. *Journal of Experimental Psychology: General, 136*, (2), 323–345.

Gordon, B. (1983). Lexical access and lexical decision: Mechanisms of frequency sensitivity. *Journal of Verbal Learning & Verbal Behavior, 22*, 24-44.

Goslin, J., Grainger, J., & Holcomb, P. J. (2006). Syllable frequency effects in French visual word recognition: AN ERP study. *Brain Research, 1115*, 121-134.

Grainger, J. (2007). Cracking the orthographic code: An introduction. *Language and Cognitive Processes, 23* (1), 1-35.

Grainger, J., & Ferrand, L. (1994). Phonology and orthography in visual word recognition: Effects of masked homophone primes. *Journal of Memory and Language, 33*, 218-233.

Grainger, J., & Jacobs, A. M. (1994). A dual-read out model of word context effects in letter perception: Further investigations of the word superiority effect. *Journal of Experimental Psychology: Human Perception and Performance, 20*, 1158-1176.

Grainger, J., & Jacobs, A. M. (1993). Masked partial-word priming in visual word recognition: effects of positional letter frequency. *Journal of Experimental Psychology: Human Perception and Performance, 19*(5), 951-964.

Grainger, J., & Jacobs, A. M. (1996). Orthographic processing in visual word recognition: A multiple read-out model. *Psychological Review, 103*, 518-565.

Grainger, J., O'Regan, K., Jacobs, A., & Seguí, J. (1989). On the role of competing word units in visual word recognition: The neighborhood frequency effect. *Perception & Psychophysics, 45*, 189-195.

Gumnior, H., Bölte, J., & Zwitserlood, P. (2006). A chatterbox is a box: Morphology in German word production. *Language and Cognitive Processes, 21*, 920–944.

Hauk, O., Patterson, K., Woollams, A., Watling, L., Pulvermüller, F., & Rogers, T. T. (2006). When would you prefer a SOSSAGE to a SAUSAGE? At about 100 msec. ERP correlates of orthographic typicality and lexicality in written word recognition. *Journal of Cognitive Neuroscience, 18(5)*, 818-832.

Hino. Y, Lupker, S. J., & Pexman, P. M. (2002). Ambiguity and synonymy effects in lexical decision, naming, and semantic categorization tasks: Interactions between orthography, phonology, and semantics. *Journal of Experimental Psychology: Learning, Memory and Cognition, 28* (4), 686-713.

Holcomb, P. J., Grainger, J., & O'Rourke, T. (2002). An electrophysiological study of the effects of orthographic neighborhood size on printed word perception. *Journal of Cognitive Neuroscience, 14*, 938–950.

Hutzler, F., Bergmann, J., Conrad, M., Kronbichler, M., Stenneken, P., & Jacobs, A. M. (2004). Inhibitory effects of first syllable-frequency in lexical decision: An event related potential study. *Neuroscience Letters, 372*, 179-184.

Hutzler, F., Conrad, M., & Jacobs, A. M. (2005). Effects of syllable-frequency in lexical decision and naming: An eye movement study. *Brain and Language, 92* (2), 138-152.

Hutzler, F., Ziegler, J. C., Perry, C., Wimmer, H., & Zorzi, M. (2004). Do current connectionist learning models account for reading development in different languages? *Cognition, 91,* 273-296.

Hoeks, J. C. J., Stowe, L. A., & Doedens, G. (2004). Seeing words in context: the interaction of lexical and sentence level information during reading, *Cognitive Brain Research, 19* (1): 59-73.

Isel, F., Gunter, T. C., & Friederici, A. D. (2003). Prosody-Assisted Head-Driven Access to Spoken German Compounds. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 29*, 277–288.

Jacobs, A. M., & Grainger, J. (1992). Testing a semistochastic variant of the interactive activation model in different word recognition experiments. *Journal of Experimental Psychology: Human Perception and Performance, 18*(4), 1174-1188.

Jacobs, A. M., & Grainger, J. (1994). Models of visual word recognition: Sampling the state of the art. *Journal of Experimental Psychology: Human Perception and Performance, 20,* 1311-1334.

Jacobs, A. M., Rey, A., Ziegler, J. C., & Grainger, J. (1998). MROM-P: An interactive activation, multiple read-out model of orthographic and phonological processes in visual word recognition. In J. Grainger, J. & A.M. Jacobs (Eds.), *Localist connectionist approaches to human cognition*. (pp.147-187). Mahwah, NJ: Lawrence Erlbaum Associates.

Jacobs, A.M., Graf, R., & Kinder, A. (2003). Receiver-Operating Characteristics in the Lexical Decision Task: evidence for a simple signal detection process simulated by the

Multiple Read-Out Model. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 29*(3), 481-488.

Kessler, B., & Treiman, R. (2001). Relationships between sounds and letters in English monosyllables. *Journal of Memory and Language, 44* (4), 592-617.

Kaye, J., & Lowestamm, J. (1984). De la syllabicité (On syllabicity). In F. Dell, D. Hirst, & J. R. Vergnaud (Eds.), *Forme sonore du langage*. Paris: Hermann.

Kroll, J. F., & Merves, J. S. (1986). Lexical access for concrete and abstract words. *Journal of Experimental Psychology: Learning, Memory and Cognition, 12*, 92 – 107.

Laporte, E. (1993). Phonetic syllables in French: combinations, structure, and formal definitions. *Acta Linguistica Hungarica, 41*, 175-189.

Laudanna, A., Burani, C., & Cermele, A. (1994). Prefixes as processing units. *Language and Cognitive Processes, 9* (3), 295-316.

Levelt, W. J. M., & Wheeldon, L. (1994). Do speakers have access to a mental syllabary? *Cognition, 50*, 239-269.

Levelt, W. J. M., Roelofs, A., & Meyer, A. S. (1999). A theory of lexical access in speech production. *Behavioral and Brain Sciences, 22*, 1–38.

Lima, S. D., & Pollatsek, A. (1983). Lexical access via an orthographic code? The basic orthographic syllable structure (BOSS) reconsidered. *Journal of Verbal Learning and Verbal Behavior, 22*, 310-332.

Lukatela G., Frost, S. J., Turvey, M. T. (1998). Phonological priming by masked nonword primes in the lexical decision task. *Journal of Memory & Language, 39*, 666-683.

Lukatela, G., Eaton, T., Lee, C. H., Carello, C., & Turvey, M. T. (2002). Equal homophonic priming with words and pseudowords. *Journal of Experimental Psychology: Human Perception & Performance, 28*, 3-21.

Lukatela, G., Turvey, M. T. (1994).Visual lexical access is initially phonological: 1. Evidence from associative priming by words, homophones, and pseudohomophones. *Journal of Experimental Psychology: General, 123*, 107-128.

Lupker, S. J., Brown, P., & Colombo, L. (1997). Strategic Control in a Naming Task: Changing Routes or Changing Deadlines? *Journal of Experimental Psychology: Learning, Memory, and Cognition, 23*(3), 570-590.

Macizo, P., & Van Petten, C. (2007). Syllable frequency in lexical decision and naming of English words. *Reading and Writing, 20*, 295–331.

MacNeilage, P. F., & Davis, B. L. (2001). Motor mechanisms in speech ontogeny: Phylogenetic, neurobiological and linguistic implications. *Current Opinions in Neurology, 11*, 696–700.

Massaro, D. W., & Cohen, M. M. (1994). Visual, orthographic, phonological, and lexical influences in reading. *Journal of Experimental Psychology: Human Perception and Performance, 20*(6), 1107-1128.

Mathey, S., & Zagar, D. (2002). Lexical similarity in visual word recognition: The effect of syllabic neighborhood in French. *Current Psychology Letters: Behavior, Brain & Cognition, 8*, 107-121.

Mathey, S., Zagar, D., Doignon, N., & Seigneuric, A. (2006). The nature of the syllabic neighbourhood effect in French. *Acta Psychologica, 123*, 372-393.

Mc Clelland, J. L., & Rumelhart, D. E. (1981). An interactive activation model of context effects in letter perception: Part 1. An account of basic finding. *Psychological Review, 88*, 375-407.

McKinnon, R., Allen, M., & Osterhout, L. (2003). Morphological decomposition involving non-productive morphemes: ERP evidence. *NeuroReport 14*, 883–886.

Mehler, J., Dommergues, J., Frauenfelder, U., & Seguí, J. (1981). The syllable´s role in speech segmentation. *Journal of Verbal Learning & Verbal Behavior, 20*, 298-305.

Millis, M. L. (1986). Syllables and spelling units affect feature integration in words. *Memory & Cognition, 14*, 409-419.

Morais, J., Content, A., Cary, L., Mehler, J., & Seguí, J. (1989). Syllabic segmentation and literacy. *Language and Cognitive Processes, 4*, 57-67.

Moscoso del Prado Martín, F., Ernestus, M., & Baayen, R. H. (2004). Do type and token reflect different mechanisms? Connectionist modeling of Dutch past-tense formation and final devoicing. *Brain and Language, 90*, 287-298.

Moscoso del Prado Martín, F., Kostic, A., & Baayen, R. H. (2004). Putting the bits together: An information theoretical perspective on morphological processing. *Cognition, 94*, 1-18.

New, B., Pallier, C., Brysbaert, M., & Ferrand, L. (2004). Lexique 2: A new French lexical database. *Behavior Research Methods, Instruments, & Computers, 36*(3), 516-524.

Newman A. J., Pancheva, R., Ozawa, K., Neville, H. J., & Ullman, M. T. (2001). An event-related fMRI study of syntactic and semantic violations. *Journal of Psycholinguistic Research, 30* (3), 339-364.

Nuerk, H. C., Rey, A., Graf, R., & Jacobs, A. M. (2000). Phonographic sublexical units in visual word recognition. *Current Psychology Letters, 2*, 25-36.

Paap, K. R., Johansen, L. S. (1994). The case of the vanishing frequency effect. *Journal of Experimental Psychology: Human Perception and Performance, 20*, 1129-1157.

Pallier, C., Dupoux, E., Jeannin, X. (1997). EXPE: an expandable programming language for on-line psychological experiments. *Behaviour Research Methods, Instruments and Computer, 29*(3), 322-327.

Perea, M., & Carreiras, M. (1995). Efectos de frecuencia silábica en tareas de identificación. *Psicológica, 16*, 483-496.

Perea, M., & Carreiras, M. (1996). Efectos de frecuencia silábica y vecindad ortográfica en la pronunciación de palabras y pseudopalabras. *Psicológica, 17*, 425-440.

Perea, M., & Carreiras, M. (1998). Effects of syllable frequency and syllable neighborhood frequency in visual word recognition. *Journal of Experimental Psychology: Human Perception & Performance, 24*, 134-144.

Perea, M., & Lupker, S. J. (2004). Can CANISO activate CASINO? Transposed-letter similarity effects with nonadjacent letter positions. *Journal of Memory and Language, 51* (2), 231-246.

Perea, M., Carreiras, M., & Grainger, J. (2004). Blocking by word frequency and neighborhood density in visual word recognition: A task-specific response criteria account. *Memory & Cognition, 32*(7), 1019-1102.

Perfetti, C. A., & Bell, L. (1991). Phonemic activation during the first 40 ms of word identification: Evidence from backward masking and priming. *Journal of Memory & Language, 30*, 473-485.

Perret, C., Bonin, P., & Meot, A. (2006). Syllabic priming effects in picture naming in French - Lost in the sea! *Experimental Psychology, 53* (2), 95-104.

Perry, C., Ziegler, J. C., & Zorci, M. (2007). Nested incremental modeling in the development of computational theories: The CDP+ model of reading aloud. *Psychological Review, 114* (2), 273-315.

Plaut, D. C., McClelland, J. L., Seidenberg, M. S., & Patterson, K. (1996). Understanding normal and impaired word reading: Computational principles in quasi-regular domains. *Psychological Review, 103*, 56–115.

Pollatsek A., Lesch, M., Morris, R. K., & Rayner K. (1992). Phonological codes are used in integrating information across saccades in word identification and reading. *Journal of Experimental Psychology: Human Perception & Performance, 18*, 148-162.

Pollatsek, A., Perea, M., & Carreiras, M. (2005). Does conal prime CANAL more than cinal? Masked phonological priming effects in Spanish with the lexical decision task. *Memory & Cognition, 33*,557-565

Prinzmetal, W., Treiman, R., & Rho, S. H. (1986). How to see a reading unit. *Journal of Memory and Language, 25*, 461-475.

Pulgram, E. (1970). *Syllable, word, nexus, cursus*. The Hague: Mouton.

Rapp, B. (1992). The nature of sublexical orthographic organization: The bigram trough hypothesis examined. *Journal of Memory and Language, 31*(1), 33-53.

Rastle, K., Davis, M. H., & New, B. (2004). The broth in my brother's brothel: Morpho-orthographic segmentation in visual word recognition. *Psychonomic Bulletin & Review, 11* (6), 1090-1098.

Ratcliff, R., Gomez, P., & McKoon, G. (2004). A diffusion model account of the lexical decision task. *Psychological Review, 111*, 159-182.

Real Academica Española (Comisión de Gramática) (1982). *Esbozo de una Nueva Gramática de la Lengua Española*. Espasa-Calde, S. A., Madrid.

Reichle, E. D, & Perfetti, C. A. (2003). Morphology in Word Identification: A Word-Experience Model That Accounts for Morpheme Frequency Effects. *Scientific Studies of Reading, 7*, (3), 219-237.

Rey, A., Ziegler, J. C., & Jacobs, A. M. (2000). Graphemes are perceptual reading units. *Cognition, 75, B1-B12.*

Rey, A., Jacobs, A. M., Schmidt-Weigand, F., & Ziegler, J. C (1998). A phoneme effect in visual word recognition. *Cognition, 68*, 41-50.

Roelofs, A., & Baayen H. (2002). Morphology by itself in planning the production of spoken words. *Psychonomic Bulletin & Review 9* (1), 132-138.

Rösler, F., Putz, P., Friederici, A. D., Hahne, A. (1993). Event-related brain potentials while encountering semantic and syntactic constraint violations. *Journal of Cognitive Neuroscience, 5* (3), 345-362.

Rouibah, A., & Taft, M. (2001). The role of syllabic structure in French visual word recognition. *Memory & Cognition, 29*, 373-381.

Rubenstein, H., Lewis, S. S., Rubenstein, M. A. (1971). Evidence for phonemic recoding in visual word recognition. *Journal of Verbal Learning and Verbal Behaviour, 10, 647-657.*

Schiller, N. O. (1998). The effect of visually masked syllabic primes on the naming latencies of words and pictures. Journal of Memory and Language, 39, 484-507.

Schiller, N. O. (2000). Single word production in English: The role of subsyllabic units during phonological encoding. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 26*, 512-528.

Schiller, N. O., & Costa, A. (2006). Different selection principles of freestanding and bound morphemes in language production. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 32*, (5), 1201–1207.

Schoonbaert, S., & Grainger, J. (2004). Letter position coding in printed word perception: Effects of repeated and transposed letters. *Language and Cognitive Processes, 19* (3), 333-367.

Schreuder, R., Baayen, H. (1995). Modeling morphological processing. In: Feldman, L.B. (Ed.), *Morphological Aspects of Language Processing*. Erlbaum Press, Hillsdale, NJ, pp. 131–154.

Schriefers, H., Jescheniak, J. D., & Hantsch, A. (2005). Selection of Gender-Marked Morphemes in Speech Production. *Journal of Experimental Psychology: Learning, Memory, and Cognition 31* (1), 159 –168.

Sebastián-Gallés, N., Martí, M. A., Carreiras, M., & Cuetos, F. (2000). *LEXESP: Una base de datos informatizada del español.* Barcelona: Servicio de Publicaciones de la Universitat de Barcelona.

Seidenberg, M. S. (1987). Sublexical structures in visual word recognition: Access units or orthographic redundancy? In M. Coltheart (Ed.), *Attention and performance XII: Reading* (pp. 245-263). Hillsdale, NJ: Erlbaum.

Seidenberg, M. S. (1989). Reading complex words. In G. Carlson & M. Tannenhaus (Eds.), *Linguistic Structure in language processing.* (pp. 53-105). Amsterdam: Reidel.

Seidenberg, M. S., & McClelland, J. L. (1989). A distributed, developmental model of word recognition and naming. *Psychological Review, 96*(4), 523-568.

Selkirk, E. (1984). On the major class features and syllable theory. In: M. Aronoff & R.T. Oehrle (Eds.), *Language Sound Structure*. (pp 107-136). Cambridge, Mass.: MIT Press.

Spoehr, K. T., & Smith, E. E. (1973). The role of syllables in perceptual processing. *Cognitive Psychology, 5*, 71-89.

Stenneken, P., Bastiaanse, R., Huber, W., & Jacobs, A. M. (2005). Syllable structure and sonority in language inventory and aphasic neologisms. *Brain and Language***,** *95* (2), 280-292.

Stenneken, P., Conrad, M., Hutzler, F., Braun, M., & Jacobs, A.M. (2005). Frequency effects with visual words and syllables in a dyslexic reader. *Behavioral Neurology, 16*, 103-117.

Taft, M. (1987) Morphographic processing. The BOSS re-emerges. In M. Coltheart (Ed.), *Attention and performance, XII*. London: Lawrence Erlbaum Associates Limited.

Taft, M. (1979a). Recognition of affixed words and the word frequency effect. *Memory & Cognition, 7*, 263-272.

Taft, M. (1979b). Lexical access via an orthographic code: the basic orthographic syllable structure (BOSS). *Journal of Verbal Learning and Verbal Behaviour, 18*, 21-39

Taft, M. (1992). The body of the BOSS: Subsyllabic units in the processing of polysyllabic words. *Journal of Experimental Psychology: Human Perception and Performance, 18*, 1004-1014.

Taft, M. (1994). Interactive-activation as a framework for understanding morphological processing. *Language and Cognitive Processes, 9*, 271-294.

Taft, M., & Forster, K. I. (1975). Lexical storage and retrieval of prefixed words. *Journal of Verbal Learning and Verbal Behaviour, 14, 271-294.*

Tousman, S., & Inhoff, A. W. (1992). Phonology in multisyllabic word recognition. Journal of *Psycholinguistic Research, 21*, 525-544.

Treiman, R., & Chafetz, J. (1987). Are there onset and rime-like units in printed words? In M. Coltheart (Ed.), *Attention and performance, XII: Reading* (pp.281-298). Hillsdale, NJ: Erlbaum.

Treiman, R., Kessler, B., & Bick, S. (2002). Context sensitivity in the spelling of English vowels. *Journal of Memory and Language, 47* (3), 448-468.

Van Orden, G. C. (1987). A ROWS is a ROSE: spelling, sound, and reading. Memory & *Cognition, 15*, 181-198.

Van Orden, G. C., Johnston, J. C., Hale, B. L. (1988).Word identification in reading proceeds from spelling to sound to meaning. *Journal of Experimental Psychology: Learning Memory & Cognition, 14*, 371-386.

Wiese, R. (1996). *The Phonology of German*. Oxford: Clarendon Press.

Ziegler, J. C., Jacobs, A. M., & Stone, G. O. (1996). Statistical analysis of the bi-directional inconsistency of spelling and sound in French. *Behavior Research Methods, Instruments, & Computers, 28*, 504-515.

Ziegler, J.C., Jacobs, A.M., & Klüppel, D. (2001). Pseudohomophone effects in lexical decision: still a challenge for current word recognition models. *Journal of Experimental Psychology: Human Perception and Performance 27* (3), 547–559.

Ziegler, J. C., Perry, C., & Coltheart, M. (2000). The DRC model of visual word recognition and reading aloud: An extension to German. *European Journal of Cognitive Psychology, 12*, 413-430.

Ziegler, J, C., Stone, G. O., & Jacobs, A. M. (1997). What is the pronunciation for -ough and the spelling for lu/? A database for computing feedforward and feedback consistency in English. *Behavior Research Methods, Instruments & Computers, 29* (4), 600-618.

Zorzi, M., Houghton, G., & Butterworth, B. (1998). Two routes or one in reading aloud? A connectionist dual-process model. *Journal of Experimental Psychology: Human Perception and Performance, 24*, 1131-116.

Zwitserlood, P. (2004). Sublexical and morphological information in speech processing. *Brain and Language, 90*, 368–377.

Zwitserlood, P., Bölte, J., & Dohmes, P. (2000). Morphological effects on speech production: Evidence from picture naming. *Language and Cognitive Processes, 15*, 563–591.

Appendices

Stimuli used in the experiments presented in the different Chapters together with their corresponding mean correct response latencies and error percentages

Appendix A Materials of Chapter 1

Appendix B Materials of Chapter 2

Appendix C Materials of Chapter 3

Appendix D Materials of Chapter 4

Stimulus Materials

Table A 1

Words used in Experiments 1 (Lexical Decision Task; LDT) and 2 (Naming) of Chapter 1 together with their corresponding mean correct response latencies (RT; in Milliseconds) and error percentages (%Err)

Words with high Word Frequency

High initial Syllable Frequency					Low initial Syllable Frequency				
	LDT		Naming			LDT		Naming	
	RT	%Err	RT	%Err		RT	%Err	RT	%Err
BEGINN	560	07	523	06	BAUER	604	04	523	03
BESUCH	499	00	511	00	BESSER	578	04	507	03
BEVOR	609	07	554	12	BILDEN	581	04	544	00
BEZIRK	696	21	615	06	BITTEN	580	00	536	03
BISHER	609	00	570	00	BODEN	554	04	531	00
DAHER	570	07	516	09	DENKEN	555	00	522	03
DAVON	646	11	538	12	DIREKT	574	00	554	03
DIENEN	632	00	613	00	DOLLAR	596	00	533	00
GEFAHR	573	00	557	03	GELTEN	602	00	536	00
GENUG	569	04	527	03	GRENZE	550	04	573	03
GEWALT	531	00	510	03	GRUPPE	604	00	570	03
HABEN	561	00	550	00	HANDEL	515	00	564	00
HINAUS	643	11	560	12	HILFE	569	00	508	03
HINTER	566	00	525	09	HOTEL	539	00	519	03
JEDOCH	579	07	558	03	JUNGE	548	00	509	03
KOMMEN	551	00	561	00	KOSTEN	551	00	533	03
MACHEN	567	00	517	03	MONTAG	530	00	529	03
MITTE	535	00	488	06	MUSIK	550	04	524	03
MITTEL	576	00	509	03	MUTTER	541	00	515	06
NATUR	575	00	525	06	NENNEN	585	04	539	03
RECHEN	658	04	556	00	RUFEN	613	00	544	00
REDEN	568	00	546	03	RUHIG	535	00	575	00
SACHE	593	00	576	03	SELBER	617	04	561	03
SOGAR	610	11	573	03	SETZEN	596	00	586	12
SOLDAT	548	00	574	03	SORGE	582	00	561	06
SOWOHL	581	00	574	03	SUCHEN	523	00	569	03
WASSER	526	00	527	03	WARTEN	545	04	511	00
WIRKEN	577	00	565	06	WARUM	567	00	516	03

Table A 1 continued

Words with low Word Frequency									
High initial Syllable Frequency					Low initial Syllable Frequency				
	LDT		Naming			LDT		Naming	
	RT	%Err	RT	%Err		RT	%Err	RT	%Err
BECHER	575	00	540	00	BAGGER	647	07	566	00
BEGABT	624	04	547	09	BARON	696	11	559	03
BEINAH	685	11	574	06	BENGEL	590	07	539	06
BELEBT	632	00	589	00	BERGAB	733	11	591	15
BELEG	673	00	543	03	BONBON	653	00	561	09
DATIV	709	11	571	03	DIPLOM	580	00	599	00
DERBY	814	50	618	09	DOPPEL	559	00	530	03
DERLEI	828	54	646	03	DOSIS	688	07	535	00
GEHIRN	575	04	531	03	GEISEL	576	00	547	06
GELEIT	708	14	597	03	GIEBEL	713	04	611	06
GENICK	781	21	594	03	GIGANT	668	14	608	03
GESELL	687	11	606	06	GOTIK	678	11	559	00
HAPERN	744	36	577	12	HEKTIK	683	07	573	06
HAREM	856	39	613	03	HEROLD	728	25	550	15
JAWORT	681	04	557	03	JAUCHE	662	07	561	03
KOMMA	617	00	583	03	KOBOLD	666	04	591	03
MAGIE	617	07	543	09	MOLLIG	630	00	545	00
MAGNET	630	07	540	03	MUFFIG	639	04	561	03
MAKEL	635	00	557	06	MUSKEL	577	00	538	09
NAGELN	665	00	581	03	NOTAR	592	00	534	09
REGUNG	695	07	597	00	RANZIG	685	11	573	00
REPORT	658	11	580	00	ROSIG	597	04	569	06
SALAT	546	00	539	03	SALTO	682	07	581	03
SATAN	623	07	575	06	SENKE	610	00	570	03
SELIG	559	04	584	03	SEUCHE	606	00	575	00
SOPRAN	792	29	648	03	SUPPE	573	04	565	03
WIRBEL	566	00	558	00	WALZE	579	00	531	00
WIRTIN	709	11	584	06	WIMPER	624	04	562	00

Table A 2

Nonwords used in Experiments 1 (Lexical Decision Task; LDT) and 2 (Naming) of Chapter 1 together with their corresponding mean correct response latencies (RT; in Milliseconds) and error percentages (%Err)

High initial Syllable Frequency					Low initial Syllable Frequency				
	LDT		Naming			LDT		Naming	
	RT	%Err	RT	%Err		RT	%Err	RT	%Err
BEILER	914	40	593	06	BAGZEN	638	00	633	00
BEIMA	690	00	586	00	BAPOT	632	00	648	12
BEMUD	638	04	585	06	BASJE	622	04	602	09
BETOL	653	00	585	00	BIPIK	603	00	645	45
BEVIS	661	04	564	13	BRUGIL	642	00	680	18
BISSAK	687	04	587	12	BUWUT	656	07	624	17
DASAM	756	08	563	03	DAKWAK	636	00	666	15
DAVIS	890	39	539	09	DOTPOD	692	00	615	13
DERDIR	641	04	638	10	DRUPIR	656	04	676	29
DIEBUZ	618	00	631	00	DUFSAM	703	04	625	03
DIEPOM	732	11	673	08	DUSGUS	611	04	621	03
EINMUD	841	25	583	06	EHFAM	660	04	642	13
EINRIM	704	00	651	21	EHJAK	558	00	688	03
EINZEN	831	25	581	03	EHVET	580	00	668	14
ENTGOS	662	00	583	06	ELGOS	615	07	594	00
ENTLOG	726	04	590	03	ELGUS	598	00	585	03
ENTNEM	707	07	596	19	ELHIR	602	00	653	12
ENTSIR	663	00	632	13	ELKUM	619	00	582	03
ENTZIV	613	00	636	19	ENFUS	631	00	581	19
GEBOP	617	00	621	12	GEKZEN	672	04	632	14
GEGOS	663	04	591	03	GEMJOK	568	00	612	10
GEJAK	569	00	610	03	GITOL	608	00	670	10
GERIM	657	04	607	13	GOFAT	585	00	579	06
GEVID	598	00	604	03	GOVID	631	04	581	03
GEVIT	606	00	588	03	GUSMOG	586	00	603	09
HAGOS	633	04	569	09	HAFZU	653	04	618	13
HAPES	670	00	556	12	HENON	629	00	602	00
HINLA	634	04	584	03	HIMPES	670	00	556	06
HINRUB	750	00	587	09	HUKBUK	597	04	639	13
INGOR	796	08	562	00	ISGID	594	00	599	06
INLOD	602	00	616	09	ISVIS	574	00	631	03
INRIM	632	04	586	06	ISWAK	556	00	562	00
JAFAM	617	00	605	03	JAKDAK	575	00	589	13
JALIZ	618	04	623	06	JAKPES	571	00	627	06
JAPIR	652	00	565	03	JARFAM	606	00	625	29
JAVIS	649	04	564	06	JUMGLU	596	04	694	27
JEVIT	568	00	567	03	JUNNIT	611	00	582	03

Table A 2 continued

KOMSI	655	04	620	09	KELIN	733	12	614	19
KOMVIS	704	04	615	09	KUGZIV	588	00	714	12
LEVET	670	04	584	00	LAVOI	587	00	577	09
NEUGA	611	07	564	00	NEFMIT	629	00	659	03
NEUKUM	636	07	575	03	NEPMIT	614	00	650	21
NEUSI	644	00	555	12	NETSI	616	00	585	12
NEUZI	609	00	574	03	NULFON	617	00	604	19
PROBUG	699	00	682	14	PARGUS	706	04	624	06
PROGID	676	04	694	17	PERPET	659	08	649	07
PROIST	791	04	715	31	POKPON	712	00	674	41
PROPOM	720	00	681	19	PONLAK	656	00	674	10
RETEI	676	00	663	23	REGTEI	703	00	665	14
UMHUB	669	04	590	03	ULMUD	640	00	590	12
UMJAK	596	00	588	03	ULPET	607	04	567	00
UMNOT	817	42	637	00	ULRUF	668	00	610	06
UMTAM	659	00	644	03	URBID	664	15	566	12
UMVER	652	00	595	03	URDAN	622	04	606	03
ZULOG	683	00	663	00	ZENBUS	655	00	649	09
ZUWAK	617	00	610	10	ZODIR	603	04	609	03

Table B 1

Words used in Experiment 1 (Chapter 2) together with their corresponding mean correct response latencies (RT; in Milliseconds) and error percentages (%Err)

Experiment 1 A						Experiment 1 B					
Initial Token Syllable Frequency						Initial Type Syllable Frequency					
High			Low			High			Low		
	RT	%Err		RT	%Err		RT	%Err		RT	%Err
luna	620	00	bebé	602	00	botín	769	03	furia	633	00
mural	758	03	beca	655	03	botón	609	03	furor	780	21
muro	702	11	bella	651	03	labio	664	03	fusil	736	03
musa	733	11	belén	668	00	labor	714	00	helio	901	42
mutuo	820	11	beso	594	03	lacio	839	32	hilo	731	06
nota	648	05	betún	845	22	latín	637	03	honor	701	00
vaca	620	06	burra	732	11	ligue	740	09	horror	704	00
vago	695	08	fecha	643	00	limón	631	03	hotel	632	03
vagón	732	14	feria	645	06	morro	728	12	humor	632	03
valla	768	12	feroz	685	06	pino	648	00	junio	664	03
valle	686	03	feto	669	00	piso	608	00	llano	668	03
vano	745	24	foco	647	09	recién	781	03	lleno	661	06
vapor	681	00	foro	698	15	robot	678	00	necio	779	26
vara	914	28	forro	741	23	rosa	602	03	nene	707	06
varón	689	06	fosa	723	09	rosal	701	08	neto	845	36
vaso	662	00	foto	621	06	tablón	668	00	nube	667	00
vela	648	03	goma	668	00	tabú	712	03	nuca	690	14
velar	715	03	gorra	594	08	taco	686	03	tubo	640	00
vello	730	16	gota	628	06	tacón	676	06	tumor	734	00
veloz	679	00	jamón	640	00	talla	684	06	turrón	661	00
vena	716	05	jarra	673	06	talle		62	vocal	620	03
venus	724	06	pila	755	03	taller	662	00	voraz	814	33
vera*	776	55	talón	767	09	tapiz	727	03	voto	655	05
veraz	848	08	tarro	698	08	tasa	680	09	zorro	617	03

*This word entered the analyses, because its corresponding error percentage has been below the exclusion criterion of 50 percent before the rejection of outlier response latencies.

Table B 2

Words used in Experiment 2 (Chapter 2) together with their corresponding mean correct response latencies (RT; in Milliseconds) and error percentages (%Err)

Experiment 2 A						Experiment 2 B					
Number of Higher Frequency syllabic Neighbours controlled for											
Initial Token Syllable Frequency						Initial Type Syllable Frequency					
High			Low			High			Low		
	RT	%Err		RT	%Err		RT	%Err		RT	%Err
debut	835	29	bebé	584	00	barrio	666	03	furia	633	00
helio	901	41	bello	734	00	bola	615	00	fusil	736	03
licor	706	08	belén	660	00	botín	697	03	helio	852	44
lila	832	06	beso	598	03	botón	609	03	hilo	735	06
limón	635	03	betún	813	21	labio	664	03	honor	697	00
lino	748	08	feroz	685	06	labor	672	00	horror	709	00
lirio	780	14	feto	669	00	latín	636	03	hotel	632	03
mono	739	00	foca	628	03	licor	688	08	humor	632	03
mural	758	03	gorro	614	00	limón	631	03	julio	636	03
muro	702	11	pila	738	03	pino	648	00	llano	650	03
musa	721	11	pino	648	00	piso	608	00	lleno	661	06
mutuo	820	11	rural	709	11	recién	728	03	neto	847	37
nasal	677	03	tablón	668	00	salud	611	03	nube	667	00
natal	735	06	tabú	712	03	solar	703	03	nudo	746	08
rara	715	03	tacón	676	06	taco	661	03	nulo	796	26
tenis	621	03	talle		62	tacón	676	06	tubo	640	00
tiro	641	11	talón	733	09	talla	684	06	tumor	731	00
tirón	710	06	tapiz	703	03	talle		62	turrón	661	00
vela	661	03	tarro	698	08	taller	662	00	vocal	620	03
vera*	829	51	voto	655	05	tasa	674	09	voto	655	05

*This word entered the analyses, because its corresponding error percentage has been below the exclusion criterion of 50 percent before the rejection of outlier response latencies. This was not the case in Experiment 3.

Table C 1

Word Stimuli used in Experiment 1 (Chapter 3); corresponding mean correct Response Latencies (RT; in Milliseconds) and Percentage of Errors (%Err)

Bigram Trough at the Syllable Boundary											
Yes						No					
Frequency of the first Syllable						Frequency of the first Syllable					
High			Low			High			Low		
	RT	%Err		RT	%Err		RT	%Err		RT	%Err
ansia	919	26	asma	880	10	antro	1084	34	asta	1018	67
desliz	950	21	brava	830	12	credo	942	16	breva	982	25
forja	896	17	bruma	826	09	crema	706	00	chelo	930	67
hebra	979	24	bruta	712	04	fino	751	11	clero	801	07
letal	837	05	buda	825	27	heno	951	60	fobia	727	02
lila	778	11	cheque	830	07	hombro	703	07	foca	662	04
litro	748	02	choque	799	02	honor	732	04	foco	717	00
lujo	678	00	duelo	714	04	horror	725	00	folio	758	02
mulo	852	16	foto	686	07	lacia	911	74	foro	728	13
muro	780	07	frita	794	09	lana	680	02	forro	773	05
musa	786	09	furor	795	04	liso	666	00	foso	774	21
plaga	805	04	giro	742	00	malla	995	17	freno	677	09
plagio	1015	11	grito	664	02	manual	741	02	fresa	705	04
proa	947	30	gula	898	30	meca	972	45	genial	700	07
progre	1173	93	humor	630	00	nasa	881	22	genio	676	04
puma	715	05	kilo	746	02	noble	696	04	goce	904	31
quema	775	05	manga	846	02	plana	741	16	gorro	663	00
quieta	854	00	nube	700	02	plano	675	02	junio	728	02
rojo	665	00	nudo	762	02	prosa	904	07	manta	787	02
rota	777	04	nula	817	10	pueril	958	48	piano	660	04
sede	934	30	nulo	844	14	recia	1074	34	plena	716	13
suma	760	07	ruda	896	27	roce	805	09	tinta	658	00
trapo	779	07	rumor	727	05	socia	894	40	vocal	719	00
vate	846	84	rural	797	02	tambor	768	02	yegua	955	05
veda	833	76	salva	840	13	vaca	666	02	yema	858	09
velo	792	09	water	936	68	valla	877	08	yeso	762	07
veto	905	65	zumo	688	00	vano	845	11	yodo	963	15

Table C 2

Word Stimuli used in Experiment 2 (Chapter 3); corresponding mean correct Response Latencies (RT; in Milliseconds) and Percentage of Errors (%Err)

High Frequency of the first Syllable			Low Frequency of the first Syllable		
	Mean RT	%Err		Mean RT	%Err
baba	826	02	ciclo	727	02
babor	1058	58	ciclón	762	03
bala	884	07	cifra	757	02
ballet	791	21	cima	740	00
balón	715	13	cita	690	00
banal	954	57	doblez	871	17
barra	718	07	dote	822	32
barril	779	02	dócil	796	05
barro	737	00	dólar	739	05
bata	773	00	fuga	684	05
mecha	890	00	fugaz	738	02
mechón	788	07	furia	715	02
mella	1008	62	furor	771	04
melón	714	02	fusil	731	07
mesón	870	09	nube	681	02
meta	718	04	nuca	805	16
metal	708	02	nudo	752	02
metro	720	00	pico	696	07
nasa	895	22	pila	766	00
nasal	744	02	pilar	806	03
natal	777	11	pino	663	07
nato	961	42	pipa	726	00
naval	816	05	pito	752	15
nave	780	02	piña	633	02
nazi	905	31	quicio	823	42
nácar	921	24	tabla	724	02
sabor	663	00	tablón	699	00
saco	748	02	tabú	764	02
sacra	872	44	taco	692	00
saga	944	29	tacón	710	07
sagaz	965	41	taller	658	04
sana	720	07	talón	761	09
sapo	675	04	tapa	637	00
saque	818	26	tapiz	735	02
savia	930	20	tarro	775	10
saña	1049	68	tasa	691	14

Table C 3

Word Stimuli used in Experiment 3 (Chapter 3); corresponding mean correct Response Latencies (RT; in Milliseconds) and Percentage of Errors (%Err)

High Frequency of the first Bigram			Low Frequency of the first Bigram		
	Mean RT	%Err		Mean RT	%Err
cuba	743	05	daga	835	28
cubo	673	03	dama	690	03
culo	674	00	danés	924	29
cuna	730	05	dato	792	18
cupo	885	17	daño	694	03
cura	708	00	hebra	1007	35
miga	789	24	hedor	954	27
mili	813	73	heno	986	44
milla	900	22	hilo	724	03
millar	841	12	himen	1117	49
millón	696	03	hipo	835	22
mimo	908	25	hito	941	32
mina	870	16	lidia	810	19
mirón	830	05	ligue	796	08
mitin	1242	70	lino	729	10
pudor	746	00	lirio	909	14
puma	814	20	liso	655	05
puro	740	03	litio	1012	39
puta	706	05	locuaz	916	35
puñal	743	03	lona	801	24
puño	722	00	losa	894	21
tajo	789	28	lote	775	11
tapia	848	23	líder	713	00
tapón	698	00	necio	904	21
taza	659	03	neto	901	26
tibio	843	17	rabia	717	03
tigre	694	03	radar	776	13
tilo	854	59	rama	762	03
timo	799	18	rapaz	899	17
timón	818	08	raso	873	24
tino	842	36	rata	640	00
tiro	803	11	rayo	778	11
tirón	743	06	raza	693	08
tiza	723	05	raíz	717	03

Table D 1

Words used in Comparison 1 (Chapter 4) with their corresponding mean Response Latencies (RT; in Milliseconds) and Percentages of Errors (%err)

High Syllable Frequency						Low Syllable Frequency					
	RT	%err		RT	%err		RT	%err		RT	%err
colombe	697	00	milice	784	29	biceps	747	15	girafe	675	02
comète	721	10	milliard	727	00	billard	678	10	gorille	723	05
coriace	840	20	millième	753	05	binette	868	37	halage		88
correct	.641	00	mineur	680	02	biseau		51	hamac	726	10
courroie	763	10	minime	971	24	burin	891	39	hameau	768	07
courroux	742	34	minium		71	bécasse	739	00	hareng	715	22
donneur	680	02	minois	824	24	dallage		49	homard	702	12
dorure	929	27	minou	834	12	damas		76	juteux	852	20
faillite	825	22	morose	864	29	danois	748	20	loriot		80
falot		88	morue	753	02	danseur	617	00	neveu	714	07
famine	715	07	panache	766	10	femelle	691	02	nigaud	773	12
fanal		73	parade	714	07	fenouil	757	20	nomade	775	15
fanion		51	paraphe		71	fourreau	725	20	pileux		46
farouche	772	07	parrain	685	02	féroce	690	02	pillage	789	07
jarret	781	12	parure	764	12	gaillard	772	17	pilote	699	12
maillot	645	02	penaud		49	galette	706	02	pilule	684	20
malice	665	07	semoule	682	02	galoche	797	29	pinède	799	27
mamelle	775	07	serein	775	07	galop	659	10	pirogue	829	20
manette	853	22	serin	828	34	galère	647	02	piscine	607	00
maniaque	754	02	sommier	719	05	gamelle	763	05	romance	652	02
manioc	847	41	sonate	798	39	garrigue	912	12	tomate	573	05
manège	653	02	vinyle	839	37	garrot	796	15	tonique	668	02
marelle	860	27	viseur	716	15	gavroche	847	20	tonneau	736	00
marraine	761	12	visière	750	07	gigogne		46	torride	696	05
microbe	758	10	visuel	691	00	gigot	731	10	vorace	803	10

Table D 2

Words used in Comparison 2 (Chapter 4) with their corresponding mean Response Latencies (RT; in Milliseconds) and Percentages of Errors (%err)

Comparison 2A						Comparison 2B					
Orthographic Syllable Frequency						Phonological Syllable Frequency					
High			Low			High			Low		
	RT	%err		RT	%err		RT	%err		RT	%err
caillou	707	00	aisance	811	12	anchois	772	07	besace	791	22
camion	590	00	bolide	840	32	bolide	839	32	besogne	765	12
canal	612	05	bonnet	693	07	bonnet	693	07	fortune	628	00
dollar	628	05	cellule	640	05	cachot	782	05	furie	752	05
donnée	601	00	chorale	723	15	caillou	694	00	fusil	636	00
dorure	884	27	cigogne	774	10	chorale	723	15	fusion	663	02
microbe	725	10	ciseau	776	07	cigogne	772	10	fusée	660	05
milice	784	29	forum	738	07	ciseau	756	07	hussard	815	34
million	709	02	forêt	620	00	haleine	705	12	liseron	822	41
minet	740	22	fusil	663	00	hommage	659	00	musée	620	00
minime	948	24	fusion	685	02	honneur	618	00	oubli	625	00
minium	.	71	fusée	675	05	horreur	652	02	perron .		46
minois	816	24	haleine	705	12	kayak	798	24	placard	641	02
minou	819	12	hommage	654	00	message	660	02	planeur	737	10
minuit	644	07	honneur	606	00	mécène	880	41	planète	613	00
minute	615	02	horreur	652	02	mégot	678	05	purée	629	00
misère	653	00	kayak	795	24	méthode	619	05	tennis	604	00
mécène	895	41	liseré	855	34	péché	625	05	terrain	668	02
mégot	704	05	livret	657	07	pétoche	901	29	terreau	710	27
méthode	619	05	livrée	703	07	rameau	715	05	terreur	640	02
perron	.	46	légume	601	00	ramure.		46	terrier	732	05
rameau	710	05	oubli	644	00	rappel	616	02	terrine	654	07
rappel	616	02	purée	640	00	raton	883	29	terroir	639	00
raton	846	29	péché	625	05	sauveur	687	02	ticket	601	02
saillie	783	22	pétoche	867	29	scierie	825	37	tison	798	32
salade	632	02	sauveur	662	02	silex	750	10	tissage	702	05
saline	.	49	ticket	601	02	sillage	783	17	tomate	573	05
salive	652	02	tisane	683	07	sillon	719	07	verrou	669	05
salon	656	02	tison	817	32	sirop	613	05	verrue	666	02
serrure	654	05	tissu	631	02	sûreté	639	00	vertige	638	00

Table D 3

Words used in Comparison 3 (Chapter 4) with their corresponding mean Response Latencies (RT; in Milliseconds) and Percentages of Errors (%err)

Comparison 3A						Comparison 3B					
Higher Frequency Orthographic Syllable Neighbors						Higher Frequency Phonological Syllable Neighbors					
Many			Few			Many			Few		
	RT	%err		RT	%err		RT	%err		RT	%err
bigot		54	banal	690	02	balai	625	00	banal	690	02
bivouac	798	41	battue	729	05	bivouac	798	41	bandé	832	12
bonasse		54	bolide	897	32	bonasse		54	biceps	771	15
bourrade	811	44	centime	727	05	canard	622	00	bourreau	710	00
bourru	792	27	choral	743	32	carreau	780	00	courrier	649	00
carreau	780	00	chorale	723	15	centime	727	05	curare		63
denier	942	34	ciseau	776	07	centième	682	02	dilemme	780	27
famine	738	07	commis	728	10	choral	773	32	disette		51
finance	676	02	curare		63	chorale	723	15	fatal	656	05
fusain	740	22	disette		51	cigogne	772	10	furie	752	05
galet	777	07	dorure	950	27	ciseau	809	07	fusée	675	05
lanière	782	15	fatal	656	05	famine	738	07	girafe	675	02
larynx	832	10	fauvette	745	34	fauvette	745	34	haché	682	02
milice	784	29	forain	845	12	finance	664	02	halage		88
millième	724	05	forum	759	07	fusain	740	22	hamac	726	10
nacré	693	07	furie	752	05	galet	777	07	juron	772	07
panique	628	02	galette 7	06	02	galon	811	34	loriot		80
parade	758	07	garant	919	29	kayak	830	24	légume	601	00
parent	615	00	juron	831	07	milice	784	29	meneur	688	00
paresse	679	02	kayak	819	24	morue	744	02	menuet		51
paroi	703	12	loriot		80	mégot	704	05	mural	713	12
pillage	789	07	légume	601	00	pillage	832	07	narine	708	02
pommeau	746	22	morose	852	29	pommeau	746	22	penaud		49
recul	651	02	mural	713	12	pétoche	870	29	pesée	837	24
reproche	703	00	salade	632	02	saillie	783	22	salade	632	02
saillie	783	22	sauveur	687	02	sauveur	714	02	tenaille	781	10
semoule	710	02	serrure	654	05	sensé	742	20	terreau	705	27
serein	757	07	sillage	777	17	silex	750	10	terreux	777	24
serin	830	34	sillon	719	07	sillage	777	17	terrien	754	24
surhomme	914	15	sommaire	610	00	sirop	613	05	terrier	746	05
tamis	744	32	sonnette	653	02	sommier	753	05	terrine	644	07
tanière	734	15	sonné	693	05	surhomme	913	15	tonique	668	02
terrien	754	24	sérum	874	10	sérum	851	10	vallon	723	24
tigré	810	12	tignasse	921	17	tamis	744	32	vareuse		73
varech		78	tonique	712	02	tanière	734	15	venelle		49
venelle		49	vaillant	739	17	tigré	823	12	veneur		63
visière	717	07	vallon	740	24	tonus	638	05	venin	743	15
visuel	691	00	vareuse		73	vaurien	765	32	verrue	701	02
						visuel	691	00	vorace	774	10

Table D 4

Words used in Comparison 4 (Chapter 4)with their corresponding mean Response Latencies (RT; in Milliseconds) and Percentages of Errors (%err)

	Phonological Syllable Frequency				
	High			Low	
	RT	%err		RT	%err
bolide	839	32	benêt	761	44
bonnet	693	07	besace	794	22
chorale	723	15	forum	695	07
cigogne	772	10	forêt	620	00
ciseau	823	07	galet	710	07
kayak	798	24	galette	695	02
message	660	02	galon	775	34
microbe	725	10	galop	659	10
milice	784	29	galère	647	02
million	709	02	garage	663	05
minet	750	22	garant	761	29
minime	911	24	halage		88
minium		71	hamac	726	10
minois	841	24	hameau	746	07
minou	838	12	hareng	698	22
minuit	644	07	hasard	621	05
minute	625	02	livret	637	07
misère	653	00	livrée	710	07
mécène	903	41	pilule	674	20
mégot	704	05	piscine	607	00
méthode	619	05	romance	652	02
péché	625	05	tennis	604	00
pétoche	888	29	tension	653	05
saillie	783	22	terrain	649	02
salade	652	02	terreur	640	02
saline		49	terrier	705	05
salive	652	02	terrine	644	07
salière	777	10	terroir	671	00
salon	656	02	tomate	573	05
sarrau		93	tonnage		46
sauveur	687	02	tonneau	681	00
silex	750	10	tonus	638	05
sillage	742	17	verrou	669	05
sillon	720	07	verrue	701	02
sirop	613	05	volume	583	02

Table D 5

Words used in Comparison 5 (Chapter 4) with their corresponding mean Response Latencies (RT; in Milliseconds) and Percentages of Errors (%err)

	Frequency of the first Biphone				
	High			Low	
	RT	%err		RT	%err
dilemme	798	27	benêt	771	44
fauvette	733	34	besace	797	22
forum	702	07	fureur	714	07
galette	716	02	furie	752	05
galon	898	34	fusain	740	22
galop	659	10	fuseau	689	00
galère	647	02	fusil	637	00
gamelle	768	05	fusée	660	05
garage	692	05	liseron	834	41
garant	869	29	liseré	982	34
garrot	813	15	lisière	697	10
landau		46	livret	642	07
latex	699	07	livrée	703	07
lentille	638	00	muraille	692	05
saison	679	02	murette		51
tailleur	641	02	museau	676	05
taillis		46	musette	733	12
talon	669	07	rivage	727	00
talus	773	39	ticket	601	02
tamis	744	32	tignasse	921	17
tatouage	669	05	tison	885	32
terrasse	629	02	tissage	706	05
venin	722	15	tissu	617	02

Table D 6

Words used in Comparison 6 (Chapter 4) with their corresponding mean Response Latencies (RT; in Milliseconds) and Percentages of Errors (%err)

					Word Frequency						
			High						Low		
			Syllable Frequency						Syllable Frequency		
	High			Low			High			Low	
	RT	%err		RT	%err		RT	%err		RT	%err
bonnet	687	07	besogne	725	12	bolide	839	32	biceps	736	15
camion	623	00	billard	666	10	choral	743	32	fourreau	725	20
correct	652	00	danseur	602	00	chorale	723	15	furie	752	05
faillite	810	22	femelle	683	02	ciseau	796	07	fusain	728	22
farouche	797	07	fureur	694	07	comète	716	10	fuseau	677	00
fatal	638	05	fusion	677	02	coriace	840	20	gigot	744	10
maillot	645	02	fusée	670	05	courroie	763	10	hareng	747	22
manège	653	02	féroce	658	02	donneur	670	02	homard	691	12
million	709	02	gaillard	711	17	dorure	921	27	lentille	662	00
mineur	680	02	galop	659	10	marelle	865	27	mural	719	12
minuit	611	07	garage	668	05	microbe	758	10	nigaud	764	12
minute	615	02	hameau	750	07	milice	784	29	nomade	763	15
misère	642	00	hasard	621	05	millième	724	05	pillage	782	07
méthode	619	05	muraille	711	05	minou	829	12	romance	652	02
panique	671	02	museau	658	05	morue	744	02	terreau	742	27
parade	693	07	musette	694	12	mécène	882	41	terreux	809	24
paresse	679	02	pilote	685	12	panache	738	10	terrier	709	05
recul	651	02	piscine	607	00	parure	764	12	terrine	644	07
reproche	705	00	rivage	715	00	pesée	842	24	tignasse	880	17
salive	652	02	tennis	604	00	pétoche	876	29	tisane	723	07
sillage	774	17	terrain	679	02	saillie	783	22	tissage	725	05
sillon	715	07	terrasse	620	02	serein	775	07	tomate	573	05
sommaire	602	00	terreur	640	02	sommier	726	05	tonus	638	05
sonnette	653	02	volume	583	02	sonate	798	39	torride	696	05

Curriculum Vitae

1990 Abitur am humanistisch-neusprachlichen Karlsgymnasium München-Pasing

1997-2000 Auslandsaufenthalte in Frankreich und Südamerika

September 2002 Abschluß in Diplom-Psychologie an der Katholischen Universität Eichstätt-Ingolstadt. Titel der Diplomarbeit, vorgelegt bei Prof. Arthur Jacobs: „Einfluß der Silbenfrequenz auf die Leseleistung im Deutschen"

2002-2003 dreisemestrige Tätigkeit als Lehrbeauftragter an der Katholischen Universität Eichstätt-Ingolstadt. Veranstaltungen zu den Themen „kognitive Paradigmen der Neuropsychologie" und „Methoden der kognitiven Neurowissenschaften"

2003 siebenmonatige befristete Tätigkeit als wissenschaftlicher Mitarbeiter im Rahmen des DFG-Projektes „Einfluß des Irrelevant Speech Effect auf die Modellierung des Arbeitsgedächtnis" von Prof. Hellbrück an der Kath. Univ. Eichstätt-Ingolstadt

Februar 2004-Juni 2006 Wissenschaftlicher Mitarbeiter (50%) an der FU Berlin im Rahmen des DFG-Projekts „zur Rolle phonologischer Prozesse beim Lesen komplexer Wörter. Ein sprachvergleichender Ansatz" von Prof. Arthur Jacobs, Allgemeine und Neurokognitive Psychologie, FU Berlin. Forschungsaufenthalte and der Université de Provence, Aix-Marseille, Frankreich und an der Universidad de La Laguna, Tenerife, Spanien.

April 2006- September 2007 Wissenschaftlicher Mitarbeiter an der FU Berlin in Vertretung der Stelle von Dr. Prisca Stenneken am Lehrstuhl für Allgemeine und Neurokognitive Psychologie. Dreisemestrige Mitarbeit in Forschung und Lehre. Anleitung „Experimenteller Praktika" als Lehrveranstaltungen (2 Semesterwochenstunden).

Seit Oktober 2007 Wissenschaftlicher Mitarbeiter an der FU Berlin am Lehrstuhl für Allgemeine und Neurokognitive Psychologie.

Erklärung

Hiermit versichere ich, die vorliegende Arbeit selbständig und ohne Verwendung anderer als der angegebenen Hilfsmittel erstellt und verfaßt zu haben.
Die vorliegende Arbeit war nicht Gegenstand eines früheren Promotionsverfahrens.
Die einzelnen Kapitel dieser Dissertationsschrift wurden in marginal modifizierten Versionen in internationalen Fachzeitschriften veröffentlicht bzw. zur Veröffentlichung angenommen.

Kapitel 1 ist veröffentlicht im Jahre 2006 in der Zeitschrift „Psychonomic Bulletin & Review“, Ausgabe 13, Seite 339-345. Koautoren sind: Prisca Stenneken und Arthur M. Jacobs.
Kapitel 2 wird veröffentlicht im Jahre 2008 in der Zeitschrift „Language and Cognitive Processes“ (2008), Ausgabe 2, Seitenzahlen noch nicht verfügbar, im Internetauftritt der Zeitschrift veröffentlicht am 6.September 2007. Koautoren sind: Manuel Carreiras und Arthur M. Jacobs.
Kapitel 3 ist zur Veröffentlichung angenommen in der Zeitschrift „Journal of Experimental Psychology, Human Perception and Performance“. Koautoren sind: Manuel Carreiras, Sascha Tamm und Arthur M. Jacobs.
Kapitel 4 ist veröffentlicht im Jahre 2007 in der Zeitschrift „Memory & Cognition“, Ausgabe 35 (5), Seite 974-983. Koautoren sind: Jonathan Grainger und Arthur M. Jacobs.

Alle Koautoren können bestätigen, daß ich sowohl für die Planung, Durchführung und Auswertung der Experimente als auch für das Verfassen der Kapitel dieser Dissertationsschrift allein- oder doch zumindest hauptverantwortlich war.

Berlin, den 4. Februar 2008
Markus Conrad